

**IN THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION**

TQ DELTA, LLC,

Plaintiff,

V.

COMMScope Holding Company, Inc., COMMScope Inc., Arris International Limited, Arris Global Ltd., Arris US Holdings, Inc., Arris Solutions, Inc., Arris Technology, Inc., and Arris Enterprises, LLC,

[illegible]

Civil Action No. 2:21-cv- 310

JURY TRIAL DEMANDED

Defendants.

ORIGINAL COMPLAINT FOR PATENT INFRINGEMENT

Plaintiff TQ Delta, LLC (“TQ Delta”) and files this Original Complaint for Patent Infringement against Defendants CommScope Holding Company, Inc., CommScope Inc., ARRIS International Limited, ARRIS Global Ltd., ARRIS US Holdings, Inc., ARRIS Solutions, Inc., ARRIS Technology, Inc., and ARRIS Enterprises, LLC (collectively “CommScope”), alleging as follows:

I. INTRODUCTION

1. TQ Delta owns a portfolio of patents relating to digital subscriber line (“DSL”) technologies, including for example very-high-bit-rate digital subscriber line (“VDSL”) technology and Fast Access to Subscriber Terminals technology (“G.fast”). These patents originate from groundbreaking innovations in the DSL field, including innovations that the International Telecommunication Union (“ITU”) adopted in various DSL-related standards.

2. CommScope infringes TQ Delta's patents. CommScope provides DSL equipment, and TQ Delta has attempted to license its patents to CommScope on a worldwide, non-discriminatory basis and on reasonable terms and conditions. CommScope has refused to obtain such a license or cease its infringement. It has continued to willfully infringe upon TQ Delta's patents, taking substantial benefits from TQ Delta's inventions and harming TQ Delta. This case is to redress that harm.

II. NATURE OF THE SUIT

3. This is a claim for patent infringement arising under the patent laws of the United States, Title 35 of the United States Code.

III. THE PARTIES

4. Plaintiff **TQ Delta, LLC** is a limited liability company organized and existing under the laws of the State of Delaware and having a principal place of business at 900 S. Capital of Texas Hwy., Suite 150, Austin, Texas 78746.

5. Defendant **CommScope Holding Company, Inc.** is a corporation organized and existing under the laws of the State of Delaware, and can be served through its registered agent, United Agent Group Inc., 3411 Silverside Road Tatnall Building #104, Wilmington, DE 19810.

6. Upon information and belief, Defendant **CommScope Inc.** is a corporation organized and existing under the laws of the State of Delaware, and can be served through its registered agent, United Agent Group Inc., 3411 Silverside Road Tatnall Building #104, Wilmington, DE 19810. Upon information and belief, CommScope Inc. is a wholly owned subsidiary of CommScope Holding Company.

7. Defendants **ARRIS International Limited**, **ARRIS Global Ltd**, **ARRIS US Holdings, Inc.**, **ARRIS Solutions, Inc.**, **ARRIS Technology, Inc.**, and **ARRIS Enterprises, LLC** are collectively referred to as “ARRIS.”

8. **CommScope Holding Company, Inc.** acquired **ARRIS** in 2019.¹ On information and belief, **CommScope Holding Company, Inc.** is the parent corporation of **ARRIS**.

9. Defendant **ARRIS International Limited** f/k/a **Arris International plc** is a corporation duly organized and existing under the laws of England and Wales.

10. Defendant **ARRIS Global Ltd.** is a corporation duly organized and existing under the laws of England and Wales. On information and belief, **ARRIS Global Ltd** is a subsidiary of **ARRIS International Limited**.

11. Defendant **ARRIS US Holdings, Inc.** is a corporation organized and existing under the laws of the State of Delaware, and can be served through its registered agent, **United Agent Group Inc.**, 3411 Silverside Road, Tatnall Building, #104, Wilmington, DE 19810. On information and belief, **ARRIS US Holdings, Inc.** is a subsidiary of **ARRIS International Limited**. **CommScope** has admitted that “**Arris US Holdings, Inc.**’s business includes selling products and services throughout the United States, including in this judicial district.”²

12. Defendant **ARRIS Solutions, Inc.** is a corporation organized and existing under the laws of the State of Delaware, and can be served through its registered agent, **United Agent Group Inc.**, 3411 Silverside Road, Tatnall Building, #104, Wilmington, DE 19810. **CommScope**

¹ See, e.g., *SIPCO, LLC v. CommScope Holding Company, Inc.*, No. 5:20-CV-00168-RWS-CMC, First Amended Complaint, at ¶ 16 (“Upon information and belief, **CommScope** acquired **ARRIS** and **Ruckus** in 2019.”); *SIPCO, LLC v. CommScope Holding Company, Inc.*, No. 5:20-CV-00168-RWS-CMC, Answer to First Amended Complaint (Filed, June 7, 2021) (“**SIPCO Answer**”), at ¶ 16 (“Admitted.”).

² See, e.g., **SIPCO Answer** at ¶ 11.

has admitted that “ARRIS Solutions, Inc.’s business includes selling products and services throughout the United States, including in this judicial district.”³ On information and belief, ARRIS Solutions, Inc. is a subsidiary of ARRIS U.S. Holdings, Inc.

13. Defendant **ARRIS Technology, Inc.** is a corporation duly organized and existing under the laws of the State of Delaware and can be served through its registered agent, United Agent Group Inc., 3411 Silverside Road, Tatnall Building, #104, Wilmington, DE 19810. On information and belief, ARRIS Technology, Inc. is a subsidiary of ARRIS Solutions, Inc.

14. Defendant **ARRIS Enterprises LLC** is a corporation organized and existing under the laws of the State of Delaware, and can be served through its registered agent, United Agent Group Inc., 3411 Silverside Road, Tatnall Building, #104, Wilmington, DE 19810. CommScope has admitted that “ARRIS Enterprises LLC’s business includes selling products and services throughout the United States, including in this judicial district.”⁴ On information and belief, ARRIS Enterprises LLC is a subsidiary of ARRIS Technology, Inc.

15. On information and belief, ARRIS maintains regular and established places of business and does business in Texas at its offices at 4516 Seton Center Pkwy, Austin, Texas 78759-5370 and/or 5300 Hollister St., Houston, Texas 77040. On information and belief, ARRIS maintained a regular and established place of business in Plano, Texas prior to its acquisition by CommScope in 2019.⁵ As detailed below, CommScope (including ARRIS) maintains a regular

³ See, e.g., SIPCO Answer, at ¶ 14.

⁴ See, e.g., SIPO Answer, at ¶ 12.

⁵ See, e.g., *Venkee Communications LLC v. Arris Group, Inc.*, No. 2:18-CV-00050, Original Complaint (Dkt. 1), at ¶ 4–10 (alleging a 2018 Plano, Texas location supported by Arris job posting).

and established place of business at 2601 Telecom Parkway, Richardson, Texas 70852, located within this District.

16. Upon information and belief, all Defendants are a single combined “CommScope” company. The online websites for Defendants are combined into a single “CommScope” presence. For example, the ARRIS web domain (www.arris.com) re-directs the public to the CommScope web domain (www.commscope.com).

17. The CommScope web domain further explains that the companies operate as “combined companies” that provide their technologies, solutions, and products, such as by importation, manufacture, sale, and/or offers for sale of their products and services throughout the United States. For example, the CommScope website lists for sale ARRIS-branded DSL product lines that, prior to acquisition of ARRIS, were available from Arris’s website.⁶

18. The CommScope jobs websites (<https://jobs.commscope.com/> and <https://careers.commscope.com/>) appear to handle the job recruitment features for all of CommScope, including ARRIS. In addition, on information and belief, employees of ARRIS became employees of CommScope after the acquisition and work out of CommScope’s Richardson, Texas office located in this district.

IV. JURISDICITON AND VENUE

19. This action is for patent infringement under the patent laws of the United States, 35 U.S.C. § 1 *et seq.*

20. This Court has subject matter jurisdiction over this dispute pursuant to 28 U.S.C. §§ 1331, 1367, 1338(a), and/or 2201.

⁶ Compare e.g., <https://www.commscope.com/product-type/broadband-video-devices/broadband-devices/xdsl-gateways/> with <https://web.archive.org/web/20160301000110/http://www.arris.com/Products/Markets/Telco>.

21. This Court has personal jurisdiction over CommScope, and CommScope has acceded to this Court's jurisdiction in prior patent cases.⁷

22. The Court has personal jurisdiction over CommScope because, among other things, TQ Delta's claims arise in whole or in part from CommScope's conduct in Texas, including making, using, offering to sell and/or selling accused products in Texas, and/or importing accused products into Texas, and/or inducing others to commit acts of patent infringement in Texas. For example, on information and belief, CommScope operates offices at which it does business in Texas at the following locations: 2601 Telecom Parkway, Richardson, Texas 70852; 11312 S. Pipeline Road, Euless, Texas 76040; 4516 Seton Center Pkwy, Austin, Texas 78759-5370; 5300 Hollister St., Houston, Texas 77040; and 4101 W. Military Highway A, McAllen, Texas 78053. CommScope has admitted that it conducts business in Texas.⁸

23. Venue is proper in this District pursuant to 28 U.S.C. §§ 1391 and 1400(b). CommScope has admitted in this Court that it "has a regular and established physical place of business in the Eastern District of Texas."⁹ CommScope maintains a regular and established place

⁷ See, e.g., *SIPCO, LLC v. CommScope Holding Company, Inc.*, No. 5:20-CV-00168-RWS-CMC, Answer to First Amended Complaint, at ¶ 24 ("Defendants, for purposes of this case only, will not challenge personal jurisdiction in the Eastern District of Texas."); See, e.g., *Barkan Wireless IP Holdings, L.P. v. Sprint Corp.*, No. 2:19-CV-00336-JRG, Answer to Amended Complaint, at ¶ 14 ("For the purposes of this action only, CommScope does not challenge the Court's personal jurisdiction over CommScope.").

⁸ See, e.g., *Barkan Wireless IP Holdings, L.P. v. Sprint Corp.*, No. 2:19-CV-00336-JRG, Answer to Amended Complaint, at ¶ 14 ("CommScope admits that it conducts business in Texas.").

⁹ *SIPCO, LLC v. CommScope Holding Company, Inc.*, No. 5:20-CV-00168-RWS-CMC, First Amended Complaint, at ¶ 24 ("Plaintiff is informed and believes, and on that basis alleges, that CommScope has a regular and established physical place of business in the Eastern District of Texas, including at 2601 Telecom Parkway, Richardson Texas 70852 . . ."); *SIPCO* Answer at ¶ 24 ("Admitted."); see also *Barkan Wireless IP Holdings, L.P. v. Sprint Corp.*, No. 2:19-CV-00336-JRG, Answer to Amended Complaint, at ¶ 16 ("CommScope admits that it has a regular and established place of business in this judicial district at 2601 Telecom Parkway, Richardson, Texas

of business in 2601 Telecom Parkway, Richardson, Texas 70852, located within this District that contains CommScope's employees and/or other individuals CommScope directs or controls.¹⁰ Venue is also proper in this District pursuant to 28 U.S.C § 1391(c)(3) on the basis that ARRIS International Limited and ARRIS Global Ltd are not residents of the United States.

24. On information and belief, CommScope has current and former employees, including engineers, managers, and executives, in this District and/or Texas, including personnel relating to the DSL functionality of the Accused CommScope DSL CPE Products.¹¹

25. On information and belief, CommScope also employed personnel relating to ITU-T standards in Texas and this District.

26. On information and belief, CommScope also has major customers with locations in Texas and this District, including, for example, AT&T.

27. CommScope's commission of acts of infringement in this District, and the presence of an office at which CommScope does business in the Eastern District of Texas, establishes venue over CommScope under 28 U.S.C. § 1400(b).

70852.”).

¹⁰ See, e.g., <https://www.collincad.org/propertysearch?prop=2075393&year=2021> (listing CommScope Inc. as owner of property in Collin County with a tax valuation of \$13,867,489 in 2021).

¹¹ See, e.g., <https://www.linkedin.com/in/joseph-z-yu> (“Firmware development for DSL modems.”); <https://www.linkedin.com/in/stevecochran> (“I led a distributed team of software engineers continuing the development and support of the Pace DSL residential gateway product. These routers are deployed by AT&T and other service providers to millions of subscriber homes.”); <https://www.linkedin.com/in/wchatila> (regional VP of Sales at CommScope); <https://www.linkedin.com/in/bryce-garrett-8bba71/> (former Director of Sales that “[m]anaged the AT&T Account with responsibility for deployment of all ARRIS Residential Gateways (RGs), Wireless Access Points (WAPs) and home entertainment receivers for U-Verse, Business and Legacy subscribers. Sales were achieved through direct B2B as well as channel partners, VARs and distribution. . . .The ARRIS CPE portfolio includes DSL, VDSL, VDSL2, Bonded VDSL, G.fast and GigaPower Fiber gateways . . .”).

V. BACKGROUND

A. TQ Delta and the DSL Standards

28. TQ Delta is the successor-in-interest in patents from Aware, Inc. (“Aware”). Aware was a world-leading innovator and provider of DSL technologies.

29. This cause of action asserts infringement of the following TQ Delta’s patents, United States Patent Nos. 7,453,881 (“the ’881 Patent”); 7,570,686 (“the ’686 Patent”); 7,844,882 (“the ’882 Patent”); 8,090,008 (“the ’008 Patent”); 8,276,048 (“the ’048 Patent”); 8,462,835 (“the ’835 Patent”); 8,468,411 (“the ’411 Patent”); 8,937,988 (“the ’988 Patent”); 9,094,348 (“the ’348 Patent”); 9,154,354 (“the ’354 Patent”); 9,485,055 (“the ’055 Patent”); 10,567,112 (“the ’112 Patent”); and 10,833,809 (“the ’809 Patent”). (collectively, “the TQ Delta Patents”).

30. The primary inventor of TQ Delta’s DSL patents, Marcos Tzannes, has worked on DSL-related technologies for almost 30 years. Mr. Tzannes was the head of the DSL technology group at Aware, and major semiconductor companies purchased Aware’s chip designs.

31. Mr. Tzannes also had significant involvement in developing industry standards for DSL technology. Mr. Tzannes attended the DSL standard group meetings on behalf of Aware (and continued to do so on behalf of TQ Delta). Mr. Tzannes has been a participant and contributor at ITU meetings in 1997 and, over the years, served as the chair of a number of ITU standards committees. Those include committees relating to DSL, including G.bond. In 2012, the ITU recognized Mr. Tzannes for his contributions on eight different standards.

32. On information and belief, representatives of CommScope also attended these ITU standards meetings at the time Mr. Tzannes attended them.

33. The ITU has adopted a number of industry standards relating to DSL technologies. Those include ITU-T ADSL2/2+, ITU-T VDSL2, ITU-T G.bond, ITU-T G.inp, ITU-T G.vector, and ITU-T G.fast.

B. CommScope's Infringement of the TQ Delta's Patents

34. CommScope infringes the TQ Delta Patents. Its products comply with and implement the DSL standards, including ADSL2/2+, VDSL2, G.bond, G.inp, G.vector, and G.fast. CommScope markets and has marketed its products as complying with these standards. CommScope makes, uses, sells, offers for sale, and/or imports customer premise equipment ("CPE") products, including without limitation gateways, modems, and service managers, that operate in accordance with one or more of the DSL standards ("DSL CPE Products"). The DSL CPE Products operate in accordance with ADSL2/2+, VDSL2, G.bond, G.inp, and/or G.vector.¹² The DSL CPE Products also operate in accordance with G.fast.¹³

35. CommScope provides DSL CPE Products to telephone/broadband carriers and such carriers' subscribers/customers (collectively, "Customers") knowing that its DSL CPE Products will be deployed and used in a DSL network to provide DSL service by operating in accordance with the DSL Standards. CommScope also provides instructions and support (including, for example, providing upgrades, troubleshooting, and warranty support) to its Customers to ensure that its DSL CPE Products operate as intended (*e.g.*, in accordance with the DSL Standards). For

¹² *E.g.*, <https://www.commscope.com/globalassets/digizuite/62029-nvg44x-datasheet.pdf>.

¹³ *E.g.*, https://www.goamt.com/wp-content/uploads/2017/11/FST1305_G.FAST-VDSL2-35B-BRIDGE-MODEM_AMT.pdf.

example, on information and belief, CommScope DSL CPE Products have been deployed in networks for AT&T and Frontier Networks.¹⁴

36. CommScope has known about the TQ Delta Patents and its infringement since prior to filing of this Complaint. TQ Delta contacted ARRIS and offered to engage in licensing discussions on multiple occasions. After CommScope acquired ARRIS, TQ Delta contacted CommScope to offer to engage in licensing discussions. In multiple correspondences with CommScope, TQ Delta identified a number of ARRIS products it believed are covered by TQ Delta's patents. TQ Delta also met with CommScope in Austin, Texas. TQ Delta's attempts to license its patents to CommScope on a worldwide, non-discriminatory basis and on reasonable terms and conditions continued to this year. CommScope still refuses to accept a license TQ Delta's patents on a worldwide, non-discriminatory basis and on reasonable terms and conditions

37. CommScope has known or was willfully blind to its infringement of TQ Delta's patents. As detailed above, TQ Delta has been in near-continuous contact with CommScope for years about its infringement.

38. In addition, CommScope has known or should have known about its infringement based on the publication of the ITU DSL standards and CommScope's involvement with the standards. Since prior to CommScope's infringing conduct alleged herein, the ITU standards have been published with an intellectual-property rights warning that draws attention to the possibility that implementation of the standard may involve the use of a claimed intellectual-property right

¹⁴ See, e.g., <https://www.linkedin.com/in/bryce-garrett-8bba71/> (former Director of Sales that "[m]anaged the AT&T Account with responsibility for deployment of all ARRIS Residential Gateways (RGs), Wireless Access Points (WAPs) and home entertainment receivers for U-Verse, Business and Legacy subscribers. . . . The ARRIS CPE portfolio includes DSL, VDSL, VDSL2, Bonded VDSL, G.fast and GigaPower Fiber gateways"); <https://go.frontier.com/internet/equipment> ("Frontier® Internet works with a variety of routers, like the Arris NVG443B").

and “strongly urge[s]” implementers to consult the ITU’s database regarding applicable intellectual property.¹⁵

39. A basic search of the ITU database would have shown that TQ Delta (or its predecessor-in-interest, Aware) submitted a Patent Statement and Licensing Declarations (“PSLDs”) regarding DSL standards, exemplified below for G.fast (G.9701):

Search results for G.9701 (G.fast) showing Patent Statements and Licensing Declarations (PSLDs) submitted by TQ DELTA, LLC.

Statement id	Recommendation	Patent number	Patent application number	Version of declaration form	License option	Received date	Statement date	Organization
G9701-08	G.9701 (ex. G.fast-phv)	None	None	23 April 2012	2	2014-05-19	2014-05-13	TQ DELTA, LLC
G9701_Amd1-02	G.9701 (ex. G.fast-phv)	None	None	26 June 2015	2	2016-02-23	2016-02-22	TQ DELTA, LLC
G9701_Amd2-01	G.9701 (ex. G.fast-phv)	None	None	26 June 2015	2	2016-02-23	2016-02-22	TQ DELTA, LLC

40. Similar searches for TQ Delta (or Aware) would have shown submitted PSLDs for G.inp, G.bond, and VDSL2, among others.

41. The PSLDs identify the standard that a patent holder believes the practice of which requires a license. The ITU PSLDs are publicly available.

¹⁵ See, e.g., https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-G.9700-201404-S!!PDF-E&type=items (G.fast); https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-G.998.4-201006-S!!PDF-E&type=items (G.inp).

42. For example, TQ Delta submitted a PSLD in connection with G.fast (G.9701) stating that it “believe[d] that it holds granted and/or pending application for Patents, the use of which would be required to implement [ITU-T G.9701].” TQ Delta and Aware submitted similar PSLDs for G.inp, G.bond, and VDSL2 standards, among others.¹⁶ These PSLDs have been publicly available prior to filing of this Complaint.

43. On information and belief, CommScope is familiar with the PSLD database and the contents of declarations filed with the ITU.

44. Thus, prior to the filing of this Complaint, CommScope had actual knowledge of, and was familiar with, the intellectual-property rights warnings, the ITU procedures and requirements for submissions of PSLDs, and the process of identifying parties who had submitted PSLDs for the DSL standards.

45. Defendants have had actual notice of the TQ Delta Patents and their infringement prior to the filing of this Complaint.

46. Defendants’ infringement, as detailed above, has been willful.

VI. CLAIMS

A. Infringement of the ’881 Patent

47. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein and form the basis for the following cause of action against each Defendant.

¹⁶ See, e.g., https://www.itu.int/ITU-T/recommendations/related_ps.aspx?id_prod=10418 (G.998.4); https://www.itu.int/ITU-T/recommendations/related_ps.aspx?id_prod=8548 (G.993.2); https://www.itu.int/ITU-T/recommendations/related_ps.aspx?id_prod=10414 (G.993.5).

48. A true and correct copy of the '881 Patent, entitled "Systems and methods for multi-pair ATM over DSL," and with Marcos Tzannes as the first named inventor, is attached hereto as Exhibit 1.

49. The '881 Patent duly and legally issued on November 18, 2008.

50. TQ Delta is the current owner by assignment of all rights, title, and interest in and under the '881 Patent. TQ Delta has standing to sue for infringement of the '881 Patent.

51. The G.bond (ITU-T G.998.1 and G.998.2) standards specify functionality for a plurality of bonded transceivers, each bonded transceiver utilizing at least one transmission parameter value to reduce a difference in latency between the bonded transceivers, wherein a data rate for a first of the bonded transceivers is different than a data rate for a second of the bonded transceivers (*e.g.*, using forward error correction and/or interleaving parameter values to reduce the difference in latency between the higher and lower speed links).¹⁷

52. CommScope's DSL CPE Products comply with G.bond (ITU-T G.998.1 and G.998.2).¹⁸

53. CommScope has directly infringed and continues to infringe at least claim 17 of the '881 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell DSL CPE Products in the United States, or importing said DSL CPE Products into the United States.

54. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 17 of the '881 Patent in violation of 35 U.S.C. § 271(b). CommScope users and

¹⁷ See, *e.g.*, ITU-T G.998.1 at Summary, Table 7.7, Table C.7-7, §§ 1, 11.4.1, K.2.7; ITU-T G.998.2 at Summary, §§ 6, 61.2.2.5.

¹⁸ See, *e.g.*, <https://www.commscope.com/globalassets/digizuite/62029-nvg44x-datasheet.pdf> (disclosing support for ADSL2/2+ bonding and VDSL2 bonding).

customers (*e.g.*, service providers) of DSL CPE Products directly infringed at least claim 17 of the '881 Patent when they used the DSL CPE Products in the ordinary, customary, and intended way to operate within the G.bond (ITU-T G.998.1 and G.998.2) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement G.bond (ITU-T G.998.1 and G.998.2)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 17 of the '881 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the DSL CPE Products within the United States, or knowingly inducing customers to use the DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the DSL CPE Products in the United States, which CommScope knows or should know infringes at least claim 17 of the '881 Patent.

55. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '881 Patent, by selling DSL CPE Products to customers in the United States for use in practicing at least claim 17 of the '881 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '881 Patent. Specifically, CommScope sold

the DSL CPE Products to customers knowing that the products directly infringe the '881 Patent when used for their normal and intended purpose, including by operating in accordance with G.bond (ITU-T G.998.1 and G.998.2). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

56. CommScope knew or should have known of the '881 Patent but was willfully blind to the existence of the Patent. CommScope has had actual knowledge of the '881 Patent since at least as early as the filing and service of this Complaint. By the time of the trial of this case, CommScope will have known and intended that its continued actions since receiving such notice would infringe and actively induce and contribute to the infringement of one or more claims of the '881 Patent. CommScope's infringement of the '881 Patent has been willful and deliberate.

B. Infringement of the '686 Patent

57. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein and form the basis for the following cause of action against each Defendant.

58. A true and correct copy of the '686 Patent, entitled "Systems and methods for establishing a diagnostic transmission mode and communicating over the same," and with David Krinsky as the first named inventor, is attached hereto as Exhibit 2.

59. The '686 Patent duly and legally issued on August 4, 2009.

60. TQ Delta is the current owner by assignment of all rights, title, and interest in and under the '686 Patent. TQ Delta has standing to sue for infringement of the '686 Patent.

61. The ADSL2/2+ (G.992.3/5) and VDSL2 (ITU-T G.993.2) standards specify functionality for an information storage media comprising instructions that when executed communicate diagnostic information over a communication channel using multicarrier modulation comprising: instructions that when executed direct a transceiver to receive or transmit an initiate

diagnostic mode message; and instructions that when executed transmit from the transceiver a diagnostic message using multicarrier modulation with DMT symbols that are mapped to one bit of the diagnostic message, wherein the diagnostic message comprises a plurality of data variables representing the diagnostic information about the communication channel, and wherein one variable comprises an array representing is frequency domain received idle channel noise information (*e.g.*, loop diagnostic mode procedures).¹⁹

62. CommScope's DSL CPE Products include products that operate in accordance with VDSL2 (ITU-T G.993.2).²⁰

63. CommScope's DSL CPE Products include products that operate in accordance with ASDSL2/2+ (ITU-T G.992.3/5).²¹

64. CommScope has directly infringed and continues to infringe at least claim 36 of the '686 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell the DSL CPE Products in the United States, or importing said DSL CPE Products into the United States.

65. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 36 of the '686 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 36 of the '686 Patent when they used the DSL CPE Products in the ordinary, customary, and intended

¹⁹ See, *e.g.*, ITU-T G.992.3/5 §§ 8.8, 8.15 (including, for examples, Tables 8-21, 8-23, 8-42, 8-52, 8-62).; ITU-T G.993.2 §§ 10.4, 11.4, 12.4 (including, for examples, Tables 12-6, 12-10, 12-16, 12-74, 12-71, 12-75).

²⁰ See, *e.g.*, <https://www.commscope.com/globalassets/digizuite/62029-nvg44x-datasheet.pdf> (disclosing support for ITU-T G.993.2).

²¹ See, *e.g.*, <https://www.commscope.com/globalassets/digizuite/62029-nvg44x-datasheet.pdf> (disclosing support for ITU-T G.992.3 and G.992.5).

way to operate within the VDSL2 (ITU-T G.993.2) and/or ADSL2/2+ (ITU-T G.992.3/5) standards. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement VDSL2 (ITU-T G.993.2) and/or ADSL2/2+ (ITU-T G.992.3/5)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 36 of the '686 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the DSL CPE Products within the United States, or knowingly inducing customers to use the DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the DSL CPE Products in the United States, which CommScope knows or should know infringes at least claim 36 of the '686 Patent.

66. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '686 Patent, by selling the DSL CPE Products to customers in the United States for use in practicing at least claim 36 of the '686 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '686 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '686 Patent

when used for their normal and intended purpose, including by operating in accordance with VDSL2 (ITU-T G.993.2) and ADSL2/2+ (ITU-T G.992.3/5). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

67. CommScope knew or should have known of the '686 Patent but was willfully blind to the existence of the Patent. CommScope has had actual knowledge of the '686 Patent since at least as early as the filing and service of this Complaint. By the time of the trial of this case, CommScope will have known and intended that its continued actions since receiving such notice would infringe and actively induce and contribute to the infringement of one or more claims of the '686 Patent. CommScope's infringement of the '686 Patent has been willful and deliberate.

C. Infringement of the '882 Patent

68. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein and form the basis for the following cause of action against each Defendant.

69. A true and correct copy of the '882 Patent, entitled "Resource sharing in a telecommunications environment," and with Marcos Tzannes as the first named inventor, is attached hereto as Exhibit 3.

70. The '882 Patent duly and legally issued on November 30, 2010.

71. TQ Delta is the current owner by assignment of all rights, title, and interest in and under the '882 Patent. TQ Delta has standing to sue for infringement of the '882 Patent.

72. The VDSL2 (ITU-T G.993.2) standard specifies functionality relating to a system that allocates shared memory using a transceiver transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver; determining an amount of memory required by the deinterleaver to deinterleave

a first plurality of Reed Solomon (RS) coded data bytes within a shared memory; allocating a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message; allocating a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes received at a second data rate; and deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the [shared] memory allocated to the interleaver, wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver (*e.g.*, allocating an amount of shared memory to a deinterleaver based on a `max_delay_octetDS` value received in the O-PMS message).²²

73. CommScope's DSL CPE Products include products that operate in accordance with VDSL2 (ITU-T G.993.2).²³ On information and belief, the DSL CPE Products allocate amounts of shared memory to an interleaver and deinterleaver in the manner described in VDSL 2 (ITU-T G.993.2) above.

74. CommScope has directly infringed and continues to infringe at least claim 13 of the '882 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell the DSL CPE Products in the United States, or importing said DSL CPE Products into the United States.

²² See, *e.g.*, ITU-T G.993.2 at §§ 5.1, 6.2.8, 7.1, 9.4, 12.3.5.2.1.3.

²³ See, *e.g.*, <https://www.commscope.com/globalassets/digizuite/62029-nvg44x-datasheet.pdf> (disclosing support for ITU-T G.993.2).

75. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 13 of the '882 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 13 of the '882 Patent when they used the DSL CPE Products in the ordinary, customary, and intended way to operate within the VDSL2 (ITU-T G.993.2) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement VDSL2 (ITU-T G.993.2)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 13 of the '882 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the DSL CPE Products within the United States, or knowingly inducing customers to use the DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the DSL CPE Products in the United States, which CommScope knows or should know infringes at least claim 13 of the '882 Patent.

76. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '882 Patent, by selling the DSL CPE Products to customers in the United States for use in practicing at least claim 13 of the '882 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles

or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '882 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '882 Patent when used for their normal and intended purpose, including by operating in accordance with ITU-T VDSL2 (G.993.2). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

77. CommScope knew or should have known of the '882 Patent but was willfully blind to the existence of the Patent. CommScope has had actual knowledge of the '882 Patent since at least as early as the filing and service of this Complaint. By the time of the trial of this case, CommScope will have known and intended that its continued actions since receiving such notice would infringe and actively induce and contribute to the infringement of one or more claims of the '882 Patent. CommScope's infringement of the '882 Patent has been willful and deliberate.

D. Infringement of the '008 Patent

78. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein and form the basis for the following cause of action against each Defendant.

79. A true and correct copy of the '008 Patent, entitled "System and method for scrambling the phase of the carriers in a multicarrier communications system," and with Marcos Tzannes as the first named inventor, is attached hereto as Exhibit 4.

80. The '008 Patent duly and legally issued on January 3, 2012.

81. TQ Delta is the current owner by assignment of all rights, title, and interest in and under the '008 Patent. TQ Delta has standing to sue for infringement of the '008 Patent.

82. The VDSL2 (ITU-T G.993.2) standard specifies functionality for a multicarrier system including a first transceiver that uses a plurality of carrier signals for modulating a bit

stream, wherein each carrier signal has a phase characteristic associated with the bit stream, the transceiver capable of: associating each carrier signal with a value determined independently of any bit value of the bit stream carried by that respective carrier signal, the value associated with each carrier signal determined using a pseudo-random number generator; computing a phase shift for each carrier signal based on the value associated with that carrier signal; and combining the phase shift computed for each respective carrier signal with the phase characteristic of that carrier signal to substantially scramble the phase characteristics of the plurality of carrier signals, wherein multiple carrier signals corresponding to the scrambled carrier signals are used by the first transceiver to modulate the same bit value (*e.g.*, a quadrant scrambler and message bit mapping that causes the same bit to be transmitted on multiple subcarriers).²⁴

83. The Accused CommScope DSL CPE Products include products that operate in accordance with VDSL2 (ITU-T G.993.2).²⁵

84. CommScope has directly infringed at least claim 14 of the '008 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell the DSL CPE Products in the United States, or importing said DSL CPE Products into the United States.

85. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 14 of the '008 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 14 of the '008 Patent when they used the DSL CPE Products in the ordinary, customary, and intended

²⁴ See, *e.g.*, ITU-T G.993.2 at §§ 10.3.3.2.1, 10.4.3, 12.2, 12.3.3.3.1.2, 12.3.3.3.3.2, 12.3.4.3.1.8, 12.3.4.3.2.8, 12.3.5.3.1, 12.3.5.3.2, 12.3.6.2.

²⁵ See, *e.g.*, <https://www.commscope.com/globalassets/digizuite/62029-nvg44x-datasheet.pdf> (disclosing support for ITU-T G.993.2).

way to operate within the VDSL2 (ITU-T G.993.2) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement VDSL2 (ITU-T G.993.2)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 14 of the '008 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the DSL CPE Products within the United States, or knowingly inducing customers to use the DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the CPE Products in the United States, which CommScope knows or should know infringes at least claim 14 of the '008 Patent.

86. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '008 Patent, by selling the DSL CPE Products standard to customers in the United States for use in practicing at least claim 14 of the '008 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '008 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '008 Patent when used for their normal and intended purpose, including by operating in

accordance with ITU-T VDSL2 (G.993.2). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

87. CommScope knew or should have known of the '008 Patent but was willfully blind to the existence of the Patent. CommScope has had actual knowledge of the '008 Patent since at least as early as the filing and service of this Complaint. By the time of the trial of this case, CommScope will have known and intended that its continued actions since receiving such notice would infringe and actively induce and contribute to the infringement of one or more claims of the '008 Patent. CommScope's infringement of the '008 Patent has been willful and deliberate.

E. Infringement of the '048 Patent

88. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein and form the basis for the following cause of action against each Defendant.

89. A true and correct copy of the '048 Patent, entitled "Resource sharing in a telecommunications environment," and with Marcos Tzannes as the first named inventor, is attached hereto as Exhibit 5.

90. The '048 Patent duly and legally issued on September 25, 2012.

91. TQ Delta is the current owner by assignment of all rights, title, and interest in and under the '048 Patent. TQ Delta has standing to sue for infringement of the '048 Patent.

92. The VDSL2 (ITU-T G.993.2) standard specifies functionality relating to a system that allocates shared memory through a transceiver that is capable of: transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver; determining an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within the shared memory; allocating a first number of bytes of the shared memory to the interleaver to interleave the first

plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes specified in the message; allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate; and interleaving the first plurality of RS coded data bytes within the shared memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver, wherein the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver (*e.g.*, allocating an amount of shared memory to an interleaver based on a `max_delay_octetUS` value received in the O-PMS message).²⁶

93. The Accused CommScope DSL CPE Products include products that operate in accordance with VDSL2 (ITU-T G.993.2).²⁷ On information and belief, the DSL CPE Products allocate an amount of shared memory to an interleaver and deinterleaver in the manner described in VDSL 2 (ITU-T G.993.2) above.

94. CommScope has directly infringed and continues to infringe at least claim 1 of the '048 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell the DSL CPE Products in the United States, or importing said DSL CPE Products into the United States.

95. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 1 of the '048 Patent in violation of 35 U.S.C. § 271(b). CommScope users and

²⁶ See, *e.g.*, ITU-T G.993.2 at §§ 5.1, 6.2.8, 7.1, 9.4, 12.3.5.2.1.3.

²⁷ See, *e.g.*, <https://www.commscope.com/globalassets/digizuite/62029-nvg44x-datasheet.pdf> (disclosing support for ITU-T G.993.2).

customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 1 of the '048 Patent when they used the DSL CPE Products in the ordinary, customary, and intended way to operate within the VDSL2 (ITU-T G.993.2) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement VDSL2 (ITU-T G.993.2)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 1 of the '048 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the DSL CPE Products within the United States, or knowingly inducing customers to use the DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the CPE Products in the United States, which CommScope knows or should know infringes at least claim 1 of the '048 Patent.

96. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '048 Patent, by selling the DSL CPE Products to customers in the United States for use in practicing at least claim 1 of the '048 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '048 Patent. Specifically, CommScope sold

the DSL CPE Products to customers knowing that the products directly infringe the '048 Patent when used for their normal and intended purpose, including by operating in accordance with ITU-T VDSL2 (G.993.2). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

97. CommScope knew or should have known of the '048 Patent but was willfully blind to the existence of the Patent. CommScope has had actual knowledge of the '048 Patent since at least as early as the filing and service of this Complaint. By the time of the trial of this case, CommScope will have known and intended that its continued actions since receiving such notice would infringe and actively induce and contribute to the infringement of one or more claims of the '048 Patent. CommScope's infringement of the '048 Patent has been willful and deliberate.

F. Infringement of the '835 Patent

98. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein and form the basis for the following cause of action against each Defendant.

99. A true and correct copy of the '835 Patent, entitled "Impulse noise management," and with Marcos Tzannes as the first named inventor, is attached hereto as Exhibit 6.

100. The '835 Patent duly and legally issued on June 11, 2013.

101. TQ Delta is the current owner by assignment of all rights, title, and interest in and under the '835 Patent. TQ Delta has standing to sue for infringement of the '835 Patent.

102. The VDSL2 (ITU-T G.993.2) standard specifies functionality for an apparatus configurable to adapt forward error correction and interleaver parameter (FIP) settings during steady-state communication or initialization comprising: a transceiver, including a processor, configurable to: receive a signal using a first FIP setting, receive a flag signal, and switch to using for reception, a second FIP setting following reception of the flag signal, wherein: the first FIP

setting comprises at least one first FIP value, the second FIP setting comprises at least one second FIP value, different than the first FIP value, and the switching occurs on a pre-defined forward error correction codeword boundary following the flag signal. (*e.g.*, changing the interleave depth).²⁸ This functionality is mandatory for using the G.vector (ITU-T G.993.5) standard with VDSL2.

103. The Accused CommScope DSL CPE Products include products that operate in accordance with VDSL2 (ITU-T G.993.2), the including G.vector (ITU-T G.993.5) standard.²⁹

104. CommScope has directly infringed and continues to infringe at least claim 24 of the '835 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell DSL CPE Products in the United States, or importing said Accused CommScope DSL CPE Products into the United States.

105. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 24 of the '835 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 24 of the '835 Patent when they used the DSL CPE Products in the ordinary, customary, and intended way to operate within the VDSL2 (ITU-T G.993.2) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers

²⁸ See, *e.g.*, ITU-T G.993.2 at Figure 13-1, Table 12-57, §§ 3.64, 9.4.1, 13.3; ITU-T G.993.5 at General, § 6.1.

²⁹ See, *e.g.*, <https://www.commscope.com/globalassets/digizuite/62029-nvg44x-datasheet.pdf> (disclosing support for ITU-T G.993.2 and G.993.5 vectoring).

(for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement VDSL2 (ITU-T G.993.2)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 24 of the '835 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the DSL CPE Products within the United States, or knowingly inducing customers to use the DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the CPE Products in the United States, which CommScope knows or should know infringes at least claim 24 of the '835 Patent.

106. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '835 Patent, by selling the DSL CPE Products to customers in the United States for use in practicing at least claim 24 of the '835 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '835 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '835 Patent when used for their normal and intended purpose, including by operating in accordance with ITU-T VDSL2 (G.993.2). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

107. CommScope knew or should have known of the '835 Patent but was willfully blind to the existence of the Patent. CommScope has had actual knowledge of the '835 Patent since at least as early as the filing and service of this Complaint. By the time of the trial of this case,

CommScope will have known and intended that its continued actions since receiving such notice would infringe and actively induce and contribute to the infringement of one or more claims of the '835 Patent. CommScope's infringement of the '835 Patent has been willful and deliberate.

G. Infringement of the '411 Patent

108. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein and form the basis for the following cause of action against each Defendant.

109. A true and correct copy of the '411 Patent, entitled "Packet retransmission," and with Marcos Tzannes as the first named inventor, is attached hereto as Exhibit 7.

110. The '411 Patent duly and legally issued on June 18, 2013.

111. TQ Delta is the current owner by assignment of all rights, title, and interest in and under the '411 Patent. TQ Delta has standing to sue for infringement of the '411 Patent.

112. The G.inp (ITU-T G.998.4) standard specifies functionality for a transceiver capable of packet retransmission comprising: a receiver portion capable of: receiving a plurality of packets, identifying at least one packet of the plurality of packets as a packet that should be retransmitted and allocating a memory between a retransmission function and an interleaving and/or deinterleaving function wherein the memory is allocated between the retransmission function and the interleaving function and/or the deinterleaving function in accordance with a message received during an initialization of the transceiver and wherein at least a portion of the memory may be allocated between the retransmission function and the interleaving and/or deinterleaving function at any one particular time depending on the message (*e.g.*, allocating amounts of shared memory to an interleaver or deinterleaver function and a retransmission function in accordance information provided in an initialization message).³⁰

³⁰ See, *e.g.*, ITU-T G.998.4, at Summary, §§ 1, 2, 6, 8.2, 8.3, 8.4, Annex D.1.1, C.2.1.3, C.2.1.4.

113. The Accused CommScope DSL CPE Products include products that operate in accordance with G.inp (ITU-T G.998.4).³¹ On information and belief, the DSL CPE Products to allocate memory in the manner described above.

114. CommScope has directly infringed and continues to infringe at least claim 18 of the '411 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell the Accused CommScope DSL CPE Products in the United States, or importing said Accused CommScope DSL CPE Products into the United States.

115. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 18 of the '411 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 18 of the '411 Patent when they used the DSL CPE Products in the ordinary, customary, and intended way to operate within the G.inp (ITU-T G.998.4) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement G.inp (ITU-T G.998.4)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 18 of the '411 Patent. CommScope's inducements may

³¹ See, *e.g.*, <https://www.commscope.com/globalassets/digizuite/62029-nvg44x-datasheet.pdf> (disclosing support for ITU-T G.998.4).

further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, or knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the CPE Products in the United States, which CommScope knows or should know infringes at least claim 18 of the '411 Patent.

116. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '411 Patent, by selling the DSL CPE Products to customers in the United States for use in practicing at least claim 18 of the '411 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '411 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '411 Patent when used for their normal and intended purpose, including by operating in accordance with G.inp (ITU-T G.998.4). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

117. CommScope knew or should have known of the '411 Patent but was willfully blind to the existence of the Patent. CommScope has had actual knowledge of the '411 Patent since at least as early as the filing and service of this Complaint. By the time of the trial of this case, CommScope will have known and intended that its continued actions since receiving such notice would infringe and actively induce and contribute to the infringement of one or more claims of the '411 Patent. CommScope's infringement of the '411 Patent has been willful and deliberate.

H. Infringement of the '988 Patent

118. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein and form the basis for the following cause of action against each Defendant.

119. A true and correct copy of the '988 Patent, entitled "Systems and methods for a multicarrier modulation system with a variable margin" and with Marcos Tzannes as the first named inventor, is attached hereto as Exhibit 8.

120. The '988 Patent duly and legally issued on January 20, 2015.

121. TQ Delta is the current owner by assignment of all rights, title, and interest in and under the '988 Patent. TQ Delta has standing to sue for infringement of the '988 Patent.

122. The G.fast (ITU-T G.9701) standard specifies functionality for an apparatus comprising: a multicarrier communications transceiver operable to demodulate for reception a first plurality of bits from a first carrier using a first Signal to Noise Ratio (SNR) margin and to demodulate for reception a second plurality of bits from a second carrier using a second SNR margin, and to demodulate for reception a third plurality of bits from the first carrier using a third SNR margin, wherein the first SNR margin specifies a first value for an allowable increase in noise without an increase in the bit error rate (BER) associated with the first carrier, wherein the second SNR margin specifies a second value for an allowable increase in noise without an increase in the bit error rate (BER) associated with the second carrier, wherein the third SNR margin specifies a third value for an allowable increase in noise without an increase in the bit error rate (BER) associated with said first carrier, wherein the first SNR margin is different than the second SNR margin, wherein the first SNR margin is different than the third SNR margin, and wherein the first plurality of bits, the second plurality of bits and the third plurality of bits are each different from

one another (*e.g.*, utilizing different signal-to-noise ratio margins for respective carriers associated with different channels).³²

123. The Accused CommScope DSL CPE Products include products that operate in accordance with G.fast (ITU-T G.9701).³³

124. CommScope has directly infringed at least claim 16 of the '988 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell the DSL CPE Products in the United States, or importing said DSL CPE Products into the United States.

125. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 16 of the '988 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 16 of the '988 Patent when they used the DSL CPE Products in the ordinary, customary, and intended way to operate within the G.fast (ITU-T G.9701) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement G.fast (ITU-T G.9701)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or

³² See, *e.g.*, ITU-T G.9701, at Figures 9-3, 10-3, Table 12-53, 11, §§ 5.3.4, 5.3.7, 7.1.3.2, 7.1.6.1, 9.1, 9.8.3.2, 9.8.3.4, 10.2.1.2, 10.4.3, 12.3.4.2.7, 12.3.4.2.8.

³³ See, *e.g.*, https://www.goamt.com/wp-content/uploads/2017/11/FST1305_G.FAST-VDSL2-35B-BRIDGE-MODEM_AMT.pdf (disclosing support for ITU-T G.9701).

should know infringes at least claim 16 of the '988 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, or knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the CPE Products in the United States, which CommScope knows or should know infringes at least claim 16 of the '988 Patent.

126. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '988 Patent, by selling the DSL CPE Products to customers in the United States for use in practicing at least claim 16 of the '988 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '988 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '988 Patent when used for their normal and intended purpose, including by operating in accordance with G.fast (ITU-T G.9701). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

127. CommScope knew or should have known of the '988 Patent but was willfully blind to the existence of the Patent. CommScope has had actual knowledge of the '988 Patent since at least as early as the filing and service of this Complaint. By the time of the trial of this case, CommScope will have known and intended that its continued actions since receiving such notice would infringe and actively induce and contribute to the infringement of one or more claims of the '988 Patent. CommScope's infringement of the '988 Patent has been willful and deliberate.

I. Infringement of the '348 Patent

128. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein and form the basis for the following cause of action against each Defendant.

129. A true and correct copy of the '348 Patent, entitled "Packet Retransmission" and with Marcos Tzannes as the first named inventor, is attached hereto as Exhibit 9.

130. The '348 Patent duly and legally issued on July 28, 2015.

131. TQ Delta is the current owner by assignment of all rights, title, and interest in and under the '348 Patent. TQ Delta has standing to sue for infringement of the '348 Patent.

132. The G.inp (ITU-T G.998.4) and G.VDSL2 (ITU-T G.993.2) standards specify functionality for an apparatus comprising: a multicarrier transceiver including a processor and memory operable to: receive a packet using a forward error correction decoder and a deinterleaver, wherein the packet comprises a header field and a plurality of PTM-TC codewords, a plurality of ATM cells or a plurality of Reed-Solomon codewords, and wherein the header field comprises a sequence identifier (SID); and transmit a plurality of messages using a forward error correction encoder and without using an interleaver, wherein each message of the plurality of messages is transmitted in a different DMT symbol and wherein at least one message of the plurality of messages includes an acknowledgement (ACK) or a negative acknowledgement (NACK) of the received packet (*e.g.*, using a forward error correction decoder and a deinterleaver as part of packet retransmission processing).³⁴

133. The G.fast (ITU-T G.9701) standard specifies functionality relating to an apparatus comprising: a multicarrier transceiver including a processor and memory operable to: transmit a

³⁴ See, *e.g.*, ITU-T G.993.2, at §§ 10.4.3; ITU-T G.998.4, at Figs. 6-1, 6-2, 6-3, 8-1, 9-1, Table C.6, §§ 3.11, 3.12, 3.13, 3.14, 3.17, 6, 8.1, 8.4, 9.2, 9.3, C.2.2.2 .

packet using a forward error correction encoder and an interleaver, wherein the packet comprises a header field and a plurality of PTM-TC codewords, a plurality of ATM cells or a plurality of Reed-Solomon codewords, and wherein the header field comprises a sequence identifier (SID); and receive a plurality of messages using a forward error correction decoder and without using a deinterleaver, wherein each message of the plurality of messages is received in a different DMT symbol and wherein at least one message of the plurality of messages includes an acknowledgement (ACK) or a negative acknowledgement (NACK) of the transmitted packet (*e.g.*, using a forward error correction encoder and an interleaver as part of packet retransmission processing).³⁵

134. The Accused CommScope DSL CPE Products include products that operate in accordance with G.inp (ITU-T G.998.4).³⁶

135. The Accused CommScope DSL CPE Products include products that operate in accordance with G.fast (ITU-T G.9701).³⁷

136. CommScope has directly infringed and continues to infringe at least claims 1 and 9 of the '348 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell the Accused CommScope DSL CPE Products in the United States, or importing said Accused CommScope DSL CPE Products into the United States.

³⁵ See, *e.g.*, ITU-T G.9701, at Tables 9-4, 9-5, 9-8, §§ 8.2, 9.1, 9.3, 9.4, 9.6, 10.4.3.

³⁶ See, *e.g.*, <https://www.commscope.com/globalassets/digizuite/62029-nvg44x-datasheet.pdf> (disclosing support for ITU-T G.998.4).

³⁷ See, *e.g.*, https://www.goamt.com/wp-content/uploads/2017/11/FST1305_G.FAST-VDSL2-35B-BRIDGE-MODEM_AMT.pdf (disclosing support for ITU-T G.9701).

137. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 9 of the '348 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 9 of the '348 Patent when they used the DSL CPE Products in the ordinary, customary, and intended way to operate within the G.inp (ITU-T G.998.4) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement G.inp (ITU-T G.998.4)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 9 of the '348 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, or knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the CPE Products in the United States, which CommScope knows or should know infringes at least claim 9 of the '348 Patent.

138. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 1 of the '348 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 1 of the '348 Patent when they used the DSL CPE Products in the ordinary, customary, and intended

way to operate within the G.fast (ITU-T G.9701) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement G.fast (ITU-T G.9701)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 1 of the '348 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the DSL CPE Products within the United States, or knowingly inducing customers to use the DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the DSL CPE Products in the United States, which CommScope knows or should know infringes at least claim 1 of the '348 Patent.

139. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '348 Patent, by selling the DSL CPE Products to customers in the United States for use in practicing at least claim 9 of the '348 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '348 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '348 Patent when used for their normal and intended purpose, including by operating in accordance with G.inp

(ITU-T G.998.4). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

140. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '348 Patent, by selling the DSL CPE Products to customers in the United States for use in practicing at least claim 1 of the '348 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '348 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '348 Patent when used for their normal and intended purpose, including by operating in accordance with G.fast (ITU-T G.9701). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

141. CommScope knew or should have known of the '348 Patent but was willfully blind to the existence of the Patent. CommScope has had actual knowledge of the '348 Patent since at least as early as the filing and service of this Complaint. By the time of the trial of this case, CommScope will have known and intended that its continued actions since receiving such notice would infringe and actively induce and contribute to the infringement of one or more claims of the '348 Patent. CommScope's infringement of the '348 Patent has been willful and deliberate.

J. Infringement of the '354 Patent

142. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein and form the basis for the following cause of action against each Defendant.

143. A true and correct copy of the '354 Patent, entitled "System and methods for a multicarrier modulation system with a variable margin" and with Marcos Tzannes as the first named inventor, is attached hereto as Exhibit 10.

144. The '354 Patent duly and legally issued on October 6, 2015.

145. TQ Delta is the current owner by assignment of all rights, title, and interest in and under the '354 Patent. TQ Delta has standing to sue for infringement of the '354 Patent.

146. The G.inp (ITU-T G.998.4) and G.VDSL2 (ITU-T G.993.2) standards specify functionality for a multicarrier communications transceiver operable to: receive a multicarrier symbol comprising a first plurality of carriers and a second plurality of carriers; receive a first plurality of bits on the first plurality of carriers using a first SNR margin; receive a second plurality of bits on the second plurality of carriers using a second SNR margin; wherein the first plurality of carriers is different than the second plurality of carriers, wherein the first SNR margin is different than the second SNR margin, and wherein the first SNR margin provides more robust reception than the second SNR margin (*e.g.*, utilizing different signal-to-noise ratio margins for respective carriers associated with different channels).³⁸

147. The G.fast (ITU-T G.9701) standard specifies functionality relating to a multicarrier communications transceiver operable to: receive a multicarrier symbol comprising a first plurality of carriers and a second plurality of carriers; receive a first plurality of bits on the first plurality of carriers using a first SNR margin; receive a second plurality of bits on the second plurality of carriers using a second SNR margin; wherein the first plurality of carriers is different than the second plurality of carriers, wherein the first SNR margin is different than the second

³⁸ See, *e.g.*, ITU-T G.993.2, at Table 12-49, §§ 9.5.3.1, 9.5.3.2, 10.3.1, 10.4.3, 12.3.5.2.1.1, 12.3.7.1, ; ITU-T G.998.4, at Figs. 6-1, 6-2, 6-3, 8-1, 9-1, Table 12-57, 12-64, 12-65, §§ 9, 10.1, 11.4.1.6.2, 11.4.1.6.4, C.1.2.

SNR margin, and wherein the first SNR margin provides more robust reception than the second SNR margin (*e.g.*, utilizing different signal-to-noise ratio margins for respective carriers associated with different channels).³⁹

148. The Accused CommScope DSL CPE Products include products that operate in accordance with G.inp (ITU-T G.998.4).⁴⁰

149. The Accused CommScope DSL CPE Products include products that operate in accordance with G.fast (ITU-T G.9701).⁴¹

150. CommScope has directly infringed at least claim 10 of the '354 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell the Accused CommScope DSL CPE Products in the United States, or importing said Accused CommScope DSL CPE Products into the United States.

151. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 10 of the '354 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 10 of the '354 Patent when they used the DSL CPE Products in the ordinary, customary, and intended way to operate within the G.inp (ITU-T G.998.4) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing

³⁹ See, *e.g.*, ITU-T G.9701, at Figure 9-3, §§ 9.1, 9.8.3.2, 9.8.3.4, 10.2.1.2, 10.4.3, 12.3.4.2.7, 12.3.4.2.8.

⁴⁰ See, *e.g.*, <https://www.commscope.com/globalassets/digizuite/62029-nvg44x-datasheet.pdf> (disclosing support for ITU-T G.998.4).

⁴¹ See, *e.g.*, https://www.goamt.com/wp-content/uploads/2017/11/FST1305_G.FAST-VDSL2-35B-BRIDGE-MODEM_AMT.pdf (disclosing support for ITU-T G.9701).

consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement G.inp (ITU-T G.998.4)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 10 of the '354 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, or knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the CPE Products in the United States, which CommScope knows or should know infringes at least claim 10 of the '354 Patent.

152. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 10 of the '354 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 10 of the '354 Patent when they used the DSL CPE Products in the ordinary, customary, and intended way to operate within the G.fast (ITU-T G.9701) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-

provider customers to use to the products to implement G.fast (ITU-T G.9701)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 10 of the '354 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the DSL CPE Products within the United States, or knowingly inducing customers to use the DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the DSL CPE Products in the United States, which CommScope knows or should know infringes at least claim 10 of the '354 Patent.

153. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '354 Patent, by selling the DSL CPE Products to customers in the United States for use in practicing at least claim 10 of the '354 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '354 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '354 Patent when used for their normal and intended purpose, including by operating in accordance with G.inp (ITU-T G.998.4). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

154. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '354 Patent, by selling the DSL CPE Products to customers in the United States for use in practicing at least claim 10 of the '354 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles

or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '354 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '354 Patent when used for their normal and intended purpose, including by operating in accordance with G.fast (ITU-T G.9701). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

155. CommScope knew or should have known of the '354 Patent but was willfully blind to the existence of the Patent. CommScope has had actual knowledge of the '354 Patent since at least as early as the filing and service of this Complaint. By the time of the trial of this case, CommScope will have known and intended that its continued actions since receiving such notice would infringe and actively induce and contribute to the infringement of one or more claims of the '354 Patent. CommScope's infringement of the '354 Patent has been willful and deliberate.

K. Infringement of the '055 Patent

156. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein and form the basis for the following cause of action against each Defendant.

157. A true and correct copy of the '055 Patent, entitled "Packet retransmission and memory sharing" and with Marcos Tzannes as the first named inventor, is attached hereto as Exhibit 11.

158. The '055 Patent duly and legally issued on November 1, 2016.

159. TQ Delta is the current owner by assignment of all rights, title, and interest in and under the '055 Patent. TQ Delta has standing to sue for infringement of the '055 Patent.

160. The G.fast (ITU-T G.9701) standard specifies functionality for a transceiver operable to transmit a first type of packet and to transmit a second type of packet, wherein the first

type of packet is stored in a retransmission buffer after transmission and the second type of packet is not stored in a retransmission buffer after transmission, and wherein the first and second types of packet comprise a header field that indicates whether a transmitted packet is a first type of packet or a second type of packet, and wherein the header field of the first type of packet comprises a sequence identifier (SID) that is incremented after the first type of packet is transmitted and the header field of the second type of packet does not comprise the SID of the first type of packet (*e.g.*, transmitting two types of packets, one stored in a retransmission buffer after transmission and one not stored in a retransmission buffer after transmission, such as processing of data transfer units (DTUs) and dummy DTUs).⁴²

161. The Accused CommScope DSL CPE Products include products that operate in accordance with G.fast (ITU-T G.9701).⁴³

162. CommScope has directly infringed and continues to infringe at least claim 11 of the '055 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell the DSL CPE Products in the United States, or importing said DSL CPE Products into the United States.

163. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 11 of the '055 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 11 of the '055 Patent when they used the DSL CPE Products in the ordinary, customary, and intended

⁴² See, *e.g.*, ITU-T G.9701, at Fig. 5-1, §§ 3.2.8, 3.2.11, 8.2, 9; ITU-T G.9711, at §§ 3.2, 8.2, 9.1, 9.8.

⁴³ See, *e.g.*, https://www.goamt.com/wp-content/uploads/2017/11/FST1305_G.FAST-VDSL2-35B-BRIDGE-MODEM_AMT.pdf (disclosing support for ITU-T G.9701).

way to operate within the G.fast (ITU-T G.9701) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement G.fast (ITU-T G.9701)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 11 of the '055 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, or knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the CPE Products in the United States, which CommScope knows or should know infringes at least claim 11 of the '055 Patent.

164. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '055 Patent, by selling the DSL CPE Products to customers in the United States for use in practicing at least claim 11 of the '055 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '055 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '055 Patent when used for their normal and intended purpose, including by operating in accordance with G.fast

(ITU-T G.9701). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

165. CommScope knew or should have known of the '055 Patent but was willfully blind to the existence of the Patent. CommScope has had actual knowledge of the '055 Patent since at least as early as the filing and service of this Complaint. By the time of the trial of this case, CommScope will have known and intended that its continued actions since receiving such notice would infringe and actively induce and contribute to the infringement of one or more claims of the '055 Patent. CommScope's infringement of the '055 Patent has been willful and deliberate.

L. Infringement of the '112 Patent

166. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein and form the basis for the following cause of action against each Defendant.

167. A true and correct copy of the '112 Patent, entitled "Impulse noise management" and with Marcos Tzannes as the first named inventor, is attached hereto as Exhibit 12.

168. The '112 Patent duly and legally issued on February 18, 2020.

169. TQ Delta is the current owner by assignment of all rights, title, and interest in and under the '112 Patent. TQ Delta has standing to sue for infringement of the '112 Patent.

170. The G.fast (ITU-T G.9701) standard specifies functionality for a transceiver comprising: a receiver operable to receiving, during steady-state communication, using a first forward error correction and interleaving parameter (FIP) setting that comprises a forward error correction (FEC) codeword size and a first number of FEC coding parity bytes; and the receiver further operable to switch, during the steady-state communication, to receiving using a second FIP setting that comprises a second FEC codeword size that is different than the first FEC codeword size and a second number of FEC coding parity bytes that is different than the first number of FEC

coding parity bytes, wherein the switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes is based on a counter reaching a value (*e.g.*, seamless rate adaptation).⁴⁴

171. The Accused CommScope DSL CPE Products include products that operate in accordance with G.fast (ITU-T G.9701).⁴⁵

172. CommScope has directly infringed and continues to infringe at least claim 8 of the '112 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell the Accused CommScope DSL CPE Products in the United States, or importing said Accused CommScope DSL CPE Products into the United States.

173. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 8 of the '112 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 8 of the '112 Patent when they used the DSL CPE Products in the ordinary, customary, and intended way to operate within the G.fast (ITU-T G.9701) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-

⁴⁴ See, *e.g.*, ITU-T G.9701, at §§ 12.3.4.2, 13.1.1., 13.2.1; ITU-T G.9711, at §§ 9.3, 12.3.4.2, 13.1.

⁴⁵ See, *e.g.*, https://www.goamt.com/wp-content/uploads/2017/11/FST1305_G.FAST-VDSL2-35B-BRIDGE-MODEM_AMT.pdf (disclosing support for ITU-T G.9701).

provider customers to use to the products to implement G.fast (ITU-T G.9701)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 8 of the '112 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, or knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the CPE Products in the United States, which CommScope knows or should know infringes at least claim 8 of the '112 Patent.

174. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '112 Patent, by selling the DSL CPE Products to customers in the United States for use in practicing at least claim 8 of the '112 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '112 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '112 Patent when used for their normal and intended purpose, including by operating in accordance with G.fast (ITU-T G.9701). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

175. CommScope knew or should have known of the '112 Patent but was willfully blind to the existence of the Patent. CommScope has had actual knowledge of the '112 Patent since at least as early as the filing and service of this Complaint. By the time of the trial of this case, CommScope will have known and intended that its continued actions since receiving such notice

would infringe and actively induce and contribute to the infringement of one or more claims of the '112 Patent. CommScope's infringement of the '112 Patent has been willful and deliberate.

M. Infringement of the '809 Patent

176. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein and form the basis for the following cause of action against each Defendant.

177. A true and correct copy of the '809 Patent, entitled "Techniques for packet and message communication in a multicarrier transceiver environment" and with Marcos Tzannes as the first named inventor, is attached hereto as Exhibit 13.

178. The '809 Patent duly and legally issued on November 10, 2020.

179. TQ Delta is the current owner by assignment of all rights, title, and interest in and under the '809 Patent. TQ Delta has standing to sue for infringement of the '809 Patent.

180. The G.inp (ITU-T G.998.4) and G.VDSL2 (ITU-T G.993.2) standards specify functionality for an apparatus comprising: a multicarrier transceiver including a processor and memory capable of: receiving a packet using forward error correction decoding and deinterleaving, wherein the packet comprises a header field and a plurality of Reed-Solomon codewords, and wherein the header field comprises a sequence identifier (SID); and transmitting a message using forward error correction encoding and without using interleaving, wherein the message is transmitted in a single DMT symbol and wherein the message includes an acknowledgement (ACK) or a negative acknowledgement (NACK) of the received packet (*e.g.*, block deinterleaving of data transmission units (DTUs), for which acknowledgment status is transmitted via the retransmission return channel (RRC)).⁴⁶

⁴⁶ See, *e.g.*, ITU-T G.993.2, at § 10.4; ITU-T G.998.4, at Fig. 6-1, 6-2, Table C.6, §§ 3.11, 3.12, 3.13, 3.14, 3.17, 8.1, 8.4, 9.2 .

181. The G.fast (ITU-T G.9701) standard specifies functionality relating to an apparatus comprising: a multicarrier transceiver including a processor and memory capable of: transmitting a packet using forward error correction encoding and interleaving, wherein the packet comprises a header field and a plurality of Reed-Solomon codewords, and wherein the header field comprises a sequence identifier (SID); and receiving a message using forward error correction decoding and without using deinterleaving, wherein the message is received in a single DMT symbol, and wherein the message includes an acknowledgement (ACK) or a negative acknowledgement (NACK) of the transmitted packet (*e.g.*, block interleaving of data transmission units (DTUs), for which acknowledgment status is received via the retransmission return channel (RRC)).⁴⁷

182. The Accused CommScope DSL CPE Products include products that operate in accordance with G.inp (ITU-T G.998.4).⁴⁸

183. The Accused CommScope DSL CPE Products include products that operate in accordance with G.fast (ITU-T G.9701).⁴⁹

184. CommScope has directly infringed and continues to infringe at least claim 8 of the '809 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell the Accused CommScope DSL CPE Products in the United States, or importing said Accused CommScope DSL CPE Products into the United States.

⁴⁷ See, *e.g.*, ITU-T G.9701, at Tables 9-4, 9-5, 9-8, §§ 8.2, 9.1, 9.3, 9.4, 9.6, 10.4.3.

⁴⁸ See, *e.g.*, <https://www.commscope.com/globalassets/digizuite/62029-nvg44x-datasheet.pdf> (disclosing support for ITU-T G.998.4).

⁴⁹ See, *e.g.*, https://www.goamt.com/wp-content/uploads/2017/11/FST1305_G.FAST-VDSL2-35B-BRIDGE-MODEM_AMT.pdf (disclosing support for ITU-T G.9701).

185. CommScope has directly infringed and continues to infringe at least claim 1 of the '809 Patent in violation of 35 U.S.C. § 271(a) by, directly or through intermediaries and without TQ Delta's authority, making, using, selling, or offering to sell the Accused CommScope DSL CPE Products in the United States, or importing said Accused CommScope DSL CPE Products into the United States.

186. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 8 of the '809 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products directly infringed at least claim 8 of the '809 Patent when they used the DSL CPE Products in the ordinary, customary, and intended way to operate within the G.inp (ITU-T G.998.4) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement G.inp (ITU-T G.998.4)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 8 of the '809 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, or knowingly inducing customers to use the Accused CommScope DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers

to make, use, sell, or offer to sell the CPE Products in the United States, which CommScope knows or should know infringes at least claim 8 of the '809 Patent.

187. Further and in the alternative, CommScope has been actively inducing infringement of at least claim 1 of the '809 Patent in violation of 35 U.S.C. § 271(b). CommScope users and customers (*e.g.*, service providers) of the DSL CPE Products standard directly infringed at least claim 1 of the '809 Patent when they used the DSL CPE Products in the ordinary, customary, and intended way to operate within the G.fast (ITU-T G.9701) standard. CommScope's inducements included, without limitation and with specific intent to encourage the infringement, knowingly inducing consumers to use the DSL CPE Products within the United States in the ordinary, customary, and intended way by, directly or through intermediaries, supplying said DSL CPE Products to customers within the United States and instructing and encouraging such customers (for example, via distributing the DSL CPE Products to service-provider customers and instructing those service-provider customers to use the products to implement G.fast (ITU-T G.9701)) how to use the DSL CPE Products in the ordinary, customary, and intended way, which CommScope knows or should know infringes at least claim 1 of the '809 Patent. CommScope's inducements may further include, without limitation and with specific intent to encourage the infringement, knowingly inducing customers to use the DSL CPE Products within the United States, or knowingly inducing customers to use the DSL CPE Products within the United States, by, directly or through intermediaries, instructing and encouraging such customers to make, use, sell, or offer to sell the DSL CPE Products in the United States, which CommScope knows or should know infringes at least claim 1 of the '809 Patent.

188. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '809 Patent, by selling the DSL CPE

Products to customers in the United States for use in practicing at least claim 8 of the '809 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '809 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '809 Patent when used for their normal and intended purpose, including by operating in accordance with G.inp (ITU-T G.998.4). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

189. Further and in the alternative, CommScope, in violation of 35 U.S.C. § 271(c), has contributorily infringed, and is contributorily infringing, the '809 Patent, by selling the DSL CPE Products to customers in the United States for use in practicing at least claim 1 of the '809 Patent, knowing that said products are material to practicing the claimed inventions, are not staple articles or commodities of commerce suitable for substantial non-infringing use, and are especially made or especially adapted for use in an infringement of the '809 Patent. Specifically, CommScope sold the DSL CPE Products to customers knowing that the products directly infringe the '809 Patent when used for their normal and intended purpose, including by operating in accordance with G.fast (ITU-T G.9701). The products are made for the specific purpose of operating according to the DSL Standards and have no substantial non-infringing use.

190. CommScope knew or should have known of the '809 Patent but was willfully blind to the existence of the Patent. CommScope has had actual knowledge of the '809 Patent since at least as early as the filing and service of this Complaint. By the time of the trial of this case, CommScope will have known and intended that its continued actions since receiving such notice

would infringe and actively induce and contribute to the infringement of one or more claims of the '809 Patent. CommScope's infringement of the '809 Patent has been willful and deliberate.

N. Declaratory Judgment that CommScope is Not Entitled a License on a Worldwide, Non-Discriminatory Basis and on Reasonable Terms and Conditions

191. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein.

192. A substantial controversy exists between TQ Delta and CommScope of sufficient immediacy and reality to warrant the issuance of a declaratory judgment.

193. TQ Delta owns patents that are essential to standards adopted by the ITU for various DSL standards.

194. TQ Delta (or its predecessor-in-interest, Aware) submitted PSLDs regarding certain DSL standards.

195. These PSLDs expressed that TQ Delta (or its predecessor-in-interest, Aware) was "prepared to grant ... on a worldwide, non-discriminatory basis and on reasonable terms and conditions to make, use and sell implementations...." related to the referenced standard document.

196. Over years of discussion, TQ Delta was prepared to offer and did offer to license, repeatedly, any TQ Delta Patents subject to the PSLDs to CommScope on a worldwide, non-discriminatory basis and on reasonable terms and conditions, including in its July, 2021 offer to CommScope.

197. CommScope refused each of TQ Delta's offers to license these patents.

198. TQ Delta's offers to CommScope were on reasonable terms and conditions.

199. TQ Delta's offers to CommScope were non-discriminatory.

200. TQ Delta's offers to CommScope were on a worldwide basis.

201. TQ Delta has complied and continues to comply with any binding commitment of TQ Delta's (or its predecessor-in-interest, Aware's) to license its patents to CommScope on a worldwide, non-discretionary basis and on reasonable terms and conditions, including under Texas law.

202. TQ Delta's license offers to CommScope satisfied any binding obligations TQ Delta (or its predecessor-in-interest, Aware's) had to license its patents to CommScope on a worldwide, non-discretionary basis and on reasonable terms and conditions, including under Texas law.

203. CommScope repudiated, prevented performance, waived, forfeited, and/or rejected any rights it had with respect to TQ Delta's PSLDs, including the right to assert it is a third-party beneficiary of the right to a license on the terms set forth in the PSLDs, including under Texas law. For example, CommScope rejected TQ Delta's offers to license the TQ Delta Patents on a worldwide, non-discretionary basis and on reasonable terms and conditions and refused to accept any such terms for a license. CommScope is not a third-party beneficiary of TQ Delta's (or its predecessor-in-interest, Aware's) PSLD submissions that is entitled to a license to TQ Delta's patents on a worldwide, non-discriminatory basis and on reasonable terms and conditions, including under Texas law.

204. CommScope's refusal to license the TQ Delta patents on a worldwide, non-discriminatory basis and on reasonable terms and conditions prevented TQ Delta from licensing the patents to CommScope on the terms provided by the PSLDs.

205. CommScope's refusal to license the patents cost TQ Delta years of effort spent in negotiations.

206. TQ Delta and CommScope have adverse legal interests because CommScope continues to use TQ Delta's patented technology without a license, therefore infringes TQ Delta's patents, and has not paid TQ Delta for a license.

207. TQ Delta requests a declaratory judgment that TQ Delta complied with any binding commitment to be prepared to offer a license on terms set forth in the PSLDs or otherwise to license its patents on a worldwide, non-discretionary basis and on reasonable terms and conditions.

208. TQ Delta requests a declaratory judgment that CommScope is not entitled to the any terms in the PSLDs or otherwise entitled to license any of the TQ Delta Patents on a worldwide, non-discretionary basis and on reasonable terms and conditions.

VII. DAMAGES

209. The allegations of each foregoing paragraph are incorporated by reference as if fully set forth herein.

210. For the above-described infringement, TQ Delta has been injured and seeks damages to adequately compensate it for Defendant's infringement of the TQ Delta Patents. Such damages, to be proved at trial, should be no less than the amount of a reasonable royalty under 35 U.S.C. § 284, together with TQ Delta's costs and expenses, pre-judgment and post-judgment interest, and supplemental damages for any continuing post-verdict or post-judgment infringement, with an accounting as needed.

211. As set forth above, Defendant's infringement of the Asserted Patents has been willful, such that TQ Delta seeks treble damages under 35 U.S.C. § 284 as appropriate.

212. Defendant's willful infringement of the TQ Delta Patents renders this case exceptional under 35 U.S.C. § 285, such that TQ Delta seeks all reasonable attorneys' fees and costs incurred in this litigation, together with pre-judgment and post-judgment interest thereon.

VIII. PRAYER FOR RELIEF

TQ Delta respectfully requests the following relief:

- a. A judgment in favor of TQ Delta that Defendant has infringed each Asserted Patent, whether literally or under the doctrine of equivalents, and that such infringement is willful as described herein;
- b. A judgment and order requiring Defendant to pay TQ Delta its damages, costs, expenses, and pre-judgment and post-judgment interest for Defendant's infringement of each Asserted Patent as provided under 35 U.S.C. § 284, including supplemental damages for any continuing post-verdict or post-judgment infringement with an accounting as needed; and
- c. A judgment and order requiring Defendant to pay TQ Delta enhanced damages for willful infringement as provided under 35 U.S.C. § 284;
- d. A judgment and order finding this case exceptional and requiring Defendant to pay TQ Delta its reasonable attorneys' fees and costs incurred in this litigation pursuant to 35 U.S.C. § 285, together with pre-judgment and post-judgment interest thereon;
- e. A judgment that TQ Delta has complied with any binding commitments in its PSLDs in its negotiations with and/or offers to CommScope.
- f. A judgment that CommScope has, through its conduct, repudiated, prevented performance, waived, forfeited, and/or rejected any rights associated with TQ Delta's PSLDs, including the right to assert it is a third-party beneficiary of the right to a license on the terms set forth in the PSLDs; and
- g. Such other and further relief as the Court deems just and proper.

IX. JURY DEMAND

Pursuant to Federal Rule of Civil Procedure 38(b), TQ Delta requests a jury trial of all issues triable of right by a jury.

Dated: August 13, 2021

Respectfully submitted,

/s/ William E. Davis, III
William E. Davis, III
Texas State Bar No. 24047416
bdavis@davisfirm.com

Christian J. Hurt
Texas State Bar No. 24059987
churt@davisfirm.com

Rudolph "Rudy" Fink IV
Texas State Bar No. 24082997
rfink@davisfirm.com

THE DAVIS FIRM PC
213 N. Fredonia Street, Suite 230
Longview, Texas 75601
Telephone: (903) 230-9090
Facsimile: (903) 230-9661

ATTORNEYS FOR PLAINTIFF TQ
DELTA, LLC

EXHIBIT 1

(12) **United States Patent**
Tzannes et al.

(10) **Patent No.:** **US 7,453,881 B2**
(45) **Date of Patent:** **Nov. 18, 2008**

(54) **SYSTEMS AND METHODS FOR MULTI-PAIR ATM OVER DSL**

(75) Inventors: **Marcos C. Tzannes**, Orinda, CA (US);
Edmund Reiter, Lincoln, MA (US);
Christopher Cahill, Northboro, MA (US)

(73) Assignee: **Aware, Inc.**, Bedford, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1024 days.

(21) Appl. No.: **10/264,258**

(22) Filed: **Oct. 4, 2002**

(65) **Prior Publication Data**
US 2003/0091053 A1 May 15, 2003

Related U.S. Application Data
(60) Provisional application No. 60/327,440, filed on Oct. 5, 2001.

(51) **Int. Cl.** **H04L 12/28** (2006.01)
(52) **U.S. Cl.** **370/395.1; 370/535; 370/465**
(58) **Field of Classification Search** None
See application file for complete search history.

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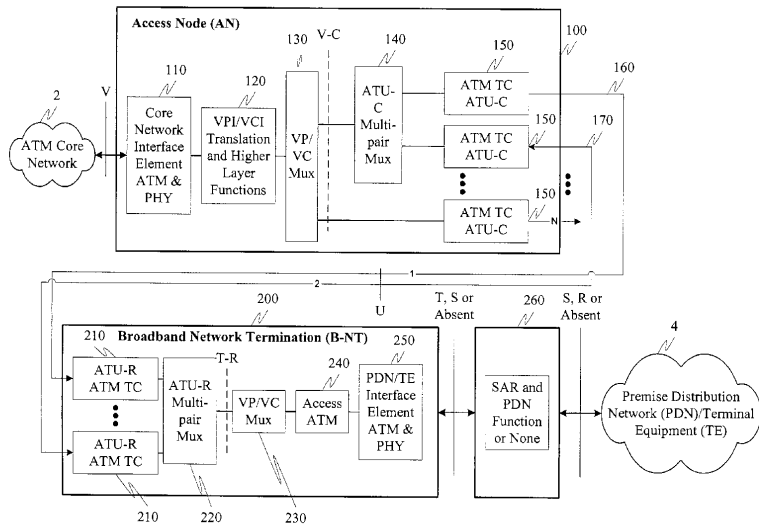
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Primary Examiner—Duc C Ho
(74) *Attorney, Agent, or Firm*—Sheridan Ross P.C.; Jason H. Vick

(57) **ABSTRACT**
At a transmitter, an ATM cell stream is received from the ATM layer and is distributed on a cell-by-cell bases across multiple DSL PHY's. At the receiver, the cells from each DSL PHY are re-combined in the appropriate order to recreate the original ATM cell stream, which is then passed to the ATM layer.

42 Claims, 7 Drawing Sheets

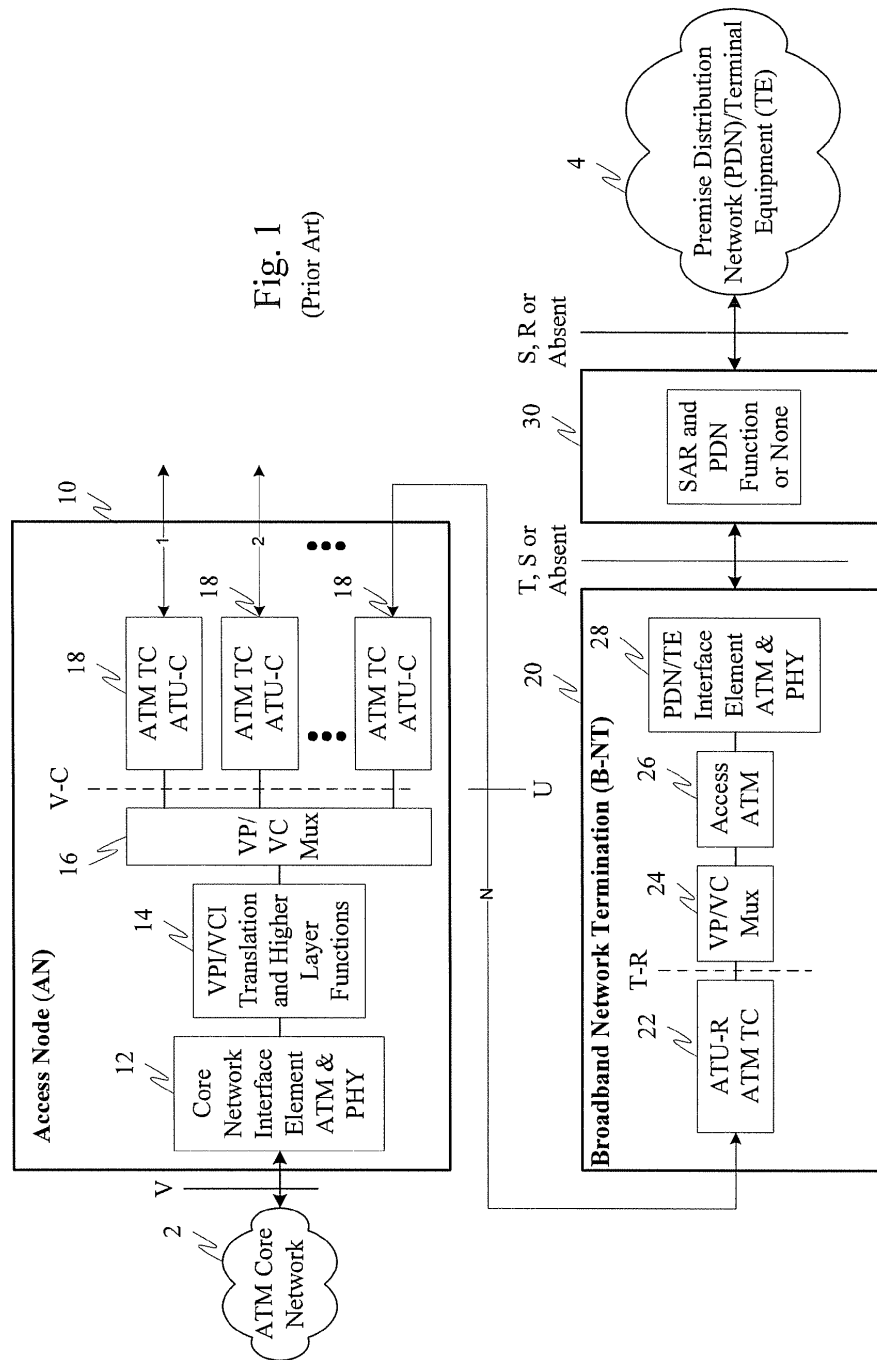


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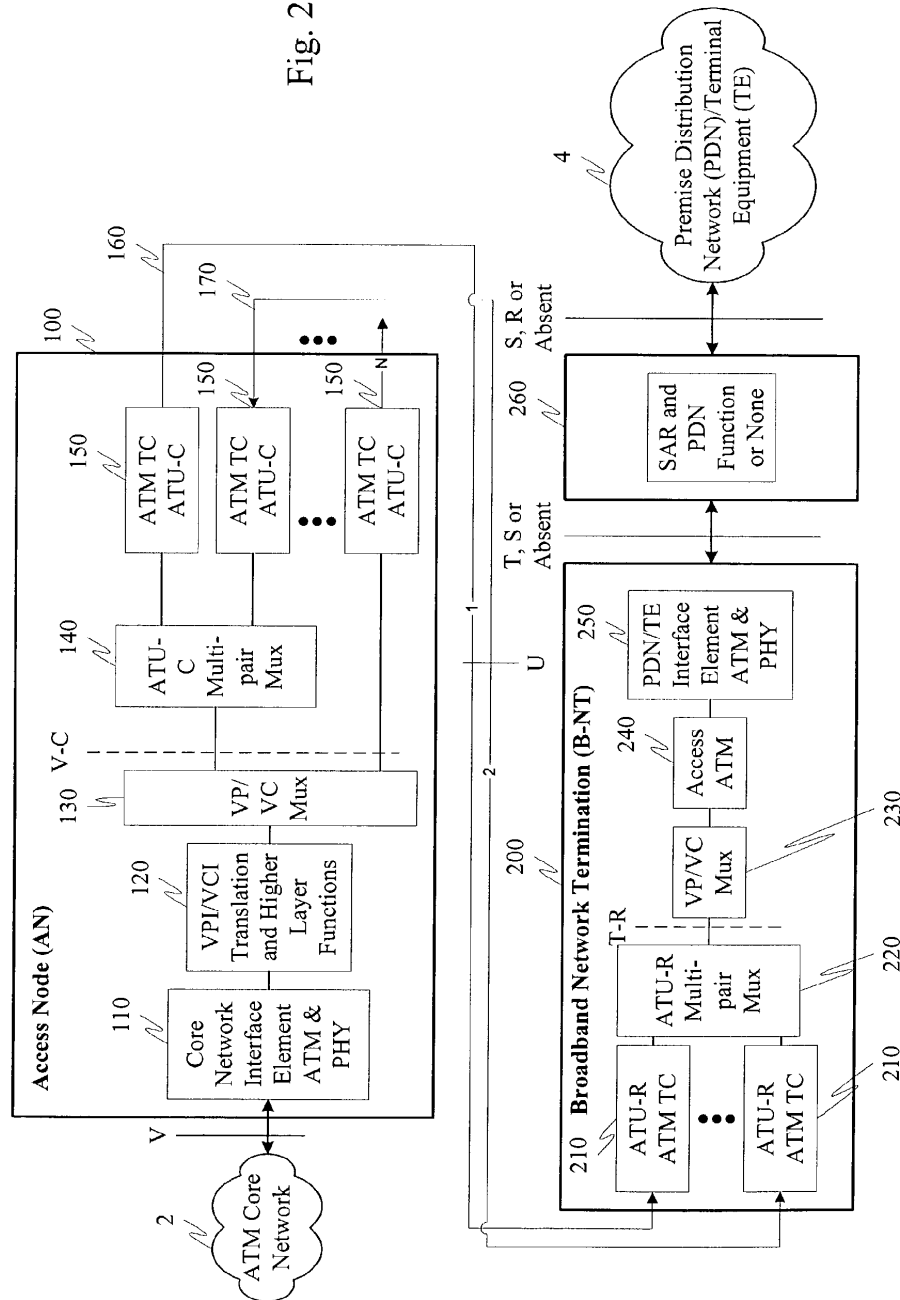
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Fig. 2



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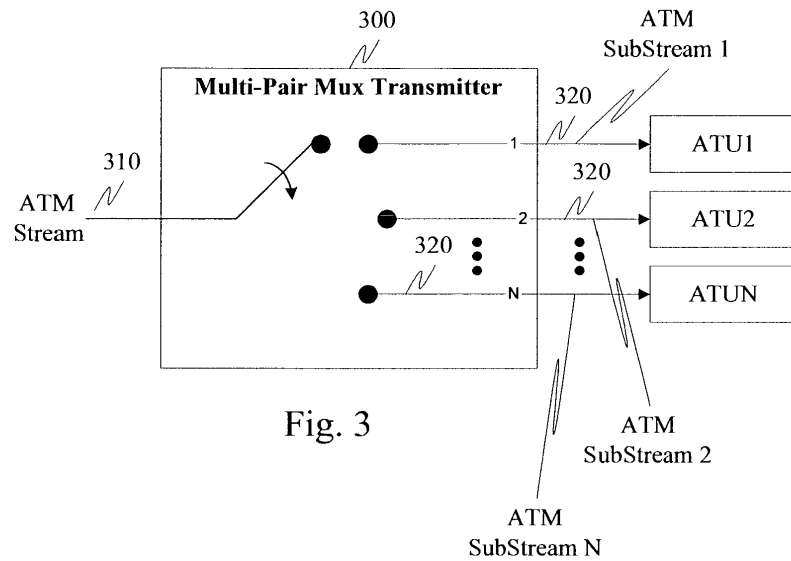


Fig. 3

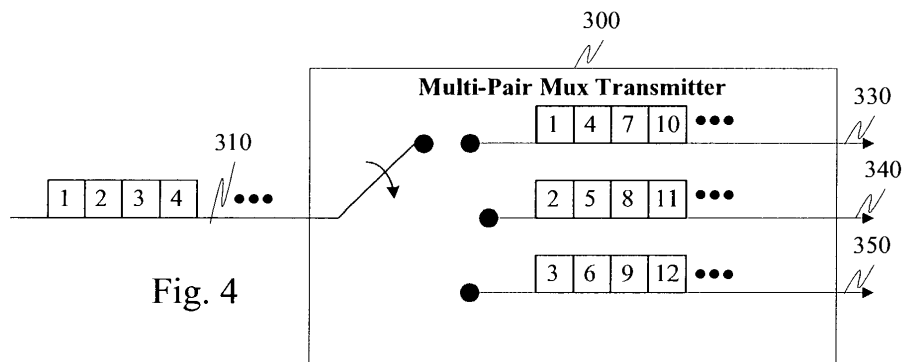


Fig. 4

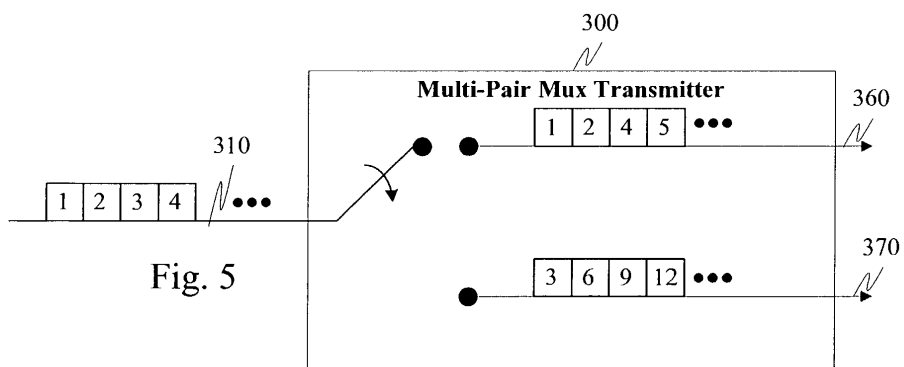


Fig. 5

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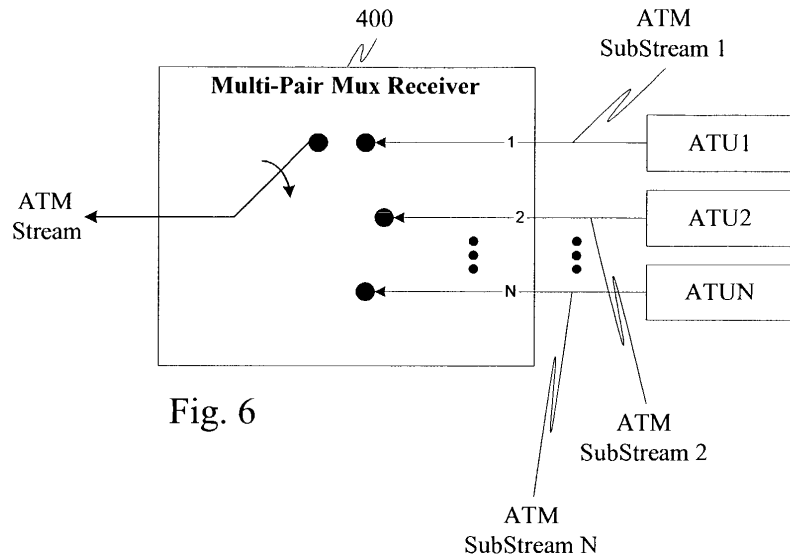


Fig. 6

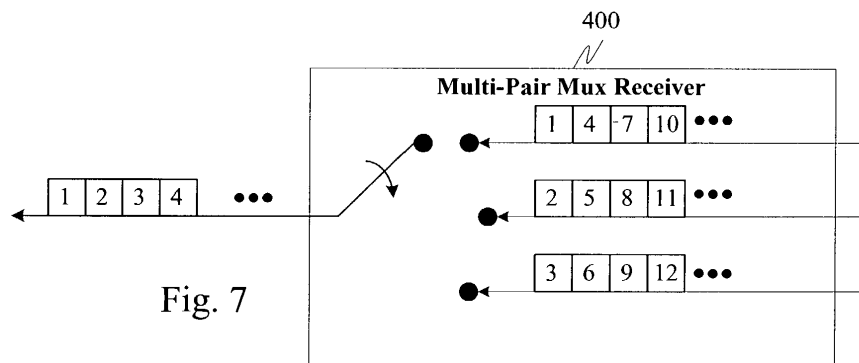


Fig. 7

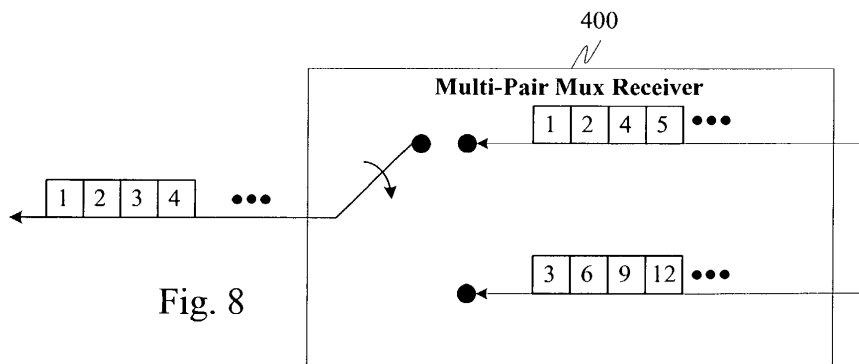


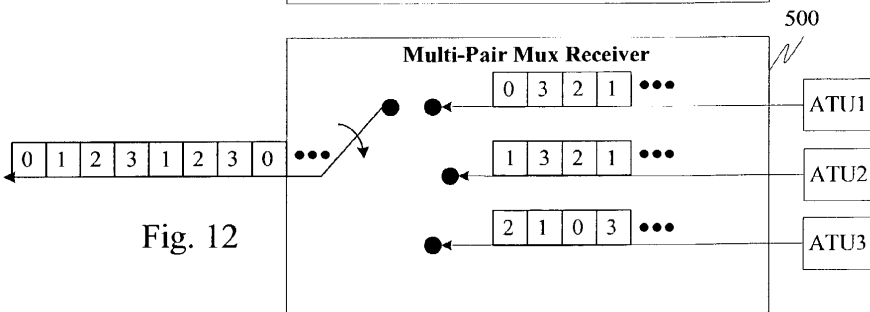
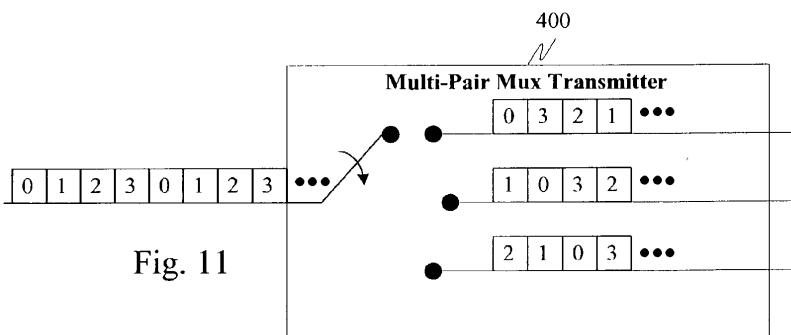
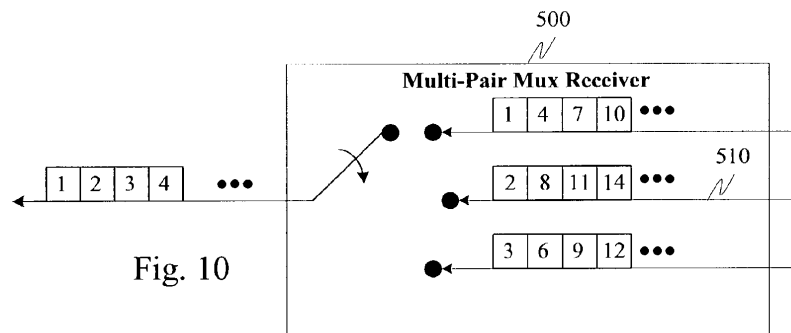
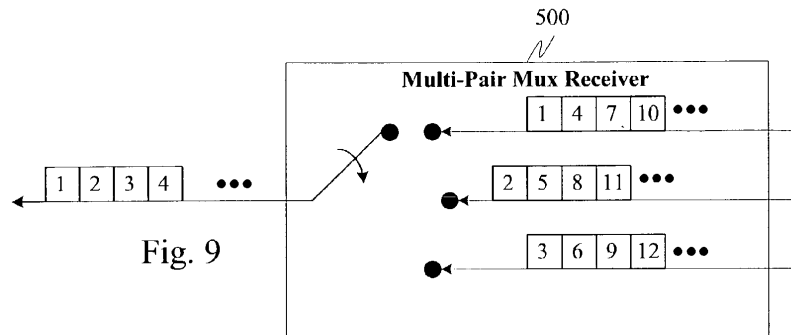
Fig. 8

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Bit	8	7	6	5	4	3	2	1
Byte 1	Flow Control (GFC)				VPI Value			
Byte 2	VPI Value				VCI Value			
Byte 3	VCI Value							
Byte 4	VCI Value				Payload Type			
Byte 5	HEC							

Fig. 13

Bit	8	7	6	5	4	3	2	1
Byte 1	Flow Control (GFC)				TIV		MP Cntr	
Byte 2	MP Counter						Reserved	
Byte 3	Reserved							
Byte 4	Reserved				Payload Type		CLP	
Byte 5	HEC							

Fig. 14

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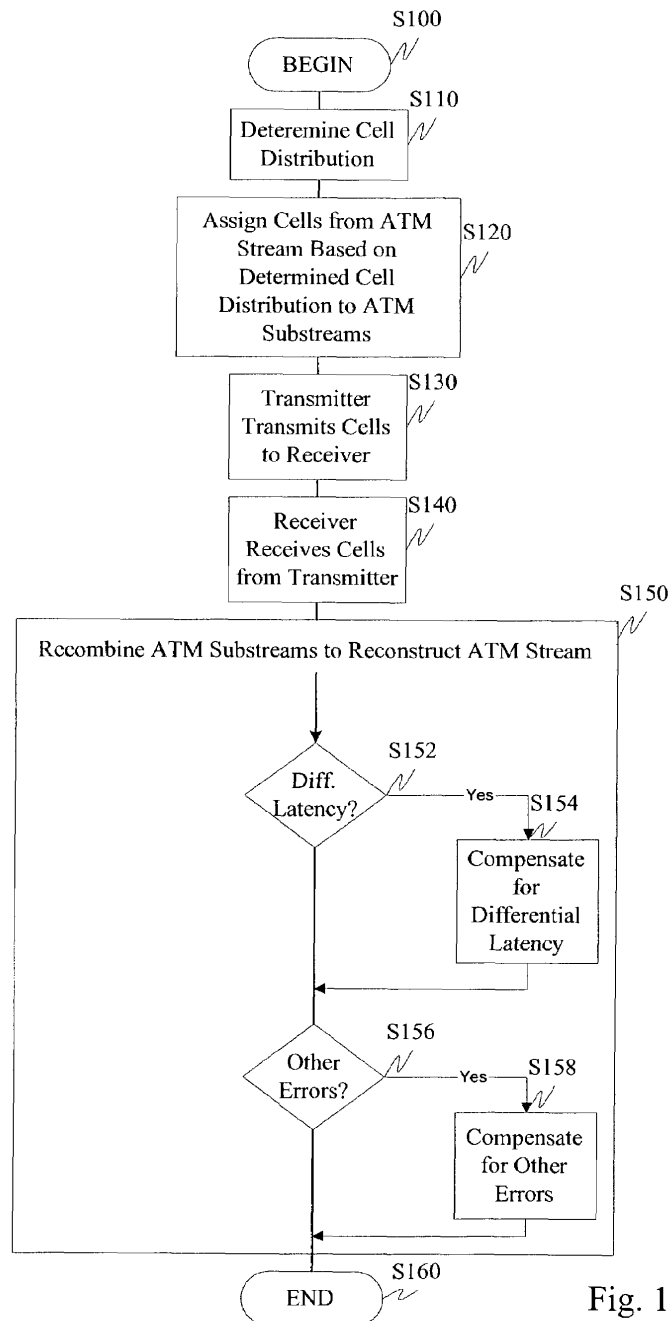


Fig. 15

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**SYSTEMS AND METHODS FOR MULTI-PAIR
ATM OVER DSL****RELATED APPLICATION DATA**

This application claims the benefit of and priority under 35 U.S.C. §119(e) to U.S. Patent Application Serial No. 60/327,440, filed Oct. 5, 2001, entitled "Multi-Pair ATM Over DSL," which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION**1. Field of the Invention**

The systems and methods of this invention generally relate to communication systems. In particular, the systems and methods of this invention relate to asynchronous transfer mode (ATM) over digital subscriber line (DSL).

2. Description of Related Art

FIG. 1 illustrates the conventional configuration of a system for transporting ATM over DSL using a single latency ADSL configuration. As of the time of filing, single latency is most common form of ADSL deployment. Further details of this specific architecture can be found in DSL Forum Recommendation TR-042, incorporated herein by reference in its entirety.

For the system illustrated in FIG. 1, the access node 10 serves as an ATM layer multiplexer/concentrator between the ATM core network 2 and the access network. As described in the above referenced DSL Forum Recommendation, for ATM systems, the channelization of different payloads is embedded within the ATM data stream using different virtual paths (VP) and/or virtual channels (VC). In the downstream direction, the VP/VC Mux module 16 and VPI/VCI translation module 14 receive cells from the core network interface element 12 and function to perform cell routing based on a virtual path identifier (VPI) and/or virtual channel identifier (VCI) to the appropriate ATU-C 18. In the upstream direction, the VP/VC Mux module 16 and the VPI/VCI translation module 14 function to combine the cell streams from the ATU-C's 18 into a single ATM cell stream to the core ATM network 2.

The broadband network termination (B-NT) 20 performs the functions of terminating the ADSL signal entering the user's premises via the twisted pair cable and the ATU-R 22 and provides either the T, S or R interface towards the premises distribution network/terminal equipment 4. The access ATM module 26 and the VP/VC Mux module 24 perform the ATM layer functions to support the TC layers in the ATU-R. The broadband network termination 100 may also contain VPI/VCI translation functions to support multiplex/demultiplex of VCI's between the ATU-R 22 and the premise distribution network/terminal equipment 4 on a VPI and/or VCI bases. The broadband network termination 20 may also comprise a PDN/TE interface element 28 and SAR module 30 the functions of which are well known and will be omitted for sake of clarity.

SUMMARY OF THE INVENTION

The exemplary systems and methods of this invention combine multiple DSL PHY's, i.e., multiple twisted wire pairs, to, for example, generate a high data rate connection for the transport of an ATM cell stream between the service provider and, for example, a DSL subscriber. The ATM cell stream may contain one or more payloads where each payload is channelized within the ATM data stream using different virtual paths (VP) and/or virtual channels (VC). At a transmitter,

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the ATM cell stream received from the ATM layer is distributed on a cell-by-cell bases across the multiple DSL PHY's. At the receiver, the cells from each DSL PHY are recombined in the appropriate order to recreate the original ATM cell stream, which is then passed to the ATM layer.

Accordingly, aspects of the invention relate to ATM communications.

Additional aspects of the invention relate to transporting ATM over DSL, and more particularly over ADSL.

Additional aspects of the invention also relate to distributing ATM cells from a single ATM cell stream across multiple twisted wire pairs.

Further aspects of the invention relate to distributing ATM cells from a single ATM cell stream across multiple DSL communication links.

Further aspects of the invention relate to varying data rates over the multiple twisted wire pairs over which distributed ATM cells are transported.

These and other features and advantages of this invention are described in, or apparent from, the following detailed description of the embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the invention will be described in detailed, with reference to the following figures, wherein:

FIG. 1 is a functional block diagram illustrating a conventional ATM over ADSL system;

FIG. 2 is a functional block diagram illustrating an exemplary system for transporting ATM over ADSL according to this invention;

FIG. 3 illustrates an exemplary functional block diagram of the multi-pair multiplexing transmitter according to this invention;

FIG. 4 illustrates a functional block diagram of a second exemplary multi-pair multiplexing transmitter according to this invention;

FIG. 5 illustrates a functional block diagram of a third exemplary embodiment of the multi-pair multiplexing transmitter according to this invention;

FIG. 6 illustrates a functional block diagram of an exemplary multi-pair multiplexing receiver according to this invention;

FIG. 7 illustrates a functional block diagram of a second exemplary multi-pair multiplexing receiver according to this invention;

FIG. 8 illustrates a functional block diagram of a third exemplary multi-pair multiplexing receiver according to this invention;

FIG. 9 is a functional block diagram illustrating a fourth exemplary multi-pair multiplexing receiver according to this invention;

FIG. 10 illustrates a functional block diagram of a fifth exemplary multi-pair multiplexing receiver according to this invention;

FIG. 11 illustrates a functional block diagram of a fourth exemplary multi-pair multiplexing transmitter according to this invention;

FIG. 12 is a functional block diagram illustrating a sixth exemplary multi-pair multiplexing receiver according to this invention;

FIG. 13 illustrates a standard five byte ATM UNI header;

FIG. 14 illustrates an exemplary modified ATM header according to this invention; and

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FIG. 15 is a flowchart outlining an exemplary embodiment of a method for combining multiple DSL PHYs to transport an ATM cell stream between a service provider and a subscriber.

DETAILED DESCRIPTION OF THE INVENTION

The exemplary systems and the methods of this invention will be described in relation to digital subscriber line communications and more particularly to asymmetric digital subscriber line communications. However, to avoid unnecessarily obscuring the present invention, the following description omits well-known structures and devices that may be shown in block diagram form or otherwise summarized. For the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It should be appreciated however that the present invention may be practiced in variety of ways beyond the specific details set forth herein. For example, the systems and methods of this invention can generally be applied to any type of communications system including wireless communication systems, such as wireless LANs, power line communications, or any other systems or combination systems that use ATM.

Furthermore, while the exemplary embodiments illustrated herein show the various components of the communication system collocated, it is to be appreciated that the various components of the system can be located at distant portions of distributed network, such as a telecommunications network and/or the Internet, or within a dedicated ATM over DSL system. Thus, it should be appreciated that the components of the communication system can be combined into one or more devices or collocated on a particular node of a distributed network, such as a telecommunications network. It will be appreciated from the following description, and for reasons of computational efficiency, that the components of the communication system can be arranged at any location within a distributed network without affecting the operation of the system.

Furthermore, it should be appreciated that the various links connecting the elements can be wired or wireless links, or a combination thereof or any other known or later developed element(s) that is capable of supplying and/or communicating data to and from the connected elements. Additionally, the term module as used herein can refer to any known or later developed hardware, software, or combination of hardware and software that is capable of performing the functionality associated with that element.

Additionally, although this invention will be described in relation to ATM systems, the systems and methods of this invention can be applied to any transport protocol that uses cells or packets for transmitting information. Therefore, for example, the same methods can be used for the bonding of PHYs that transport Ethernet or IP packets. Furthermore, although this invention will be described in relation to ATM transported over DSL PHYs, other PHYs, such as cable, voice band modems, ATM-25, and the like, can also be used.

FIG. 2 illustrates an exemplary multi-pair ATM over DSL system. In particular, the system comprises an access node 100, a broadband network termination 200, an ATM core network 2 and premise distribution network/terminal equipment 4. The access node 100 further comprises a core network interface element 110, a VPI/VCI translation module 120, a VP/VC Mux module 130, an ATU-C multi-pair multiplexer 140 and a plurality of ATM TC ATU-C modules 150. The broadband network termination 200 further comprises a plurality of ATU-R ATM TCs 210, an ATU-R multi-pair multi-

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plexer 220, a VP/VC Mux module 230, an access ATM module 240, and a PDN/TE interface module 250. Furthermore, the system comprises a SAR and PDN function module 260, wherein the functions of like components have been discussed in relation to FIG. 1.

The exemplary system illustrated in FIG. 2 distributes ATM cells from a single ATM cell stream across multiple ADSL PHY links, i.e., multiple twisted wire pairs (1 to n). The ATM cell stream, also referred to as the ATM stream, may comprise one or more payloads where each payload is channelized within the ATM stream using different virtual paths (VP) and/or virtual channels (VC). This can effectively create, for example, a high data rate ATM connection between a service provider and an ADSL subscriber.

In accordance with an exemplary embodiment of this invention, the ATU-C multi-pair multiplexer 140 is inserted between the VP/VC multiplexer 130 and the ATU-C's 150 at the V-C interface in the access node 100. Additionally, the ATU-R multi-pair multiplexer 220 is added to the broadband network termination 200 at the T-R interface. Both of these multi-pair multiplexers have transmitter and receiver sections (not shown) whose operations are comparable. The multi-pair multiplexer transmitter section performs the task of distributing cells from the ATM stream among multiple ATM cell substreams. Each ATM cell substream, also referred to as an ATM substream, is forwarded a different ATU. The multi-pair multiplexer receiver section performs the task of recombining the ATM substreams to regain the original ATM stream.

In the exemplary system illustrated in FIG. 2, two ADSL PHYs 160 and 170 are "bonded" together to transport a single ATM cell stream. However, it should be appreciated, that the number of ADSL PHYs "bonded" together can be easily expanded to any number ($N \geq 2$) of ADSL PHYs thereby, for example, enabling higher ATM data rates. In addition to the two ADSL PHYs 160 and 170 that are bonded together, it should further be appreciated that in some instances in the same access node 100, other ADSL PHYs may be operating in the traditional way. Obviously, the ADSL PHYs operating in the traditional way do not need to be connected to the multi-pair multiplexer 140. Thus, in general, it should be appreciated that any combination of "bonded" and unbonded, i.e. traditional, ADSL PHY's, may be configured between the access node 100 and the broadband network termination 200. Furthermore, it should be appreciated that all of the ADSL PHYs can be bonded together.

In many ADSL systems, the logical interface between the ATM layer the PHY is based on UTOPIA Level 2 with a cell level handshake. This same UTOPIA Level 2 logical interface can also be used between the multi-pair multiplexer and the ATM layer and also between the multi-pair multiplexer and the PHY in the access node 100 and the broadband network termination 200. Although, the above example and the remainder of this discussion will be directed toward the multi-pair multiplexer functions using an ADSL PHY, any version of DSL that has an ATM-TC, e.g., VDSL, SHDSL, or the like, may be used instead of, or conjunction with, the ADSL PHY.

FIG. 3 illustrates an exemplary multi-pair multiplexing transmitter according to this invention. The ATU-C and ATU-R multi-pair multiplexer box provide the same basic transmitter and receiver functions and thus can be summarized as one unit.

In particular, the exemplary multi-pair multiplexing transmitter 300 illustrated in FIG. 3 provides, but not limited to, accepting a single ATM stream 310 from the ATM layer and distributing the cells among N ATM substreams 320, where $N \geq 2$. Furthermore, the multi-pair multiplexing transmitter 300 maps each ATM cell substream to a different DSL con-

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nection and provides as output these ATM cell substreams to the appropriate ADSL PHY (ATUx). For the exemplary multi-pair multiplexing transmitter **300** illustrated in FIG. 3, the cells from the ATM stream **310** are distributed amongst the ATM substreams **320** based on the data rate of each DSL PHY.

The configuration of the multi-pair multiplexing transmitter **300** can be varied to, for example, provide an equal or unequal data rate on the DSL PHYs. FIG. 4 illustrates an exemplary embodiment where an equal data rate is applied to all of the DSL PHYs. In particular, if the data rate on all of the DSL PHYs is the same, then an equal number of ATM cells will be transported over every PHY connection. In this case, the multi-pair multiplexing transmitter **300** sends the first ATM cell to ATU1 **330**, the second ATM cell to ATU2 **340**, the third ATM cell to ATU3 **350**, and so on. For the multi-pair multiplexing transmitter **300** illustrated in FIG. 4, $N=3$ and an equal data rate on all DSL PHYs is illustrated, therefore the input ATM cells from the ATM stream **310**, as discussed above, are distributed equally and sequentially among the DSL PHYs.

For the multi-pair multiplexing transmitter **300** illustrated in FIG. 5, an unequal data rate is transported on the DSL PHYs. In particular, if a data rate on all the DSL PHYs is not equal, the ATM cells can be forward to the DSL PHYs, at, for example, a ratio that matches the ratios of the available PHY data rates. If, for example, $N=2$, as illustrated in FIG. 5, and the data rate of the first DSL PHY **360** is two times the data rate of the second PHY **370**, then the multi-pair multiplexer **300** would send 2 ATM cells to the first DSL PHY, i.e., cells **1** and **2**, and then send 1 ATM cell to the second DSL PHY, i.e., cell **3**. However, in general, this basic concept can be expanded at least to include the situation where $N>2$ and to non-integer data rate ratios.

For example, in a two modem environment where there is a "high-speed" and a "low-speed" implementation, an exemplary ratio of $N:1$ where $N=2$ to 8 can be specified. This means that the "high-speed" modem will have eight times the cells as the "low-speed" modem. In this exemplary configuration, there are eight cells of receiver FIFO meaning that the entire "high-speed" receiver could be emptied before needing to service the "low-speed" receiver.

FIG. 6 illustrates an exemplary multi-pair multiplexing receiver **400**. The exemplary multi-pair multiplexing receiver **400** provides, but is not limited to, accepting multiple ATM cell substreams from different DSL PHYs and recombining the ATM cells from the different ATM cell substreams to recreate the original ATM stream, which is passed to the ATM layer. In particular, and as illustrated in FIG. 6, a plurality of ATM substreams are received by the multi-pair multiplexing receiver **400** and recombined into the original ATM stream. Specifically, as in the multi-pair multiplexing transmitter, the recombining of cells from the DSL PHYs depends on the data rates of the individual PHY connections. As in the embodiment discussed in relation to FIG. 4, where all DSL PHYs had an equal data rate, the multi-pair multiplexing receiver **400** can perform the inverse of the transmitting multiplexer function and reconstruct the original ATM stream by taking one cell from each ATM substream and combining them in the appropriate order, as illustrated in FIG. 7.

Similarly, as illustrated in relation to the multi-pair multiplexing transmitter **300** illustrated in FIG. 5, where the DSL PHYs had an unequal data rate, if different ratios of data rates are used a variable number of cells will be taken from each ATM substream to reconstruct the original ATM stream in the multi-pair multiplexing receiver **400** as illustrated in FIG. 8.

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Furthermore, in addition to the changes in data rate that are possible on the DSL PHYs, ATM cells transported over a DSL PHY can have different end-to-end delay (latency) based on several parameters. This potential latency difference between bonded PHYs places implementation requirements on the multi-pair multiplexer. In particular, the multi-pair multiplexer receiver must be able to reconstruct the ATM stream even if the ATM cells are not being received in the same order as they were transmitted.

For example, some of the exemplary reasons for having different delays over different DSL PHYs include, but are not limited, configuration latency which is based on the configuration of the DSL transmission parameters. Specifically, these parameters include the data rate, coding parameters, such as the coding method, codeword size, interleaving parameters, framing parameters, or the like.

ATM-TC latency is based on cell rate decoupling in the ATM-TC. Specifically, the ATM-TC block in ADSL transceivers performs cell rate decoupling by inserting idle cells according to the ITU Standard I.432, incorporated herein by reference in its entirety. This means that depending on the ATU timing and the state of the ATU buffers, an ATM cell that is sent over a DSL PHY will experience non-constant end-to-end delay (latency) through the PHY.

Wire latency is based on differences in the twisted wire pairs. Specifically, the DSL electrical signals can experience different delays based on the difference in length of the wire, the gauge of the wire, the number bridged taps, or the like.

Design latency is based on differences in the DSL PHY design. Specifically, the latency of the PHY can also depend on the design chosen by the manufacture.

Thus, as result of the different latencies in the PHYs, it is possible that an ATM cell that was sent over a DSL PHY may be received at the multi-pair multiplexing receiver after an ATM cell that was sent out later on a different DSL PHY.

FIG. 9 illustrates an example of variable delay based on the embodiment discussed in relation to FIG. 4. Therefore, the exemplary multi-pair multiplexing receiver **500** should be able to accommodate at least these types of variations in delay. An exemplary method for dealing with the issue of delay is to have cell buffers (not shown) in the multi-pair multiplexing receiver **500** that can provide the ability to compensate for the variations in delay. As example, if there is a cell buffer that can hold several ATM cells on each input ATM substream path, the multi-pair multiplexing receiver **500** can simply wait until, for example, cell number **1** comes in path number one, while path number two will buffer cell number **2** and wait for cell number **1** to be received. This method requires a cell buffer on each ATM substream path at the input of the multi-pair multiplexing receiver **500**. The size of the cell buffer can be determined by, for example, the maximum difference in latency between the "bonded" PHYs. As an alternative, the buffer can be based on one large buffer with multiple pointers without effecting the operation of the system.

Another effective method of reducing the difference in latency between DSL PHYs is mandate that all DSL PHYs are configured with transmission parameters in order to provide the same configuration latency. An exemplary method of accomplishing the same configuration latency is by configuring the exact same data rate, coding parameters, interleaving parameters, etc. on all DSL PHYs. Alternatively, different PHYs can have, for example, different data rates but use the appropriate coding or interleaving parameters to have the same latency on all the bonded PHYs.

As an example, for Reed Solomon coding and interleaving functions as defined in ADSL standards G.992.1 and G.992.3,

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incorporated herein by reference in their entirety, the latency due to these functions is defined as:

$$\text{Latency} = N \cdot D / R,$$

where N is the number of bits in a codeword, D is the interleaver depth in codewords and R is the data in bits per second.

For example if N=1600 bits, i.e., 200 bytes, D=64 codewords and R=6400000 bps then:

$$\text{Latency} = 1600 \cdot 64 / 6400000 = 0.016 \text{ seconds.}$$

Therefore if, for example, two PHYs have different data rates, R1 and R2 then, in order to bond these PHYs together and have the same configuration latency set:

$$N1 \cdot D1 / R1 = N2 \cdot D2 / R2,$$

where N1 and N2 are the bits in a codeword for each PHY and D1 and D2 are the interleaver depths for each PHY.

This can also be rewritten as:

$$N1 \cdot D1 = (R1 / R2) \cdot N2 \cdot D2.$$

Thus, in general, the N1, N1, N2 and D2 parameters must be chosen to satisfy the above equations and this can be accomplished in several ways.

For example, if the configuration latency is specified as 0.016 seconds, and R1=6400000 bps and R2=1600000 then, as described in the example above, N1 and D1 can be configured as N1=1600 and D1=64. Therefore:

$$N2 \cdot D2 = (R2 / R1) \cdot D1 \cdot N1 = (1600000 / 6400000) \cdot 1600 \cdot 64 = 1600 \cdot 64 = 1600 \cdot 64 \cdot 4.$$

Therefore, for example, N2 and D2 can be configured as (N2=1600, D2=16) or (N2=400, D2=64) or (N2=800, D2=32), etc.

Obviously the same methods can be applied to more than 2 PHYs with different data rates.

The ATM-TC receiver in ADSL systems is specified to discard ATM cells that are received with an incorrect cyclic redundancy check, e.g., (HEC). This means that if there are bit errors as the result of transmission over the ADSL channel, ATM cells will be discarded by the ATM-TC and not sent to the multi-pair multiplexing receiver. As a result of this type of error condition, ATM cells may be received out of order in the multi-pair multiplexing receiver.

FIG. 10 illustrates an exemplary multi-pair multiplexing receiver 500 with a single ATM cell lost due to PHY channel errors using the exemplary embodiment discussed in relation to FIG. 4. In FIG. 10, ATM cell number 5 was discarded by the second DSL PHY 510 due to, for example, a HEC error. Therefore, if the multi-pair multiplexing receiver 500 is not aware of this error, the ATM cells stream can not be reconstructed appropriately.

The exemplary systems and methods of this invention utilize a multi-pair cell counter to operate in the condition where the ATM cells are discarded by DSL PHY when, for example, HEC errors occur. The multi-pair multiplexing transmitter can embed the multi-pair cell counter in the header of each ATM cell after receiving the ATM cell from the ATM layer. At the receiver, the multi-pair multiplexing receiver reads the multi-pair cell counter and removes it from the header of the ATM cell prior to sending the ATM cell to the ATM layer. The multi-pair cell counter is a value that indicates the position of a particular ATM cell in the ATM cell stream.

In its simplest form, the multi-pair cell counter can be a modulo L counter that starts at, for example, zero and increments by one for each consecutive ATM cell up to a value L-1. For example, if L equals 256, the value of the multi-pair cell

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counter could start at zero and increment by one up to a value of 255. After 255, the multi-pair counter could be started at zero again, and so on.

As previously discussed, the multi-pair cell counter can be embedded in the ATM cell header of all the ATM cells in the ATM stream. FIG. 11 illustrates the multi-pair multiplexing transmitter 400 as discussed in relation to the example illustrated in FIG. 4, with L equal to 4 and the multi-pair cell counter specified inside the ATM cell header. At the receiver, the multi-pair cell counter is read by the multi-pair multiplexing receiver and removed from the ATM cell header. The multi-pair multiplexing receiver uses the multi-pair cell counter to properly recombine the ATM cells to reconstruct the ATM stream. Therefore, as in the example above, where a cell was discarded by the DSL PHY, the multi-pair multiplexing receiver would be able to determine this error and the ATM cell(s) placed in the appropriate order.

FIG. 12 illustrates an example where the 5th ATM cell in the ATM stream was discarded by the PHY. The 5th ATM cell in the exemplary ATM stream has a multi-pair cell counter number equal to 0 and was sent on the second ATU. The exemplary multi-pair multiplexing receiver 500 can check the multi-pair cell count value of the ATU's ATM cell before inserting the cell back into the ATM stream. In this manner, when the multi-pair multiplexing receiver checks the ATM cell counter from the second ATU and reads a multi-pair cell count 3 instead of zero, the multi-pair multiplexing receiver can determine that the ATM cell with the multi-pair cell counter equal to 0 was discarded by the second ATU PHY. In this case, multi-pair multiplexing receiver will not take a cell from the ATU-2 ATM substream. Instead, the multi-pair multiplexing receiver will move to the next ATU in order to check the multi-pair cell count value, and insert the ATM cell back into the ATM stream if the multi-pair cell count is correct, and continue. Therefore, as a result of using the multi-pair cell counter, the multi-pair multiplexing receiver can properly reconstruct the original ATM cell stream even in the presence of ATM cell lost.

The exemplary main multi-pair cell parameter is the value of L. The appropriate value of L depends on the number of bonded PHYs (N) and the maximum number (M) of consecutive ATM cells that may be discarded by the PHY. The design constraint on L is that it must be large enough so that the multi-pair multiplexing receiver can still detect cell lost even when the maximum number of consecutive ATM cells are discarded by a PHY. This places the constraint that L > N * M. For example, if there are N=4 bonded PHYs, and the maximum number of consecutive ATM cells that may be discarded by the PHY is M=50, then L > 200. If, for example L is chosen to be equal to 256, then even when 50 consecutive ATM cells are lost, the multi-pair multiplexing receiver can accurately detect the error event.

There are several exemplary methods to embedding the multi-pair cell counter into the ATM cell header including, but not limited to, using the GFC field in the UNI ATM header. The GFC field is currently not used and is typically set to zero. The GFC field is a four bit field therefore the maximum value of L is 16. This could pose an issue when the channel has, for example, impulse noise and the PHY data rate is high resulting in cases where multiple ATM cells are often discarded by the PHY.

Therefore, as an alternative, bits in the VPI/VCI field can be used. The VPI field occupies 8 bits in the UNI header and identifies the route taken by the ATM cell. The VCI field occupies 16 bits in the UNI header and it identifies the circuit or connection number on the path. In order to use the VPI/VCI field for the multi-pair cell counter, the multi-pair multiplex-

ing transmitter overwrites bits in the VPI/VCI field with the multi-pair cell counter value on a cell by cell bases. At the receiver, the multi-pair multiplexing receiver reads the multi-pair cell counter value and resets and overwrites the VPI/VCI back to the original value.

This method requires the multi-pair multiplexing receiver to have knowledge of the overwritten VPI/VCI bits. As an example, this can be accomplished by communicating the VPI/VCI fields of the ATM stream during initialization/configuration of the DSL connection or during configuration or re-configuration of the ATM connection. Since the VPI/VCI field has 24 bits, the L value for the multi-pair cell counter can be set to a very large number.

One exemplary method for embedding the multi-pair cell counter in the VPI/VCI field is to construct a table of all, or a portion of, possible VPI/VCI values that may be transported by the bonded DSL PHYs. This VPI/VCI table can, for example, be stored in the multi-pair multiplexing transmitters and receivers for all PHYs. The table maps a VPI/VCI value to a table index value that is also stored in the multi-pair multiplexing transmitters and receivers for all PHYs. If there are K VPI/VCI values being transported over the bonded DSL PHYs, the VPI/VCI value could be mapped to a number from zero to K-1. At the multi-pair multiplexing transmitter, the VPI/VCI value in the ATM header is replaced with the table index value. Since there are limited numbers of VPI/VCI going to a single subscriber, the table index value can utilize only a fraction of the 24 bits available in the VPI/VCI field. Therefore, the multi-pair multiplexing transmitter can use the remaining VPI/VCI bits to transport, for example, the multi-pair cell counter.

At the receiver, the multi-pair multiplexing receiver is multi-pair cell counter that reconstructs the ATM stream as discussed above. Additionally, the multi-pair multiplexing receiver can read the table index value in the ATM header and write the VPI/VCI value corresponding to the table index value as stored in the VPI/VCI table back into the VPI/VCI header field.

As a simple example, where only one VPI/VCI is being sent over the bonded DSL connection, the VPI/VCI table will have only one value. Therefore, in this case, it is not necessary to insert the table index value at the transmitter. The transmitter may use the bits in the VPI/VCI field for the multi-pair cell counter. At the receiver, the multi-pair cell counter is read and used to reconstruct the ATM stream. Since only one VPI/VCI value is being used, the receiver can reset the VPI/VCI field to the appropriate value prior to sending the ATM stream into the ATM layer. This approach can work, for example, with many consumer based employments of a DSL, since in most cases a single VPI/VCI is used.

As an alternative, consider a four VPI/VCI situation.

TABLE 1

VPI/VCI Table	
VPI/VCI Value	Table Index Value (TIV)
Va (24 bit value)	0
Vb (24 bit value)	1
Vc (24 bit value)	2
Vd (24 bit value)	3

Table 1 contains an exemplary VPI/VCI table with four VPI/VCI addresses. Additionally, for the purpose of this example, the multi-pair cell counter is specified to be an eight bit counter, i.e., a modulo 255 counter.

FIG. 13 illustrates the format for the standard five bit ATM UNI header. The VPI/VCI values in Table 1 corresponds to the 24 bit VPI/VCI values in the UNI ATM header.

FIG. 14 illustrates an exemplary format of the ATM header after the multi-pair multiplexing transmitter has replace the VPI/VCI values with the table index value and then embedded the multi-pair cell counter in the VPI/VCI field. The first two bits the VPI/VCI field are used to transport the table index value (TIV) and the next eight bits are used to transport the multi-pair cell counter. The remaining bits can be reserved and can be used, for example, by the multi-pair multiplexing blocks for other purposes, such as the transportation of messages between the multi-pair multiplexing blocks, or the like.

At the receiver, the multi-pair multiplexing receiver reads the multi-pair cell counter value from the header in order to properly reconstruct the ATM stream. The multi-pair multiplexing receiver also reads the TIV in the ATM header and writes the VPI/VCI corresponding to the table index value as stored in the VPI/VCI table back into the VPI/VCI header field. As a result, at the output of the multi-pair multiplexing receiver, the ATM header can be completely reconstructed into the standard UNI format comprising the original data contents.

In this illustrative example, there were four VPI/VCI addresses being used in cells being transported over the bonded ADSL system. However, in many deployments, the VP is determined in the DSLAM, which means that the VPI field is the same for all packets. Therefore, in the case of terminating the VP and the DSLAM, the VP field could, for example, be used in transporting the TIV.

FIG. 15 illustrates an exemplary method of transporting ATM over DSL. In particular control begins in step S100 and continues to step S110. In step S110 the cell distributions are determined, for example, based on differing data rates between the DSL PHYs, or the like. Next, in step S120 the cells from the ATM stream are assigned based on the determined cell distribution to the appropriate ATM TC cell stream. Then, in step S130, the cells are transmitted to a receiver. Control then continues to step S140.

In step S140, a receiver receives the cells. Next, in step S150, the ATM substreams are combined to reconstruct the ATM stream. In particular, in step S152, a determination is made whether there is a difference in latency between the DSL lines. If there are differential latency problems, control continues to step S154 where the differential latency is compensated for by, for example, buffering, or the like. Otherwise, control jumps to step S156.

In step S156, a determination is made whether other errors are present in one or more of the substreams. If other errors, such as dropped cells, channel bit errors, or the like are present, control continues to step S158 where the other errors are compensated for. Otherwise, control jumps to step S160 where the control sequence ends.

The above-described ATM over DSL system can be implemented on a telecommunications device, such a modem, a DSL modem, an ADSL modem, a multicarrier transceiver, a VDSL modem, or the like, or on a separate programmed general purpose computer having a communications device. Additionally, the systems and methods of this invention can be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element(s), an ASIC or other integrated circuit, a digital signal processor, a hard-wired electronic or logic circuit such as discrete element circuit, a programmable logic device such as PLD, PLA, FPGA, PAL, modem, transmitter/receiver, or the like. In general, any device capable of implementing a state machine that is in turn capable of imple-

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menting the flowchart illustrated herein can be used to implement the various ATM over DSL methods according to this invention.

Furthermore, the disclosed methods may be readily implemented in software using object or object-oriented software development environments that provide portable source code that can be used on a variety of computer or workstation platforms. Alternatively, the disclosed ATM over DSL system may be implemented partially or fully in hardware using standard logic circuits or VLSI design. Whether software or hardware is used to implement the systems in accordance with this invention is dependent on the speed and/or efficiency requirements of the system, the particular function, and the particular software or hardware systems or microprocessor or microcomputer systems being utilized. The ATM over DSL systems and methods illustrated herein however can be readily implemented in hardware and/or software using any known or later developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

Moreover, the disclosed methods may be readily implemented in software executed on programmed general purpose computer, a special purpose computer, a microprocessor, or the like. In these instances, the systems and methods of this invention can be implemented as program embedded on personal computer such as JAVA® or CGI script, as a resource residing on a server or graphics workstation, as a routine embedded in a dedicated ATM over DSL system, or the like. The ATM over DSL system can also be implemented by physically incorporating the system and method into a software and/or hardware system, such as the hardware and software systems of a communications transceiver.

It is, therefore, apparent that there has been provided, in accordance with the present invention, systems and methods for ATM over DSL. While this invention has been described in conjunction with a number of embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable arts. Accordingly, it is intended to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and scope of this invention.

We claim:

1. A method comprising:

utilizing at least one transmission parameter value, for each transceiver in a plurality of bonded transceivers, to reduce a difference in latency between the bonded transceivers, wherein a data rate for a first of the plurality of bonded transceivers is different than a data rate for a second of the plurality of bonded transceivers.

2. The method of claim 1, wherein the at least one transmission parameter value is a Reed Solomon Coding parameter value, an interleaving parameter value, a coding parameter value, a codeword size value or a framing parameter value.

3. The method of claim 1, wherein the bonded transceivers are transporting cells or ATM cells.

4. The method of claim 1, wherein the bonded transceivers are transporting packets, Ethernet packets or IP packets.

5. The method of claim 1, wherein the at least one transmission parameter value for the first of the plurality of bonded transceivers is a first Reed Solomon Coding parameter value, and the at least one transmission parameter value for the second of the plurality of bonded transceivers is a different Reed Solomon Coding parameter value.

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6. The method of claim 5, wherein the first Reed Solomon Coding parameter value is less than the different Reed Solomon Coding parameter value when the data rate for the first of the plurality of bonded transceivers is less than the data rate for the second of the plurality of bonded transceivers.

7. The method of claim 1, wherein the at least one transmission parameter value for the first of the plurality of bonded transceivers is a first interleaving parameter value, and the at least one transmission parameter value for the second of the plurality of bonded transceivers is a different interleaving parameter value.

8. The method of claim 7, wherein the first interleaving parameter value is less than the different interleaving parameter value when the data rate for the first of the plurality of bonded transceivers is less than the data rate for the second of the plurality of bonded transceivers.

9. A method comprising:

selecting at least one transmission parameter value, for each transceiver in a plurality of bonded transceivers, to reduce a difference in latency between the bonded transceivers, wherein a data rate of a first of the plurality of bonded transceivers is different than a data rate of a second of the plurality of bonded transceivers.

10. The method of claim 9, wherein the at least one transmission parameter value is a Reed Solomon Coding parameter value, an interleaving parameter value, a coding parameter value, a codeword size value or a framing parameter value.

11. The method of claim 9, wherein the bonded transceivers are transporting cells or ATM cells.

12. The method of claim 9, wherein the bonded transceivers are transporting packets, Ethernet packets or IP packets.

13. The method of claim 9, wherein the at least one transmission parameter value for the first of the plurality of bonded transceivers is a first Reed Solomon Coding parameter value, and the at least one transmission parameter value for the second of the plurality of bonded transceivers is a different Reed Solomon Coding parameter value.

14. The method of claim 13, wherein the first Reed Solomon Coding parameter value is less than the different Reed Solomon Coding parameter value when the data rate for the first of the plurality of bonded transceivers is less than the data rate for the second of the plurality of bonded transceivers.

15. The method of claim 9, wherein the at least one transmission parameter value for the first of the plurality of bonded transceivers is a first interleaving parameter value, and the at least one transmission parameter value for the second of the plurality of bonded transceivers is a different interleaving parameter value.

16. The method of claim 15, wherein the first interleaving parameter value is less than the different interleaving parameter value when the data rate for the first of the plurality of bonded transceivers is less than the data rate for the second of the plurality of bonded transceivers.

17. A plurality of bonded transceivers, each bonded transceiver utilizing at least one transmission parameter value to reduce a difference in latency between the bonded transceivers, wherein a data rate for a first of the bonded transceivers is different than a data rate for a second of the bonded transceivers.

18. The transceivers of claim 17, wherein the at least one transmission parameter value is a Reed Solomon Coding parameter value, an interleaving parameter value, a coding parameter value, a codeword size value or a framing parameter value.

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19. The transceivers of claim 17, wherein the transceivers are capable of transporting cells or ATM cells.

20. The transceivers of claim 17, wherein the transceivers are capable of transporting packets, Ethernet packets or IP packets.

21. The transceiver of claim 17, wherein the at least one transmission parameter value for the first transceiver is a first Reed Solomon Coding parameter value that is different than a second Reed Solomon Coding parameter value for the second transceiver.

22. The transceivers of claim 21, wherein the first Reed Solomon Coding parameter value is less than the second Reed Solomon Coding parameter value when the data rate for the first transceiver is less than the data rate for the second transceiver.

23. The transceivers of claim 17, wherein the at least one transmission parameter value for the first transceiver is a first interleaving parameter value that is different than a second interleaving parameter value for the second transceiver.

24. The transceivers of claim 23, wherein the first interleaving parameter value is less than the second interleaving parameter value when the data rate for the first transceiver is less than the data rate for the second transceiver.

25. A plurality of bonded transceivers, each bonded transceiver selecting at least one transmission parameter value to reduce a difference in latency between the bonded transceivers, wherein a data rate for a first of the bonded transceivers is different than a data rate for a second of the bonded transceivers.

26. The transceivers of claim 25, wherein the at least one transmission parameter value is a Reed Solomon Coding parameter value, an interleaving parameter value, a coding parameter value, a codeword size value or a framing parameter value.

27. The transceivers of claim 25, wherein the transceivers are capable of transporting cells or ATM cells.

28. The transceivers of claim 25, wherein the transceivers are capable of transporting packets, Ethernet packets or IP packets.

29. The transceivers of claim 25, wherein the at least one transmission parameter value for the first transceiver is a first Reed Solomon Coding parameter value that is different than a second Reed Solomon Coding parameter value for the second transceiver.

30. The transceivers of claim 29, wherein the first Reed Solomon Coding parameter value is less than the second Reed Solomon Coding parameter value when the data rate for the first transceiver is less than the data rate for the second transceiver.

31. The transceivers of claim 25, wherein the at least one transmission parameter value for the first transceiver is a first interleaving parameter value that is different than a second interleaving parameter value for the second transceiver.

32. The transceivers of claim 31, wherein the first interleaving parameter value is less than the second interleaving

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parameter value when the data rate for the first transceiver is less than the data rate for the second transceiver.

33. A storage media having computer executable instructions stored thereon that:

utilize at least one transmission parameter value, for each transceiver in a plurality of bonded transceivers, to reduce a difference in latency between the bonded transceivers, wherein a data rate for a first of the plurality of bonded transceivers is different than a data rate for a second of the plurality of bonded transceivers.

34. The media of claim 33, wherein the at least one transmission parameter value is a Reed Solomon Coding parameter value, an interleaving parameter value, a coding parameter value, a codeword size value or a framing parameter value.

35. The media of claim 33, wherein the bonded transceivers are transporting cells or ATM cells.

36. The media of claim 33, wherein the bonded transceivers are transporting packets, Ethernet packets or IP packets.

37. A storage media having computer executable instructions stored thereon that:

select at least one transmission parameter value, for each transceiver in a plurality of bonded transceivers, to reduce a difference in latency between the bonded transceivers, wherein a data rate of a first of the plurality of bonded transceivers is different than a data rate of a second of the plurality of bonded transceivers.

38. The media of claim 37, wherein the at least one transmission parameter value is a Reed Solomon Coding parameter value, an interleaving parameter value, a coding parameter value, a codeword size value or a framing parameter value.

39. The media of claim 37, wherein the bonded transceivers are transporting cells or ATM cells.

40. The media of claim 37, wherein the bonded transceivers are transporting packets, Ethernet packets or IP packets.

41. A communications system comprising:
a plurality of bonded communication means,
each bonded communication means utilizing at least one transmission parameter value to reduce a difference in latency between the bonded communication means, wherein a data rate for a first of the plurality of bonded communication means is different than a data rate for a second of the plurality of bonded communication means.

42. A communications system comprising:
a plurality of bonded communication means,
each bonded communication means selecting at least one transmission parameter value to reduce a difference in latency between the bonded communication means, wherein a data rate of a first of the plurality of bonded communication means is different than a data rate of a second of the plurality of bonded communication means.

* * * * *

EXHIBIT 2



(12) **United States Patent**
Krinsky et al.

(10) **Patent No.:** **US 7,570,686 B2**
(45) **Date of Patent:** **Aug. 4, 2009**

(54) **SYSTEMS AND METHODS FOR ESTABLISHING A DIAGNOSTIC TRANSMISSION MODE AND COMMUNICATING OVER THE SAME**

(75) Inventors: **David M Krinsky**, Acton, MA (US);
Robert Edmund Pizzano, Jr., Stoneham, MA (US)

(73) Assignee: **Aware, Inc.**, Bedford, MA (US)

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(60) Provisional application No. 60/224,308, filed on Aug. 10, 2000, provisional application No. 60/174,865, filed on Jan. 7, 2000.

(51) **Int. Cl.**
H04B 1/38 (2006.01)
H04L 12/26 (2006.01)

(52) **U.S. Cl.** **375/222; 370/252**
(58) **Field of Classification Search** **375/222, 375/224-225, 227, 220, 284; 370/252, 282, 370/241; 379/22.02, 22.04, 27.01, 27.03**
See application file for complete search history.

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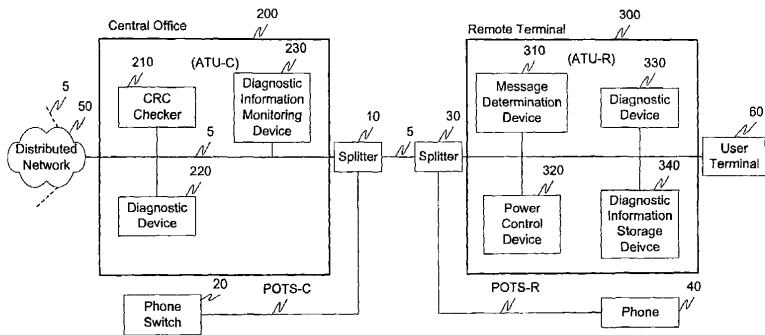
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(74) **Attorney, Agent, or Firm**—Sheridan Ross P.C.; Jason H. Vick

(57) **ABSTRACT**
Upon detection of a trigger, such as the exceeding of an error threshold or the direction of a user, a diagnostic link system enters a diagnostic information transmission mode. This diagnostic information transmission mode allows for two modems to exchange diagnostic and/or test information that may not otherwise be exchangeable during normal communication. The diagnostic information transmission mode is initiated by transmitting an initiate diagnostic link mode message to a receiving modem accompanied by a cyclic redundancy check (CRC). The receiving modem determines, based on the CRC, if a robust communications channel is present. If a robust communications channel is present, the two modems can initiate exchange of the diagnostic and/or test information. Otherwise, the transmission power of the transmitting modem is increased and the initiate diagnostic link mode message re-transmitted to the receiving modem until the CRC is determined to be correct.

41 Claims, 2 Drawing Sheets



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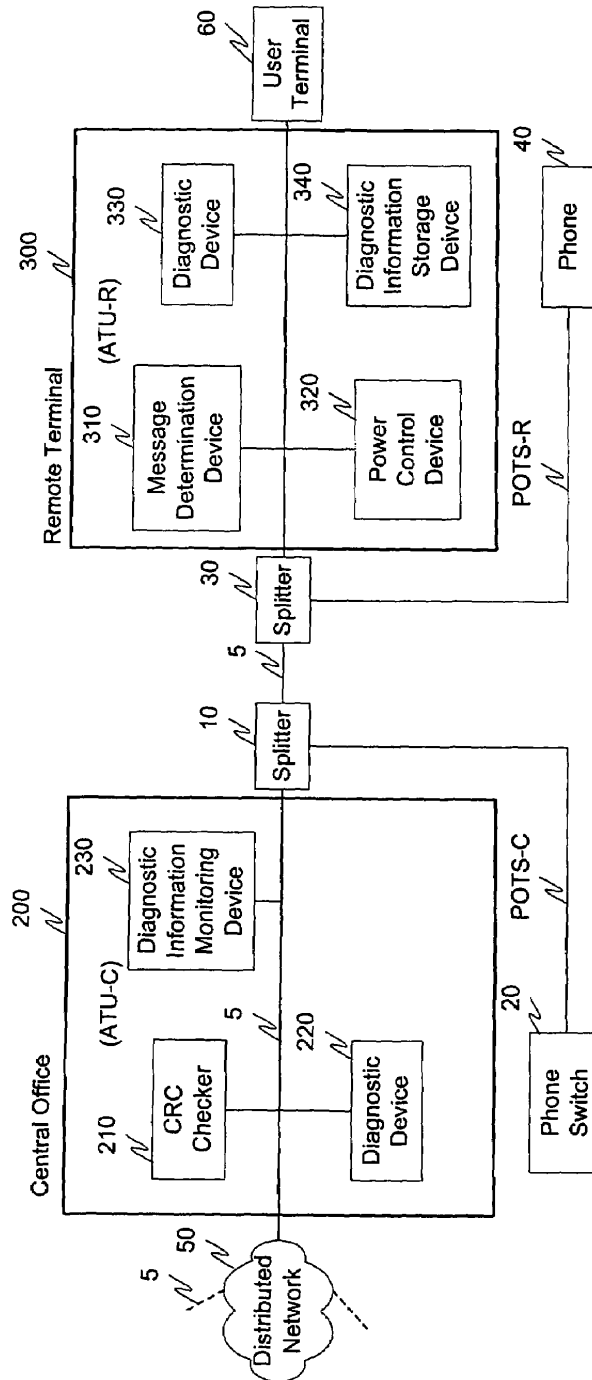


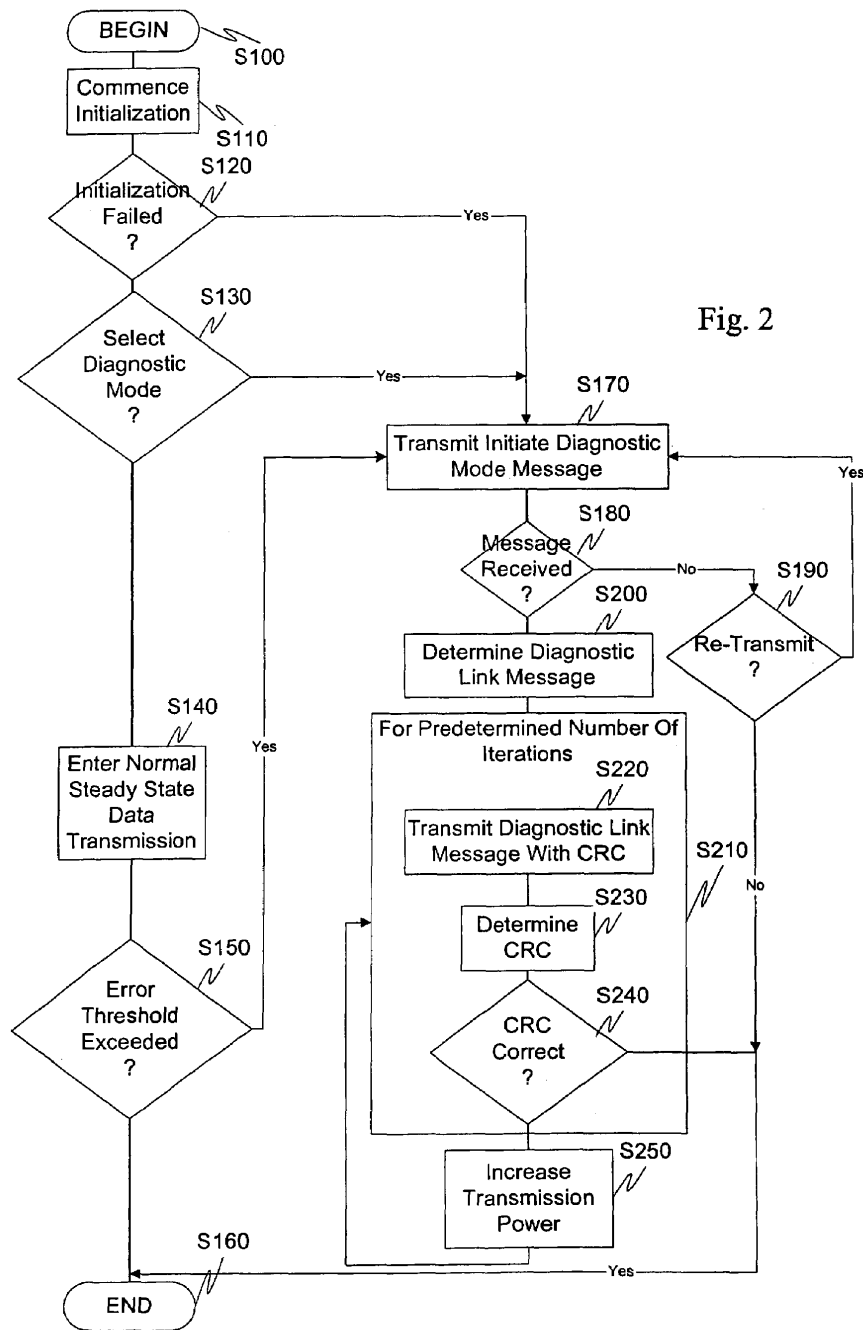
Fig. 1

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SYSTEMS AND METHODS FOR ESTABLISHING A DIAGNOSTIC TRANSMISSION MODE AND COMMUNICATING OVER THE SAME

RELATED APPLICATION DATA

This application is a Divisional Application of U.S. application Ser. No. 09/755,173 entitled "Systems and Methods For Establishing A Diagnostic Transmission Mode And Communicating Over the Same" filed Jan. 8, 2001, which claims benefit of Provisional Application Nos. 60/224,308 filed Aug. 10, 2000 and 60/174,865 filed Jan. 7, 2000 and incorporated herein by reference in their entirety.

FIELD OF THE INVENTION

This invention relates to test and diagnostic information. In particular, this invention relates to a robust system and method for communicating diagnostic information.

BACKGROUND OF THE INVENTION

The exchange of diagnostic and test information between transceivers in a telecommunications environment is an important part of a telecommunications, such as an ADSL, deployment. In cases where the transceiver connection is not performing as expected, for example, where the data rate is low, where there are many bit errors, or the like, it is necessary to collect diagnostic and test information from the remote transceiver. This is performed by dispatching a technician to the remote site, e.g., a truck roll, which is time consuming and expensive.

In DSL technology, communications over a local subscriber loop between a central office and a subscriber premises is accomplished by modulating the data to be transmitted onto a multiplicity of discrete frequency carriers which are summed together and then transmitted over the subscriber loop. Individually, the carriers form discrete, non-overlapping communication subchannels of limited bandwidth. Collectively, the carriers form what is effectively a broadband communications channel. At the receiver end, the carriers are demodulated and the data recovered.

DSL systems experience disturbances from other data services on adjacent phone lines, such as, for example, ADSL, HDSL, ISDN, T1, or the like. These disturbances may commence after the subject ADSL service is already initiated and, since DSL for internet access is envisioned as an always-on service, the effect of these disturbances must be ameliorated by the subject ADSL transceiver.

SUMMARY OF THE INVENTION

The systems and methods of this invention are directed toward reliably exchanging diagnostic and test information between transceivers over a digital subscriber line in the presence of voice communications and/or other disturbances. For simplicity of reference, the systems and methods of the invention will hereafter refer to the transceivers generically as modems. One such modem is typically located at a customer premises such as a home or business and is "downstream" from a central office with which it communicates. The other modem is typically located at the central office and is "upstream" from the customer premises. Consistent with industry practice, the modems are often referred to as "ATU-R" ("ADSL transceiver unit, remote," i.e., located at the customer premises) and "ATU-C" ("ADSL transceiver unit, cen-

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tral office" i.e., located at the central office). Each modem includes a transmitter section for transmitting data and a receiver section for receiving data, and is of the discrete multitone type, i.e., the modem transmits data over a multiplicity of subchannels of limited bandwidth. Typically, the upstream or ATU-C modem transmits data to the downstream or ATU-R modem over a first set of subchannels, which are usually the higher-frequency subchannels, and receives data from the downstream or ATU-R modem over a second, usually smaller, set of subchannels, commonly the lower-frequency subchannels. By establishing a diagnostic link mode between the two modems, the systems and methods of this invention are able to exchange diagnostic and test information in a simple and robust manner.

In the diagnostic link mode, the diagnostic and test information is communicated using a signaling mechanism that has a very high immunity to noise and/or other disturbances and can therefore operate effectively even in the case where the modems could not actually establish an acceptable connection in their normal operational mode.

For example, if the ATU-C and/or ATU-R modem fail to complete an initialization sequence, and are thus unable to enter a normal steady state communications mode, where the diagnostic and test information would normally be exchanged, the modems according to the systems and methods of this invention enter a robust diagnostic link mode. Alternatively, the diagnostic link mode can be entered automatically or manually, for example, at the direction of a user. In the robust diagnostic link mode, the modems exchange the diagnostic and test information that is, for example, used by a technician to determine the cause of a failure without the technician having to physically visit, i.e., a truckroll to, the remote site to collect data.

The diagnostic and test information can include, for example, but is not limited to, signal to noise ratio information, equalizer information, programmable gain setting information, bit allocation information, transmitted and received power information, margin information, status and rate information, telephone line condition information, such as the length of the line, the number and location of bridged taps, a wire gauge, or the like, or any other known or later developed diagnostic or test information that may be appropriate for the particular communications environment. For example, the exchanged diagnostic and test information can be directed toward specific limitations of the modems, to information relating to the modem installation and deployment environment, or to other diagnostic and test information that can, for example, be determined as needed which may aid in evaluating the cause of a specific failure or problem. Alternatively, the diagnostic and test information can include the loop length and bridged tap length estimations as discussed in U.S. patent application Ser. No. 09/755,172 now became U.S. Pat. No. 6,865,221, filed herewith and incorporated herein by reference in its entirety.

For example, an exemplary embodiment of the invention illustrates the use of the diagnostic link mode in the communication of diagnostic information from the remote terminal (RT) transceiver, e.g., ATU-R, to the central office (CO) transceiver, e.g., ATU-C. Transmission of information from the remote terminal to the central office is important since a typical ADSL service provider is located in the central office and would therefore benefit from the ability to determine problems at the remote terminal without a truckroll. However, it is to be appreciated, that the systems and the methods of this invention will work equally well in communications from the central office to the remote terminal.

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These and other features and advantages of this invention are described in or are apparent from the following detailed description of the embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the invention will be described in detail, with reference to the following figures wherein:

FIG. 1 is a functional block diagram illustrating an exemplary communications system according to this invention; and

FIG. 2 is a flowchart outlining an exemplary method for communicating diagnostic and test information according to this invention.

DETAILED DESCRIPTION OF THE INVENTION

For ease of illustration the following description will be described in relation to the CO receiving diagnostic and test information from the RT. In the exemplary embodiment, the systems and methods of this invention complete a portion of the normal modem initialization before entering into the diagnostic link mode. The systems and methods of this invention can enter the diagnostic link mode manually, for example, at the direction of a technician or a user after completing a portion of initialization. Alternatively, the systems and methods of this invention can enter the diagnostic link mode automatically based on, for example, a bit rate failure, a forward error correction or a CRC error during showtime, e.g., the normal steady state transmission mode, or the like. The transition into the diagnostic link mode is accomplished by transmitting a message from the CO modem to the RT modem indicating that the modems are to enter into the diagnostic link mode, as opposed to transitioning into the normal steady state data transmission mode. Alternatively, the transition into the diagnostic link mode is accomplished by transmitting a message from the RT modem to the CO modem indicating that the modems are to enter into the diagnostic link mode as opposed to transitioning into the normal steady state data transmission mode. For example, the transition signal uses an ADSL state transition to transition from a standard ADSL state to a diagnostic link mode state.

In the diagnostic link mode, the RT modem sends diagnostic and test information in the form of a collection of information bits to the CO modem that are, for example, modulated by using one bit per DTM symbol modulation, as is used in the C-Rates1 message in the ITU and ANSI ADSL standards, where the symbol may or may not include a cyclic prefix. Other exemplary modulation techniques include Differential Phase Shift Keying (DPSK) on a subset or all the carriers, as specified in, for example, ITU standard G.994.1, higher order QAM modulation (>1 bit per carrier), or the like.

In the one bit per DMT symbol modulation message encoding scheme, a bit with value 0 is mapped to the REVERB1 signal and a bit with a value of 1 mapped to a SEGUE1 signal. The REVERB1 and SEGUE1 signals are defined in the ITU and ANSI ADSL standards. The REVERB1 signal is generated by modulating all of the carriers in the multicarrier system with a known pseudo-random sequence thus generating a wideband modulated signal. The SEGUE1 signal is generated from a carrier by 180 degree phase reversal of the REVERB1 signal. Since both signals are wideband and known in advance, the receiver can easily detect the REVERB1 and SEGUE1 signal using a simple matched filter in the presence of large amounts of noise and other disturbances

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TABLE 1

Exemplary Message Variables

Data Sent in the Diag Link
Train Type
ADSL Standard
Chip Type
Vendor ID
Code Version
Average Reverb Received Signal
Programmable gain amplifier (PGA) Gain - Training
Programmable gain amplifier PGA Gain - Showtime
Filter Present during Idle Channel Calculation
Average Idle Channel Noise
Signal to Noise during Training
Signal to Noise during Showtime
Bits and Gains
Data Rate
Framing Mode
Margin
Reed-Solomon Coding Gain
QAM Usage
Frequency Domain Equalizer (FDQ) Coefficients
Gain Scale
Time domain equalizer (TDQ) Coefficients
Digital Echo Canceller (DEC) Coefficients

Table 1 shows an example of a data message that can be sent by the RT to the CO during the diagnostic link mode. In this example, the RT modem sends 23 different data variables to the CO. Each data variable contains different items of diagnostic and test information that are used to analyze the condition of the link. The variables may contain more than one item of data. For example, the *Average Reverb Signal* contains the power levels per tone, up to, for example, 256 entries, detected during the ADSL Reverb signal. Conversely, the *PGA Gain—Training* is a single entry, denoting the gain in dB at the receiver during the ADSL training.

Many variables that represent the type of diagnostic and test information that are used to analyze the condition of the link are sent from the RT modem to the CO modem. These variables can be, for example, arrays with different lengths depending on, for example, information in the initiate diagnostic mode message. The systems and methods of this invention can be tailored to contain many different diagnostic and test information variables. Thus, the system is fully configurable, allowing subsets of data to be sent and additional data variables to be added in the future. Therefore, the message length can be increased or decreased, and diagnostic and test information customized, to support more or less variables as, for example, hardware, the environment and/or the telecommunications equipment dictates.

Therefore, it is to be appreciated, that in general the variables transmitted from the modem being tested to the receiving modem can be any combination of variables which allow for transmission of test and/or diagnostic information.

FIG. 1 illustrates an exemplary embodiment of the additional modem components associated with the diagnostic link mode. In particular, the diagnostic link system 100 comprises a central office modem 200 and a remote terminal modem 300. The central office modem 200 comprises, in addition to the standard ATU-C components, a CRC checker 210, a diagnostic device 220, and a diagnostic information monitoring device 230. The remote terminal modem 300 comprises, in addition to the standard components associated with an ATU-R, a message determination device 310, a power control device 320, a diagnostic device 330 and a diagnostic information storage device 340. The central office modem 200 and the remote terminal model 300 are also connected, via link 5,

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to a splitter **10** for a phone switch **20**, and a splitter **30** for a phone **40**. Alternatively, the ATU-R can operate without a splitter, e.g., splitterless, as specified in ITU standard G.992.2 (G.lite) or with an in-line filter in series with the phone **40**. In addition, the remote terminal modem **300**, can also be connected to, for example, one or more user terminals **60**. Additionally, the central office modem **200** can be connected to one or more distributed networks **50**, via link **5**, which may or may not also be connected to one or more other distributed networks.

While the exemplary embodiment illustrated in FIG. 1 shows the diagnostic link system **100** for an embodiment in which the remote terminal modem **300** is communicating test and diagnostic information to the central office **200**, it is to be appreciated that the various components of the diagnostic link system can be rearranged such that the diagnostic and test information can be forwarded from the central office **200** to the remote terminal modem **300**, or, alternatively, such that both modems can send and receive diagnostic and/or test information. Furthermore, it is to be appreciated, that the components of the diagnostic link system **100** can be located at various locations within a distributed network, such as the POTS network, or other comparable telecommunications network. Thus, it should be appreciated that the components of the diagnostic link system **100** can be combined into one device for respectively transmitting, receiving, or transmitting and receiving diagnostic and/or test information. As will be appreciated from the following description, and for reasons of computational efficiency, the components of the diagnostic link system **100** can be arranged at any location within a telecommunications network and/or modem without affecting the operation of the system.

The links **5** can be a wired or wireless link or any other known or later developed element(s) that is capable of supplying and communicating electronic data to and from the connected elements. Additionally, the user terminal **60** can be, for example, a personal computer or other device allowing a user to interface with and communicate over a modem, such as a DSL modem. Furthermore, the systems and method of this invention will work equally well with splitterless and low-pass multicarrier modem technologies.

In operation, the remote terminal **300**, commences its normal initialization sequence. The diagnostic device **330** monitors the initialization sequence for a failure. If there is a failure, the diagnostic device **330** initiates the diagnostic link mode. Alternatively, a user or, for example, a technician at the CO, can specify that the remote terminal **300** enter into the diagnostic link mode after completing a portion of an initialization. Alternatively still, the diagnostic device **330** can monitor the normal steady state data transmission of the remote terminal, and upon, for example, an error threshold being exceeded, the diagnostic device **330** will initiate the diagnostic link mode.

Upon initialization of the diagnostic link mode, the diagnostic device **330**, in cooperation with the remote terminal **300** will transmit an initiate diagnostic link mode message from the remote terminal to the central office **200** (RT to CO). Alternatively, the central office modem **200** can transmit an initiate diagnostic link mode message to the remote terminal modem **300**. If the initiate diagnostic link mode message is received by the central office **200**, the diagnostic device **330**, in cooperation with the message determination device **310**, determines a diagnostic link message to be forwarded to the central office **200**. For example, the diagnostic link message can include test information that has been assembled during, for example, the normal ADSL initialization procedure. The diagnostic and/or test information can include, but is not

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limited to, the version number of the diagnostic link mode, the length of the diagnostic and/or test information, the communications standard, such as the ADSL standard, the chipset type, the vendor identifications, the ATU version number, the time domain received reverb signal, the frequency domain reverb signal, the amplifier settings, the CO transmitter power spectral density, the frequency domain received idle channel, the signal to noise ratio, the bits and gains and the upstream and downstream transmission rates, or the like.

If the initiate diagnostic link mode message is not received by the central office **200**, the initiate diagnostic link mode message can, for example, be re-transmitted a predetermined number of iterations until a determination is made that it is not possible to establish a connection.

Assuming the initiate diagnostic link mode message is received, then, for a predetermined number of iterations, the diagnostic device **330**, in cooperation with the remote terminal modem **300** and the diagnostic information storage device **340**, transmits the diagnostic link message with a cyclic redundancy check (CRC) to the central office modem **200**. However, it is to be appreciated that in general, any error detection scheme, such as bit error detection, can be used without affecting the operation of the system. The central office **200**, in cooperation with the CRC checker **210**, determines if the CRC is correct. If the CRC is correct, the diagnostic information stored in the diagnostic information storage device **340** has been, with the cooperation of the diagnostic device **330**, and the remote terminal modem **300**, forwarded to the central office **200** successfully.

If, for example, the CRC checker **210** is unable to determine the correct CRC, the diagnostic device **330**, in cooperation with power control device **320**, increases the transmission power of the remote terminal **300** and repeats the transmission of the diagnostic link message from the remote terminal **300** to the central office **200**. This process continues until the correct CRC is determined by the CRC checker **210**.

The maximum power level used for transmission of the diagnostic link message can be specified by, for example, the user or the ADSL service operator. If the CRC checker **210** does not determine a correct CRC at the maximum power level and the diagnostic link mode can not be initiated then other methods for determining diagnostic information are utilized, such as dispatching a technician to the remote site, or the like.

Alternatively, the remote terminal **300**, with or without an increase in the power level, can transmit the diagnostic link message several times, for example, 4 times. By transmitting the diagnostic link message several times, the CO modem **200** can use, for example, a diversity combining scheme to improve the probability of obtaining a correct CRC from the received diagnostic link message(s).

Alternatively, as previously discussed, the central office **200** comprises a diagnostic information monitoring device **230**. The remote terminal **300** can also include a diagnostic information monitoring device. One or more of these diagnostic information monitoring devices can monitor the normal steady state data transmission between the remote terminal **300** and the central office **200**. Upon, for example, the normal steady state data transmission exceeded a predetermined error threshold, the diagnostic information monitoring device can initiate the diagnostic link mode with the cooperation of the diagnostic device **300** and/or the diagnostic device **220**.

FIG. 2 illustrates an exemplary method for entering a diagnostic link mode in accordance with this invention. In particular, control begins in step **S100** and continues to step **S110**. In step **S110**, the initialization sequence is commenced.

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Next, in step S120, if an initialization failure is detected, control continues to step S170. Otherwise, control jumps to step S130. In step S130, a determination is made whether the diagnostic link mode has been selected. If the diagnostic link mode has been selected, control continues to step S170, otherwise, control jumps to step S140.

In step S170, the initiate diagnostic link mode message is transmitted from, for example, the remote terminal to the central office. Next, in step S180, a determination is made whether the initiate diagnostic mode message has been received by the CO. If the initiate diagnostic mode message has been received by the CO, control jumps to step S200. Otherwise, control continues to step S190. In step S190, a determination is made whether to re-transmit the initiate diagnostic mode message, for example, based on whether a predetermined number of iterations have already been completed. If the initiate diagnostic mode message is to be re-transmitted, control continues back to step S170. Otherwise, control jumps to step S160.

In step S200, the diagnostic link message is determined, for example, by assembling test and diagnostic information about one or more of the local loop, the modem itself, the telephone network at the remote terminal, or the like. Next, in step S210, for a predetermined number of iterations, steps S220-S240 are completed. In particular, in step S220 a diagnostic link message comprising a CRC is transmitted to, for example, the CO. Next, in step S230, the CRC is determined. Then, in step S240, a determination is made whether the CRC is correct. If the CRC is correct, the test and/or diagnostic information has been successfully communicated and control continues to step S160.

Otherwise, if step S210 has completed the predetermined number of iterations, control continues to step S250. In step S250, the transmission power is increased and control continues back to step S210. Alternatively, as previously discussed, the diagnostic link message may be transmitted a predetermined number of times, with or without a change in the transmission power.

In step S140, the normal steady state data transmission is entered into between two modems, such as the remote terminal and the central office modems. Next, in step S150, a determination is made whether an error threshold during the normal steady state data transmission has been exceeded. If the error threshold has been exceeded, control continues to step S170. Otherwise, control jumps to step S160. In step S160, the control sequence ends.

As shown in FIG. 1, the diagnostic link mode system can be implemented either on a single program general purpose computer, a modem, such as a DSL modem, or a separate program general purpose computer having a communications device. However, the diagnostic link system can also be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element, an ASIC or other integrated circuit, a digital signal processor, a hardwired electronic or logic circuit such as a discrete element circuit, a programmed logic device such as a PLD, PLA, FPGA, PAL, or the like, and associated communications equipment. In general, any device capable of implementing a finite state machine that is capable of implementing the flowchart illustrated in FIG. 2 can be used to implement a diagnostic link system according to this invention.

Furthermore, the disclosed method may be readily implemented in software using object or object-oriented software development environments that provide portable source code that can be used on a variety of computer, workstation, or modem hardware platforms. Alternatively, the disclosed

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diagnostic link system may be implemented partially or fully in hardware using standard logic circuits or a VLSI design. Other software or hardware can be used to implement the systems in accordance with this invention depending on the speed and/or efficiency requirements of the systems, the particular function, and a particular software or hardware systems or microprocessor or microcomputer systems being utilized. The diagnostic link system and methods illustrated herein however, can be readily implemented in hardware and/or software using any known or later developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

Moreover, the disclosed methods can be readily implemented as software executed on a programmed general purpose computer, a special purpose computer, a microprocessor, or the like. In these instances, the methods and systems of this invention can be implemented as a program embedded on a modem, such as a DSL modem, as a resource residing on a personal computer, as a routine embedded in a dedicated diagnostic link system, a central office, or the like. The diagnostic link system can also be implemented by physically incorporating the system and method into a software and/or hardware system, such as a hardware and software systems of a modem, a general purpose computer, an ADSL line testing device, or the like.

It is, therefore, apparent that there is provided in accordance with the present invention, systems and methods for transmitting a diagnostic link message. While this invention has been described in conjunction with a number of embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable arts. Accordingly, applicants intend to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and the scope of this invention.

What is claimed is:

1. In a multicarrier modulation transceiver, a method of communicating diagnostic information over a communication channel using multicarrier modulation comprising:

transmitting or receiving at the multicarrier modulation transceiver an initiate diagnostic mode message; and
transmitting from the multicarrier modulation transceiver a diagnostic message using multicarrier modulation, wherein the diagnostic message comprises a plurality of data variables representing the diagnostic information about the communication channel and each bit in the diagnostic message is mapped to at least one DMT symbol, and wherein one variable comprises an array representing frequency domain received idle channel noise information.

2. The method of claim 1, wherein the initiate diagnostic mode message is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request and a CO technician request.

3. The method of claim 1, wherein the diagnostic message comprises diagnostic information about the communication channel including at least one of a length of the diagnostic information, a time domain received reverber signal, a frequency domain reverber signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and or downstream transmission rates.

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4. The method of claim 1, wherein the transceiver is a central office modem or a remote terminal modem.

5. A diagnostic system capable of communicating diagnostic information over a communication channel using multicarrier modulation comprising:

a transceiver capable of transmitting or receiving an initiate diagnostic mode message; and

a message determination module capable of determining and, in cooperation with the transceiver, transmitting a diagnostic message from the transceiver, wherein the diagnostic message comprises a plurality of data variables representing the diagnostic information about the communication channel and each bit in the diagnostic message is mapped to at least one DMT signal, and wherein one variable comprises an array representing frequency domain received idle channel noise information.

6. The system of claim 5, wherein the initiate diagnostic mode message is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request and a CO technician request.

7. The system of claim 5, wherein the diagnostic message comprises diagnostic information about the communication channel including at least one of a length of the diagnostic information, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and or downstream transmission rates.

8. The system of claim 5, wherein the transceiver is a central office modem or a remote terminal modem.

9. A multicarrier communication transceiver capable of communicating diagnostic information over a communication channel using multicarrier modulation comprising:

means for transmitting or receiving at the multicarrier communication transceiver an initiate diagnostic mode message; and

means for transmitting from the multicarrier communication transceiver a diagnostic message using multicarrier modulation, wherein the diagnostic message comprises a plurality of data variables representing the diagnostic information about the communication channel and each bit in the diagnostic message is mapped to at least one DMT symbol, and wherein one variable comprises an array representing frequency domain received idle channel noise information.

10. The transceiver of claim 9, wherein the initiate diagnostic mode message is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request and a CO technician request.

11. The transceiver of claim 9, wherein the diagnostic message comprises diagnostic information about the communication channel including at least one of a length of the diagnostic information, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and or downstream transmission rates.

12. The transceiver of claim 9, wherein the transceiver is a central office modem or a remote terminal modem.

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13. In a multicarrier communication transceiver, a protocol for communicating diagnostic information over a communication channel using multicarrier modulation comprising:

transmitting or receiving at the multicarrier communication transceiver an initiate diagnostic mode message; and

transmitting from the multicarrier communication transceiver a diagnostic message using multicarrier modulation, wherein the diagnostic message comprises a plurality of data variables representing the diagnostic information about the communication channel and each bit in the diagnostic message is mapped to at least one DMT symbol, and wherein one variable comprises an array representing frequency domain received idle channel noise information.

14. The protocol of claim 13, wherein the initiate diagnostic mode message is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request and a CO technician request.

15. The protocol of claim 13, wherein the diagnostic message comprises diagnostic information about the communication channel including at least one of a length of the diagnostic information, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and or downstream transmission rates.

16. The protocol of claim 13, wherein the transceiver is a central office modem or a remote terminal modem.

17. An information storage media comprising instructions that when executed communicate diagnostic information over a communication channel using multicarrier modulation comprising:

instructions that when executed direct a transceiver to receive or transmit an initiate diagnostic mode message; and

instructions that when executed transmit a diagnostic message from the transceiver using multicarrier modulation, wherein the diagnostic message comprises a plurality of data variables representing the diagnostic information about the communication channel and each bit in the diagnostic message is mapped to at least one DMT symbol, and wherein one variable comprises an array representing frequency domain received idle channel noise information.

18. The media of claim 17, wherein the initiate diagnostic mode message is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request and a CO technician request.

19. The media of claim 17, wherein the diagnostic message comprises diagnostic information about the communication channel including at least one of a length of the diagnostic information, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and or downstream transmission rates.

20. In a multicarrier modulation transceiver, a method of communicating diagnostic information over a communication channel using multicarrier modulation comprising:

transmitting or receiving at the multicarrier modulation transceiver an initiate diagnostic mode message; and

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transmitting from the multicarrier modulation transceiver a diagnostic message using multicarrier modulation with DMT symbols that are mapped to one bit of the diagnostic message, wherein the diagnostic message comprises a plurality of data variables representing the diagnostic information about the communication channel, and wherein one variable comprises an array representing frequency domain received idle channel noise information.

21. The method of claim 20, wherein the initiate diagnostic mode message is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request and a CO technician request.

22. The method of claim 20, wherein the diagnostic message comprises diagnostic information about the communication channel including at least one of a length of the diagnostic information, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and or downstream transmission rates.

23. The method of claim 20, wherein the transceiver is a central office modem or a remote terminal modem.

24. A diagnostic system capable of communicating diagnostic information over a communication channel using multicarrier modulation comprising:

a transceiver capable of transmitting or receiving an initiate diagnostic mode message; and

a message determination module capable of determining and, in cooperation with the transceiver, transmitting from the transceiver a diagnostic message using multicarrier modulation with DMT symbols that are mapped to one bit of the diagnostic message, wherein the diagnostic message comprises a plurality of data variables representing the diagnostic information about the communication channel, and wherein one variable comprises an array representing frequency domain received idle channel noise information.

25. The system of claim 24, wherein the initiate diagnostic mode message is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request and a CO technician request.

26. The system of claim 24, wherein the diagnostic message comprises diagnostic information about the communication channel including at least one of a length of the diagnostic information, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and or downstream transmission rates.

27. The system of claim 24, wherein the transceiver is a central office modem or a remote terminal modem.

28. A multicarrier communication transceiver capable of communicating diagnostic information over a communication channel using multicarrier modulation comprising:

means for transmitting or receiving at the multicarrier communication transceiver an initiate diagnostic mode message; and

means for transmitting from the multicarrier communication transceiver a diagnostic message using multicarrier modulation with DMT symbols that are mapped to one

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bit of the diagnostic message, wherein the diagnostic message comprises a plurality of data variables representing the diagnostic information about the communication channel, and wherein one variable comprises an array representing frequency domain received idle channel noise information.

29. The transceiver of claim 28, wherein the initiate diagnostic mode message is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request and a CO technician request.

30. The transceiver of claim 28, wherein the diagnostic message comprises diagnostic information about the communication channel including at least one of a length of the diagnostic information, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and or downstream transmission rates.

31. The transceiver of claim 28, wherein the transceiver is a central office modem or a remote terminal modem.

32. In a multicarrier communication transceiver, a protocol for communicating diagnostic information over a communication channel using multicarrier modulation comprising:

transmitting or receiving at the multicarrier communication transceiver an initiate diagnostic mode message; and

transmitting from the multicarrier communication transceiver a diagnostic message using multicarrier modulation with DMT symbols that are mapped to one bit of the diagnostic message, wherein the diagnostic message comprises a plurality of data variables representing the diagnostic information about the communication channel, and wherein one variable comprises an array representing frequency domain received idle channel noise information.

33. The protocol of claim 32, wherein the initiate diagnostic mode message is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request and a CO technician request.

34. The protocol of claim 32, wherein the diagnostic message comprises diagnostic information about the communication channel including at least one of a length of the diagnostic information, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and or downstream transmission rates.

35. The protocol of claim 32, wherein the transceiver is a central office modem or a remote terminal modem.

36. An information storage media comprising instructions that when executed communicate diagnostic information over a communication channel using multicarrier modulation comprising:

instructions that when executed direct a transceiver to receive or transmit an initiate diagnostic mode message; and

instructions that when executed transmit from the transceiver a diagnostic message using multicarrier modulation with DMT symbols that are mapped to one bit of the diagnostic message, wherein the diagnostic message comprises a plurality of data variables representing the

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diagnostic information about the communication channel, and wherein one variable comprises an array representing frequency domain received idle channel noise information.

37. The media of claim 36, wherein the initiate diagnostic mode message is based on at least one of an initialization failure, a bit rate failure, a CRC error in an initialization message, a CRC error during the normal steady state transmission mode, a forward error correction error, a user request and a CO technician request.

38. The media of claim 36, wherein the diagnostic message comprises diagnostic information about the communication channel including at least one of a length of the diagnostic information, a time domain received reverb signal, a frequency domain reverb signal, an amplifier setting, a CO transmitter power spectral density, a frequency domain received idle channel, a signal to noise ratio, bits and gain information, and upstream and or downstream transmission rates.

39. In a multicarrier modulation transceiver, a method of communicating diagnostic information including a plurality of data variables over a communication channel using multicarrier modulation comprising:

associating, at said transceiver in a diagnostic message and based on an initiate diagnostic mode message, each bit in the diagnostic message with at least one DMT symbol,

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wherein one variable comprises an array representing frequency domain received idle channel noise information.

40. In a multicarrier modulation transceiver, a method of communicating diagnostic information over a communication channel using multicarrier modulation comprising:

transmitting, during a diagnostic mode, a diagnostic message using multicarrier modulation, wherein the diagnostic message comprises a plurality of data variables representing the diagnostic information about the communication channel and at least one bit in the diagnostic message is mapped to at least one DMT symbol, wherein one variable comprises an array representing frequency domain received idle channel noise information.

41. Communicating diagnostic information over a communication channel using multicarrier modulation comprising:

communicating from a transceiver a diagnostic message comprising a plurality of data variables representing the diagnostic information, wherein each bit in the diagnostic message is mapped to at least one DMT symbol, wherein one variable comprises an array representing frequency domain received idle channel noise information.

* * * * *

EXHIBIT 3

(12) **United States Patent**
Tzannes et al.

(10) **Patent No.:** **US 7,844,882 B2**
(45) **Date of Patent:** ***Nov. 30, 2010**

(54) **RESOURCE SHARING IN A
TELECOMMUNICATIONS ENVIRONMENT**

(75) Inventors: **Marcos C. Tzannes**, Orinda, CA (US);
Michael Lund, West Newton, MA (US)

(73) Assignee: **Aware, Inc.**, Bedford, MA (US)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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Related U.S. Application Data

(63) Continuation of application No. 11/246,163, filed on Oct. 11, 2005.
(60) Provisional application No. 60/618,269, filed on Oct. 12, 2004.

(51) **Int. Cl.**
H03M 13/00 (2006.01)
(52) **U.S. Cl.** **714/774; 714/784; 375/222**
(58) **Field of Classification Search** 709/215;
375/222; 714/774, 784; 711/147, 153, 157,
711/170, 173; 379/93.01
See application file for complete search history.

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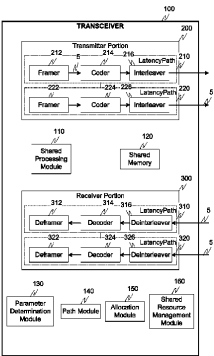
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Primary Examiner—Joon H Hwang
Assistant Examiner—Mark Pfizenmayer
(74) *Attorney, Agent, or Firm*—Jason H. Vick; Sheridan Ross, P.C.

(57) **ABSTRACT**

A transceiver is designed to share memory and processing power amongst a plurality of transmitter and/or receiver latency paths, in a communications transceiver that carries or supports multiple applications. For example, the transmitter and/or receiver latency paths of the transceiver can share an interleaver/deinterleaver memory. This allocation can be done based on the data rate, latency, BER, impulse noise protection requirements of the application, data or information being transported over each latency path, or in general any parameter associated with the communications system.

16 Claims, 3 Drawing Sheets



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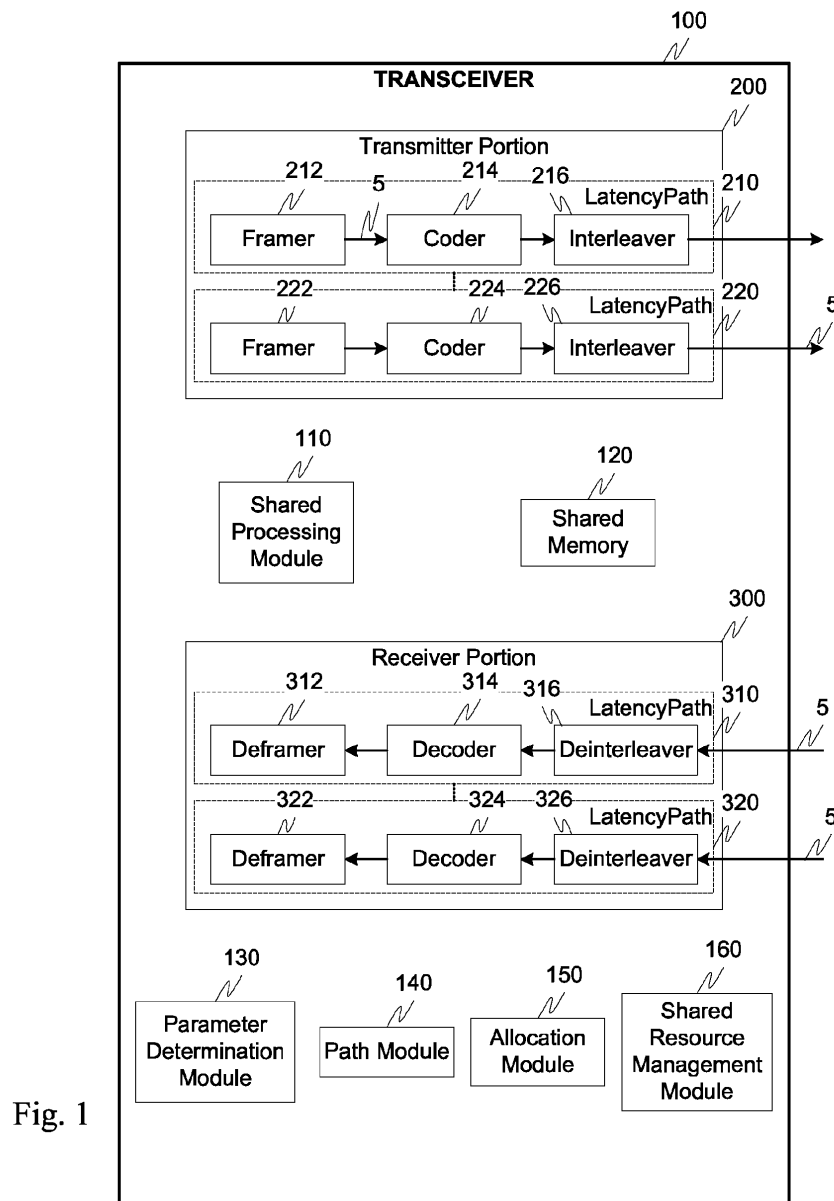


Fig. 1

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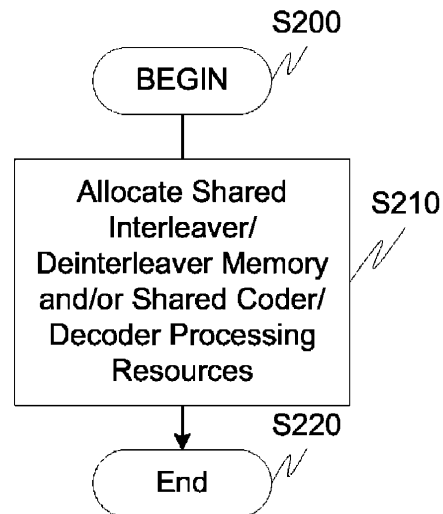


Fig. 2

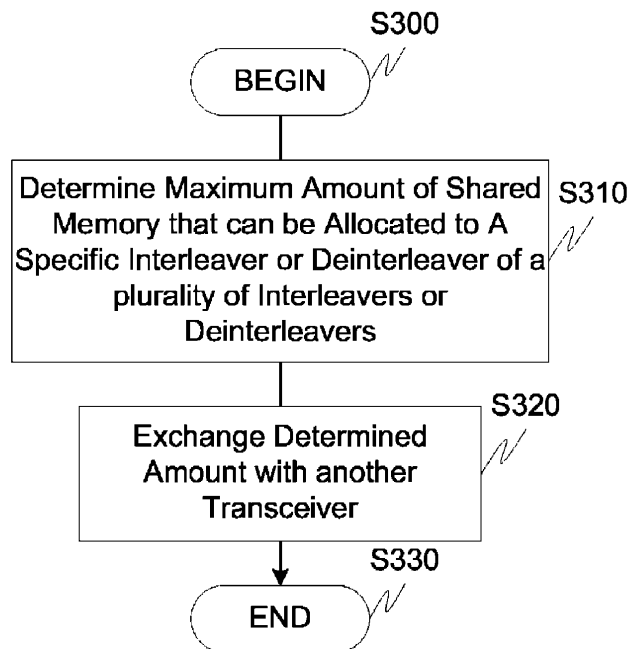


Fig. 3

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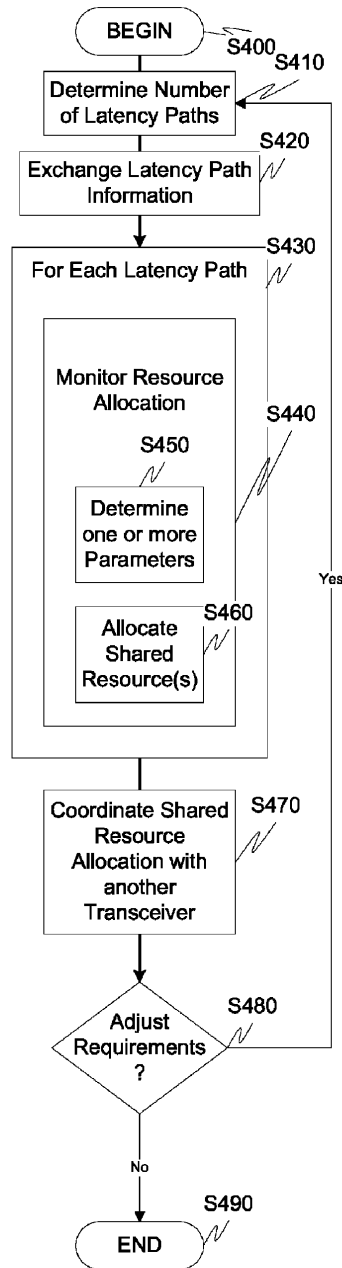


Fig. 4

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RESOURCE SHARING IN A TELECOMMUNICATIONS ENVIRONMENT

RELATED APPLICATION DATA

This application is a Continuation of U.S. application Ser. No. 11/246,163 filed Oct. 11, 2005, which claims the benefit of and priority under 35 U.S.C. § 119(e) to U.S. Patent Application No. 60/618,269, filed Oct. 12, 2004, entitled "Sharing Memory and Processing Resources in DSL Systems," each of which are incorporated herein by reference in their entirety.

BACKGROUND

1. Field of the Invention

This invention generally relates to communication systems. More specifically, an exemplary embodiment of this invention relates to memory sharing in communication systems. Another exemplary embodiment relates to processing or coding resource sharing in a communication system.

2. Description of Related Art

U.S. Pat. Nos. 6,775,320 and 6,778,589 describe DSL systems supporting multiple applications and multiple framer/coder/interleaver FCI blocks (an FCI block is also referred to as a latency path). DSL systems carry applications that have different transmission requirements with regard to, for example, data rate, latency (delay), bit error rate (BER), and the like. For example, video typically requires a low BER ($<1E-10$) but can tolerate higher latency (>20 ms). Voice, on the other hand, typically requires a low latency (<1 ms) but can tolerate BER ($>1E-3$).

As described in U.S. Pat. No. 6,775,320, different applications can use different latency paths in order to satisfy the different application requirements of the communication system. As a result a transceiver must support multiple latency paths in order to support applications such as video, Internet access and voice telephony. When implemented in a transceiver, each of the latency paths will have a framer, coder, and interleaver block with different capabilities that depend on the application requirements.

SUMMARY

One difficulty with implementing multiple latency paths in a transceiver is the fact that a latency path is a complicated digital circuit that requires a large amount of memory and processing power. An interleaver within a latency path can consume a large amount of memory in order to provide error correcting capability. For example, a typical DSL transceiver will have at least one latency path with approximately 16 kbytes of memory for the interleaver. Likewise, the coding block, for example, a Reed Solomon coder, consumes a large amount of processing power. In general, as the number of latency paths increase, the memory and processing power requirements for a communication system become larger.

Accordingly, an exemplary aspect of this invention relates to sharing memory between one or more interleavers and/or deinterleavers in a transceiver. More particularly, an exemplary aspect of this invention relates to shared latency path memory in a transceiver.

Additional aspects of this invention relate to configuring and initializing shared memory in a communication system. More particularly, an exemplary aspect of this invention relates to configuring and initializing interleaver/deinterleaver memory in a communication system.

Additional aspects of the invention relate to determining the amount of memory that can be allocated to a particular

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component by a communication system. More specifically, an exemplary aspect of the invention relates to determining the maximum amount of shared memory that can be allocated to one or more interleaves or deinterleavers.

According to another exemplary aspect of the invention, processing power is shared between a number of transceiver modules. More specifically, and in accordance with an exemplary embodiment of the invention, a coding module is shared between one or more coders and/or decoders.

Another exemplary embodiment of the invention relates to transitioning from a fixed memory configuration to a shared memory configuration during one or more of initialization and SHOWTIME (user data transmission).

An additional exemplary aspect of the invention relates to dynamically updating one or more of shared memory and processing resources based on changing communication conditions.

An additional exemplary aspect of the invention relates to updating one or more of shared memory and processing resources based on an updated communication parameter.

An additional exemplary aspect of the invention relates to updating the allocation of one or more of shared memory and processing resources based on an updated communication parameter(s).

Additional aspects of the invention relate to exchanging shared resource allocations between transceivers.

Additional exemplary aspects relate to a method of allocating shared memory in a transceiver comprising allocating the shared memory to a plurality of modules, wherein each of the plurality of modules comprise at least one interleaver, at least one deinterleaver or a combination thereof.

Still further aspects relate to the above method wherein the plurality of modules comprise interleavers.

Still further aspects relate to the above method wherein the plurality of modules comprise deinterleavers.

Still further aspects relate to the above method wherein the plurality of modules comprise at least one interleaver and at least one deinterleaver.

Additional exemplary aspects relate to a transceiver comprising a plurality of modules each including at least one interleaver, at least one deinterleaver or a combination thereof and a shared memory designed to be allocated to a plurality of the modules.

Still further aspects relate to the above transceiver wherein the plurality of modules comprise interleavers.

Still further aspects relate to the above transceiver wherein the plurality of modules comprise deinterleavers.

Still further aspects relate to the above transceiver wherein the plurality of modules comprise at least one interleaver and at least one deinterleaver.

These and other features and advantages of this invention are described in, or are apparent from, the following description of the embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the invention will be described in detail, with reference to the following figures, wherein:

FIG. 1 is a functional block diagram illustrating an exemplary transceiver according to this invention;

FIG. 2 is a flowchart outlining an exemplary method of sharing resources according to this invention;

FIG. 3 is a flowchart outlining an exemplary method of determining a maximum amount of shared memory according to this invention; and

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FIG. 4 is a flowchart outlining an exemplary resource sharing methodology according to this invention.

DETAILED DESCRIPTION

The exemplary embodiments of this invention will be described in relation to sharing resources in a wired and/or wireless communications environment. However, it should be appreciated, that in general, the systems and methods of this invention will work equally well for any type of communication system in any environment.

The exemplary systems and methods of this invention will also be described in relation to multicarrier modems, such as DSL modems and VDSL modems, and associated communication hardware, software and communication channels. However, to avoid unnecessarily obscuring the present invention, the following description omits well-known structures and devices that may be shown in block diagram form or otherwise summarized.

For purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the present invention. It should be appreciated however that the present invention may be practiced in a variety of ways beyond the specific details set forth herein.

Furthermore, while the exemplary embodiments illustrated herein show the various components of the system collocated, it is to be appreciated that the various components of the system can be located at distant portions of a distributed network, such as a telecommunications network and/or the Internet, or within a dedicated secure, unsecured and/or encrypted system. Thus, it should be appreciated that the components of the system can be combined into one or more devices, such as a modem, or collocated on a particular node of a distributed network, such as a telecommunications network. As will be appreciated from the following description, and for reasons of computational efficiency, the components of the system can be arranged at any location within a distributed network without affecting the operation of the system. For example, the various components can be located in a Central Office modem (CO, ATU-C, VTU-O), a Customer Premises modem (CPE, ATU-R, VTU-R), a DSL management device, or some combination thereof. Similarly, one or more functional portions of the system could be distributed between a modem and an associated computing device.

Furthermore, it should be appreciated that the various links, including communications channel 5, connecting the elements can be wired or wireless links, or any combination thereof, or any other known or later developed element(s) that is capable of supplying and/or communicating data to and from the connected elements. The term module as used herein can refer to any known or later developed hardware, software, firmware, or combination thereof that is capable of performing the functionality associated with that element. The terms determine, calculate and compute, and variations thereof, as used herein are used interchangeably and include any type of methodology, process, mathematical operation or technique. FCI block and latency path are used interchangeably herein as well as transmitting modem and transmitting transceiver. Receiving modem and receiving transceiver are also used interchangeably.

FIG. 1 illustrates an exemplary embodiment of a transceiver 100 that utilizes shared resources. It should be appreciated that numerous functional components of the transceiver have been omitted for clarity. However, the transceiver 100 can also include the standard components found in typical communications device(s) in which the technology of the subject invention is implemented into.

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According to an exemplary embodiment of the invention, memory and processing power can be shared among a plurality of transmitter and/or receiver latency paths, in a communications transceiver that carries or supports multiple applications. For example, the transmitter and/or receiver latency paths of the transceiver can share an interleaver/deinterleaver memory and the shared memory can be allocated to the interleaver and/or deinterleaver of each latency path. This allocation can be done based on the data rate, latency, BER, impulse noise protection requirements of the application, data or information being transported over each latency path, or in general any parameter associated with the communications system.

Likewise, for example, the transmitter and/or receiver latency paths can share a Reed-Solomon coder/decoder processing module and the processing power of this module can be allocated to each encoder and/or decoder. This allocation can be done based on the data rate/latency, BER, impulse noise protection requirements of the application data or information being transported over each latency path, or in general based on any parameter associated with the communication system.

In accordance with an exemplary operational embodiment, a first transceiver and a second transceiver transmit to one another messages during, for example, initialization which contain information on the total and/or shared memory capabilities of each transceiver and optionally information about the one or more latency paths. This information can be transmitted prior to determining how to configure the latency paths to support the application requirements. Based on this information, one of the modems can select an FCI configuration parameter(s) that meets the transmission requirements of each application being transported over each latency paths. While an exemplary of the embodiment of the invention will be described in relation to the operation of the invention and characteristics thereof being established during initialization, it should be appreciated that the sharing of resources can be modified and messages transmitted between a two transceivers at any time during initialization and/or user data transmission, i.e., SHOWTIME.

FIG. 1 illustrates an exemplary embodiment of a transceiver 100. The transceiver 100 includes a transmitter portion 200 and a receiver portion 300. The transmitter portion 200 includes one or more latency paths 210, 220, ... Similarly, the receiver portion 300 includes one or more latency paths 310, 320, ... Each of the latency paths in the transmitter portion 200 includes a framer, coder, and interleaver designated as 212, 214, 216 and 222, 224 and 226, respectively. Each of the latency paths in the receiver portion includes a deframer, decoder, and deinterleaver designated as 312, 314, 316 and 322, 324, and 326, respectively. The transceiver 100 further includes a shared processing module 110, a shared memory 120, a parameter determination module 130, a path module 140, an allocation module 150, and a shared resource management module 160, all interconnected by one or more links (not shown).

In this exemplary embodiment, the transceiver 100 is illustrated with four total transmitter portion and receiver portion latency paths, i.e., 210, 220, 310, and 320. The shared memory 120 is shared amongst the two transmitter portion interleavers 216 and 226 and two receiver portion deinterleavers 316 and 326. The shared processing module 110, such as a shared coding module, is shared between the two transmitter portion coders 214 and 224 and the two receiver portion decoders 314 and 324.

While the exemplary embodiment of the invention will be described in relation to a transceiver having a number of

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transmitter portion latency paths and receiver portion latency paths, it should be appreciated that this invention can be applied to any transceiver having any number of latency paths. Moreover, it should be appreciated that the sharing of resources can be allocated such that one or more of the transmitter portion latency paths are sharing a shared resource, one or more of the receiver portion latency paths are sharing a shared resource, or a portion of the transmitter portion latency paths and a portion of the receiver portion latency paths are sharing shared resources. Moreover, any one or more of the latency paths, or portions thereof, could also be assigned to a fixed resource while, for example, another portion of the latency path(s) assigned to a shared resource. For example, in latency path 210, the interleaver 216 could be allocated a portion of the shared memory 120, while the coder 214 could be allocated to a dedicated processing module, vice versa, or the like.

In accordance with the exemplary embodiment, a plurality of transmitter portion or receiver portion latency paths share an interleaver/deinterleaver memory, such as shared memory 120, and a coding module, such as shared processing module 110. For example, the interleaver/deinterleaver memory can be allocated to different interleavers and/or deinterleavers. This allocation can be based on parameters associated with the communication systems such as data rate, latency, BER, impulse noise protection, and the like, of the applications being transported. Similarly, a coding module, which can be a portion of the shared processing module 110, can be shared between any one or more of the latency paths. This sharing can be based on requirements such as data rate, latency, BER, impulse noise protection, and the like, of the applications being transported.

For example, an exemplary transceiver could comprise a shared interleaver/deinterleaver memory and could be designed to allocate a first portion of the shared memory 120 to an interleaver, such as interleaver 216 in the transmitter portion of the transceiver and allocate a second portion of the shared memory 120 to a deinterleaver, such as 316, in the receiver portion of the transceiver.

Alternatively, for example, an exemplary transceiver can comprise a shared interleaver/deinterleaver memory, such as shared memory 120, and be designed to allocate a first portion of shared memory 120 to a first interleaver, e.g., 216, in the transmitter portion of the transceiver and allocate a second portion of the shared memory to a second interleaver, e.g., 226, in the transmitter portion of the transceiver.

Alternatively, for example, an exemplary transceiver can comprise a shared interleaver/deinterleaver memory and be designed to allocate a first portion of the shared memory 120 to a first deinterleaver, e.g., 316, in the receiver portion of the transceiver and allocate a second portion of the shared memory to a second deinterleaver, e.g., 326, in the receiver portion of the transceiver. Regardless of the configuration, in general any interleaver or deinterleaver, or grouping thereof, be it in a transmitter portion or receiver portion of the transceiver, can be associated with a portion of the shared memory 120.

Establishment, configuration and usage of shared resources is performed in the following exemplary manner. First, and in cooperation with the path module 140, the number of transmitter and receiver latency paths (N) is determined. The parameter determination module 130 then analyzes one or more parameters such as data rate, transmitter data rate, receiver data rate, impulse noise protection, bit error rate, latency, or the like. Based on one or more of these parameters, the allocation module 150 allocates a portion of the shared memory 120 to one or more of the interleaver

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and/or deinterleavers, or groupings thereof. This process continues until the memory allocation has been determined and assigned to each of the N latency paths.

Having determined the memory allocation for each of the latency paths, and in conjunction with the shared resource management 160, the transceiver 100 transmits to a second transceiver one or more of the number of latency paths (N), the maximum interleaver memory for any one or more of the latency paths and/or the maximum total and/or shared memory for all of the latency paths.

Three examples of sharing interleaver/deinterleaver memory and coding processing in a transceiver are described below. The latency paths in these examples can be in the transmitter portion of the transceiver or the receiver portion of the transceiver.

Example #1

A first transmitter portion or receiver portion latency path may carry data from a video application, which needs a very low BER but can tolerate higher latency. In this case, the video will be transported using an latency path that has a large amount of interleaving/deinterleaving and coding (also known as Forward Error Correction (FEC) coding). For example, the latency path may be configured with Reed-Solomon coding using a codeword size of 255 bytes (N=255) with 16 checkbytes (R=16) and interleaving/deinterleaving using an interleaver depth of 64 (D=64). This latency path will require $N \cdot D = 255 \cdot 64 = 16$ Kbytes of interleaver memory at the transmitter (or de-interleaver memory at the receiver). This latency path will be able to correct a burst of errors that is less than 512 bytes in duration.

A second transmitter portion or receiver portion latency path may carry an internet access application that requires a medium BER and a medium amount of latency. In this case, the internet access application will be transported using a latency path that has a medium amount of interleaving and coding. For example, the latency path may be configured with Reed-Solomon coding using a codeword size of 128 bytes (N=128) with 8 checkbytes (R=8) and interleaving using an interleaver depth of 16 (D=32). This latency path will require $N \cdot D = 128 \cdot 32 = 4$ Kbytes of interleaver memory and the same amount of deinterleaver memory. This latency path will be able to correct a burst of errors that is less than 128 bytes in duration.

A third transmitter portion or receiver portion latency path may carry a voice telephony application, which needs a very low latency but can tolerate BER. In this case, the video will be transported using an latency path that has a large amount of interleaving and coding. For example, the third transmitter portion or receiver portion latency path may be configured with no interleaving or coding which will result in the lowest possible latency through the latency path but will provide no error correction capability.

According to the principles of this invention, a system carrying the three applications described above in Example #1, would have three latency paths that share one memory space containing at least $(16+4) = 20$ Kbytes. The three latency paths also share a common coding block that is able to simultaneously encode (in the transmitter portion) or decode (in a receiver portion) two codewords with $N=255/R=16$ and $N=128/R=8$.

According to an exemplary embodiment of this invention, the latency paths can be reconfigured at initialization or during data transmission mode (also known as SHOWTIME in

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ADSL and VDSL transceivers). This would occur if, for example, the applications or application requirements were to change.

Example #2

If instead of 1 video application, 1 internet application and 1 voice application, there were 3 internet access applications then the transmitter portion and/or receiver portion latency paths would be reconfigured to utilize the shared memory and coding module in a different way. For example, the system could be reconfigured to have 3 transmitter portion or receiver portion latency paths, with each latency path being configured with Reed-Solomon coding using a codeword size of 128 bytes ($N=128$) with 8 checkbytes ($R=8$) and interleaving using an interleaver depth of 16 ($D=32$). Each latency path will require $N*D=128*32=4$ Kbytes of interleaver memory and each block will be able to correct a burst of errors that is less than 128 bytes in duration. Based on the example of carrying the three internet access applications described, the three latency path share one memory space containing at least $3*4=12$ Kbytes. Also the three latency paths share a common coding block that is able to simultaneously encode (on the transmitter side) or decode (on the receiver side) three codewords with $N=128/R=16$, $N=128/R=8$ and $N=128/R=8$.

Example #3

The system could be configured to carry yet another set of applications. For example, the latency paths could be configured to carry 2 video applications. In this case only 2 transmitter portion or receiver portion latency paths are needed, which means that the third latency path could be simply disabled. Also, assuming that the memory is constrained based on the first example above, then the maximum shared memory for these 2 latency paths is 20 kBytes. In this case, the system could be reconfigured to have 2 latency paths, with each block being configured with Reed-Solomon coding using a codeword size of 200 bytes ($N=200$) with 10 checkbytes ($R=10$) and interleaving/deinterleaving using an interleaver depth of 50 ($D=50$). Each latency path will require $N*D=200*50=10$ Kbytes of interleaver memory and each block will be able to correct a burst of errors that is less than 250 bytes in duration. This configuration results in 20K of shared memory for both latency paths, which is the same as in the first example. In order to stay within the memory constraints of the latency paths, the error correction capability for each latency path is decreased to 250 bytes from 512 bytes in Example #1.

Another aspect of this invention is the how FCI configuration information is transmitted between a first modem and a second modem. FCI configuration information will depend on the requirements of the applications being transported over the DSL connection. This information may need to be forwarded during initialization in order to initially configure the DSL connection. This information may also need to be forwarded during SHOWTIME in order to reconfigure the DSL connection based on a change in applications or the application requirements.

According to one embodiment, a first modem determines the specific FCI configuration parameters, e.g., N , D , R as defined above, needed to meet specific application requirements, such as latency, burst error correction capability, etc. In order to determine the FCI configuration parameters, the first modem must know what are the capabilities of a second modem. For example, the first modem must know how many latency paths (FCI blocks) the second modem can support.

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Also the first modem must know the maximum amount of interleaver memory for each transmitter latency path. In addition, since the transmitter latency paths may share a common memory space the first modem must know the total shared memory for all transmitter latency paths. This way the first modem will be able to choose a configuration that can meet application requirements and also meet the transmitter portion latency path capabilities of the second modem.

For example, using values from examples above, a first transceiver could send a message to a second transceiver during initialization or during SHOWTIME containing the following information:

Number of supported transmitter and receiver latency paths=3
 Max Interleaver Memory for latency path #1=16 Kbytes
 Max Interleaver Memory for latency path #2=16 Kbytes
 Max Interleaver Memory for latency path #3=16 Kbytes
 Maximum total/shared memory for all latency paths=20 kBytes

Based on this information, and the application requirements, the first transceiver would select latency path settings. For example, if the applications are 1 video, 1 internet access and 1 voice application, the first transceiver could configure 3 latency paths as follows:

latency path #1—Video: $N=255$, $R=16$, $D=64$

latency path #2—Video: $N=128$, $R=8$, $D=32$

latency path #3—Video: $N=0$, $R=0$, $D=1$ (no coding or interleaving)

This would result in a total interleaver memory of 20 kbytes.

Alternatively, if for example, there are only 2 video applications, the first transceiver could configure 2 latency paths as follows:

latency path #1—Video: $N=200$, $R=10$, $D=50$

latency path #2—Video: $N=200$, $R=10$, $D=50$

latency path #3—Video: $N=0$, $R=0$, $D=1$ (no coding or interleaving)

This would also result in a total interleaver memory of 20 kbytes.

Alternatively, the second transceiver can determine the specific FCI configuration parameters, e.g., N , D , R as defined above, needed to meet specific application requirements, such as latency, burst error correction capability, etc. As described above for the first transceiver, in order to determine the FCI configuration parameters, the second transceiver must first know what are the capabilities of the first transceiver. In this case, the first transceiver would send a message to the second transceiver containing the information described above and based on this information and the application requirements the second transceiver would select latency path settings.

FIG. 2 outlines an exemplary method of allocating shared memory in a transceiver. More specifically, control begins in step S200 and continues to step S210. In step S210, one or more of shared interleaver/deinterleaver memory and/or shared coder/decoder processing resources are allocated to one or more latency paths, in a transceiver. Control then continues to step S220 where the control sequence ends.

FIG. 3 outlines an exemplary method of exchanging shared resource allocations according to an exemplary embodiment of this invention. In particular, control begins in step S310. In step S310, a maximum amount of shared memory that can be allocated to a specific interleaver or deinterleaver of a plurality of interleavers or deinterleavers in a transceiver is determined. Next, in step S320, the determined maximum amount for one or more of the deinterleavers and/or interleavers is

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transmitted to another transceiver. Messages containing additional information can also be transmitted to the other transceiver and/or received from the other transceiver. Control then continues to step S330 where the control sequence ends.

FIG. 4 outlines an exemplary procedure for resource sharing according to an exemplary embodiment of this invention. In particular, control begins in step S400 and continues to step S410. In step S410, the number of latency paths are determined. Then, in step S420, the latency path information (FCI block information) is transmitted to another transceiver. Messages containing additional information can also be transmitted to the other transceiver and/or received from the other transceiver. This information can be used to, for example, assist with the determination of memory allocation in the transceiver. Moreover, the messages received from the other transceiver could specify what the memory allocation is to be based on, for example, the number of latency paths, memory allocation in the remote transceiver and required applications. Control then continues to step S430.

In step S430, and for each latency path, the steps in step 440 are performed.

In step S440, and while monitoring of allocation of resources is being performed, steps 450 and 460 are performed. More specifically, in step S450, one or more parameters associated with the communication system are determined. Then, in step S460, shared resources are allocated based on one or more of the communication parameters. Control then continues to step S470.

In step S470, the allocation of shared resources is communicated to another transceiver. Next, in step S480, a determination is made as to whether there is a change in communications that would require the adjustment of the shared resource allocation. Examples of changes in communications conditions include a change in applications being transported over the system and/or changes in the channel condition, etc. If adjustments are required, control jumps back to step S410. Otherwise, control jumps to step S490 where the control sequence ends.

The above-described system can be implemented on wired and/or wireless telecommunications devices, such as a modem, a multicarrier modem, a DSL modem, an ADSL modem, an XDSL modem, a VDSL modem, a linecard, test equipment, a multicarrier transceiver, a wired and/or wireless wide/local area network system, a satellite communication system, a modem equipped with diagnostic capabilities, or the like, or on a separate programmed general purpose computer having a communications device or in conjunction with any of the following communications protocols: CDSL, ADSL2, ADSL2+, VDSL1, VDSL2, HDSL, DSL Lite, IDSL, RADSL, SDSL, UDSL or the like.

Additionally, the systems, methods and protocols of this invention can be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element(s), an ASIC or other integrated circuit, a digital signal processor, a hard-wired electronic or logic circuit such as discrete element circuit, a programmable logic device such as PLD, PLA, FPGA, PAL, a modem, a transmitter/receiver, any comparable means, or the like. In general, any device capable of implementing a state machine that is in turn capable of implementing the methodology illustrated herein can be used to implement the various communication methods, protocols and techniques according to this invention.

Furthermore, the disclosed methods may be readily implemented in software using object or object-oriented software development environments that provide portable source code that can be used on a variety of computer or workstation

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platforms. Alternatively, the disclosed system may be implemented partially or fully in hardware using standard logic circuits or VLSI design. Whether software or hardware is used to implement the systems in accordance with this invention is dependent on the speed and/or efficiency requirements of the system, the particular function, and the particular software or hardware systems or microprocessor or microcomputer systems being utilized. The communication systems, methods and protocols illustrated herein can be readily implemented in hardware and/or software using any known or later developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

Moreover, the disclosed methods may be readily implemented in software that can be stored on a storage medium, executed on programmed general-purpose computer with the cooperation of a controller and memory, a special purpose computer, a microprocessor, or the like. In these instances, the systems and methods of this invention can be implemented as program embedded on personal computer such as an applet, JAVA® or CGI script, as a resource residing on a server or computer workstation, as a routine embedded in a dedicated communication system or system component, or the like. The system can also be implemented by physically incorporating the system and/or method into a software and/or hardware system, such as the hardware and software systems of a communications transceiver.

It is therefore apparent that there has been provided, in accordance with the present invention, systems and methods for sharing resources. While this invention has been described in conjunction with a number of embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable arts. Accordingly, it is intended to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and scope of this invention.

The invention claimed is:

1. A system for allocating shared memory comprising:

means for transmitting or receiving, by a transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver;

means for determining, at the transceiver, an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory;

means for allocating, in the transceiver, a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes specified in the message;

means for allocating, in the transceiver, a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate; and

means for interleaving the first plurality of RS coded data bytes within the shared memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver, wherein the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver.

2. The system of claim 1, wherein the determining is based on an impulse noise protection requirement.

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3. The system of claim 1, wherein the determining is based on a latency requirement.

4. The system of claim 1, wherein the determining is based on a bit error rate requirement.

5. A system for allocating shared memory comprising:

means for transmitting or receiving, by a transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver;

means for determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory;

means for allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message;

means for allocating, in the transceiver, a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes received at a second data rate; and

means for deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver, wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver.

6. The system of claim 5, wherein the determining is based on an impulse noise protection requirement.

7. The system of claim 5, wherein the determining is based on a latency requirement.

8. The system of claim 5, wherein the determining is based on a bit error rate requirement.

9. A system that allocates shared memory comprising:

a transceiver that performs:

transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver;

determining an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory;

allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for

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the interleaver does not exceed the maximum number of bytes specified in the message;

allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate; and interleaving the first plurality of RS coded data bytes within the shared memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver, wherein the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver.

10. The system of claim 9 wherein the determining is based on an impulse noise protection requirement.

11. The system of claim 9, wherein the determining is based on a latency requirement.

12. The system of claim 9, wherein the determining is based on a bit error rate requirement.

13. A system that allocates shared memory comprising:

a transceiver that performs:

transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver;

determining an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory;

allocating a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message;

allocating a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes received at a second data rate; and

deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver, wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver.

14. The system of claim 13, wherein the determining is based on an impulse noise protection requirement.

15. The system of claim 13, wherein the determining is based on a latency requirement.

16. The system of claim 13, wherein the determining is based on a bit error rate requirement.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 7,844,882 B2
APPLICATION NO. : 12/761586
DATED : November 30, 2010
INVENTOR(S) : Marcos C. Tzannes et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In column 11, claim 5, line 17, delete "transmission" and insert -- reception --

In column 11, claim 5, line 23, delete "received" and insert -- transmitted --

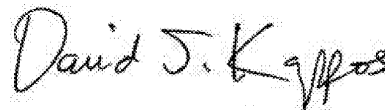
In column 11, claim 5, line 28, delete "shred" and insert -- shared --

In column 12, claim 13, line 29, delete "transmission" and insert -- reception --

In column 12, claim 13, line 35, delete "received" and insert -- transmitted --

In column 12, claim 13, line 40, delete "shred" and insert -- shared --

Signed and Sealed this
Third Day of May, 2011

A handwritten signature in black ink that reads "David J. Kappos". The signature is written in a cursive, flowing style.

David J. Kappos
Director of the United States Patent and Trademark Office

EXHIBIT 4



(12) **United States Patent**
Tzannes

(10) **Patent No.:** **US 8,090,008 B2**
(45) **Date of Patent:** ***Jan. 3, 2012**

(54) **SYSTEM AND METHOD FOR SCRAMBLING THE PHASE OF THE CARRIERS IN A MULTICARRIER COMMUNICATIONS SYSTEM**

(75) Inventor: **Marcos C. Tzannes**, Orinda, CA (US)

(73) Assignee: **Aware, Inc.**, Bedford, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 106 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/783,725**

(22) Filed: **May 20, 2010**

(65) **Prior Publication Data**
US 2010/0290507 A1 Nov. 18, 2010

Related U.S. Application Data

(63) Continuation of application No. 12/255,713, filed on Oct. 22, 2008, now Pat. No. 7,769,104, which is a continuation of application No. 11/863,581, filed on Sep. 28, 2007, now Pat. No. 7,471,721, which is a continuation of application No. 11/211,535, filed on Aug. 26, 2005, now Pat. No. 7,292,627, which is a continuation of application No. 09/710,310, filed on Nov. 9, 2000, now Pat. No. 6,961,369.

(60) Provisional application No. 60/164,134, filed on Nov. 9, 1999.

(51) **Int. Cl.**
H04B 1/38 (2006.01)
H04L 5/12 (2006.01)
H04L 27/36 (2006.01)

(52) **U.S. Cl.** **375/222; 375/261; 375/298**

(58) **Field of Classification Search** 375/219–220, 375/222, 259–262, 267, 295, 298–299, 320, 375/324, 340; 370/281, 295, 330, 343, 436, 370/478, 480–481; 455/73, 91, 108

See application file for complete search history.

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Primary Examiner — Tesfaldet Bocure

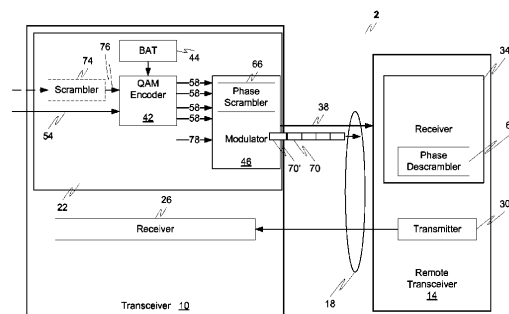
Assistant Examiner — Lawrence Williams

(74) *Attorney, Agent, or Firm* — Jason H. Vick; Sheridan Ross PC

(57) **ABSTRACT**

A system and method that scrambles the phase characteristic of a carrier signal are described. The scrambling of the phase characteristic of each carrier signal includes associating a value with each carrier signal and computing a phase shift for each carrier signal based on the value associated with that carrier signal. The value is determined independently of any input bit value carried by that carrier signal. The phase shift computed for each carrier signal is combined with the phase characteristic of that carrier signal so as to substantially scramble the phase characteristic of the carrier signals. Bits of an input signal are modulated onto the carrier signals having the substantially scrambled phase characteristic to produce a transmission signal with a reduced PAR.

26 Claims, 2 Drawing Sheets



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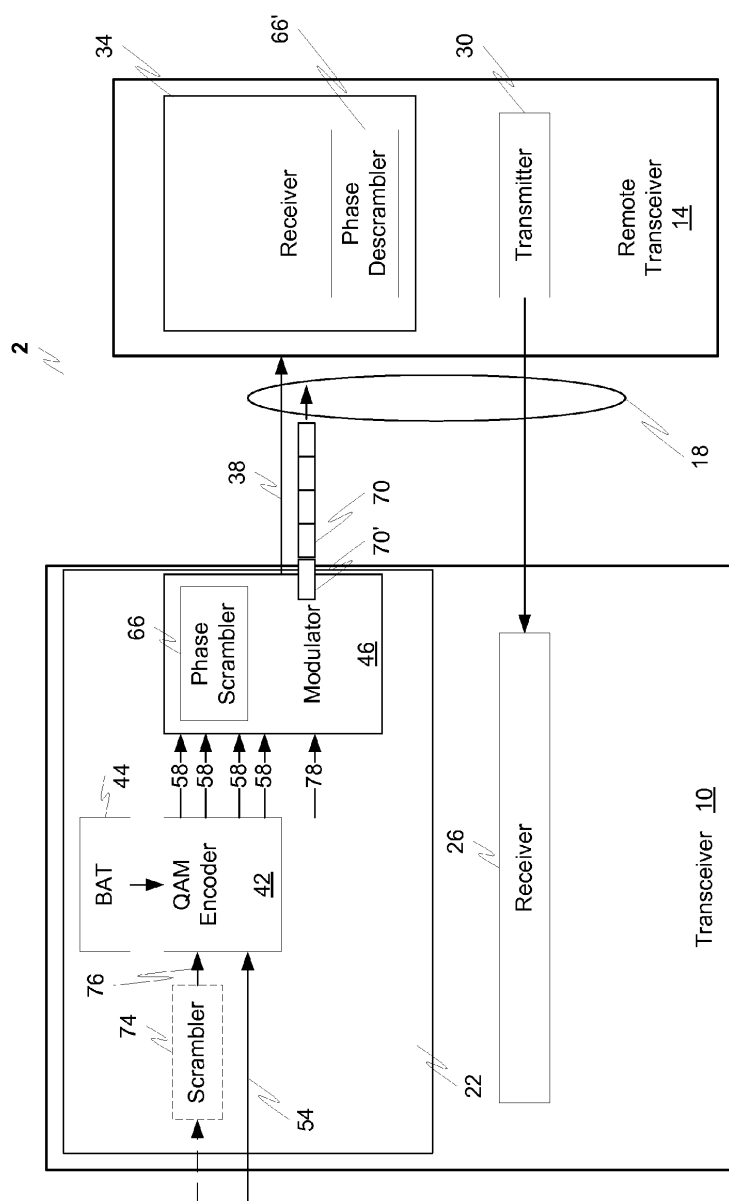


FIG. 1

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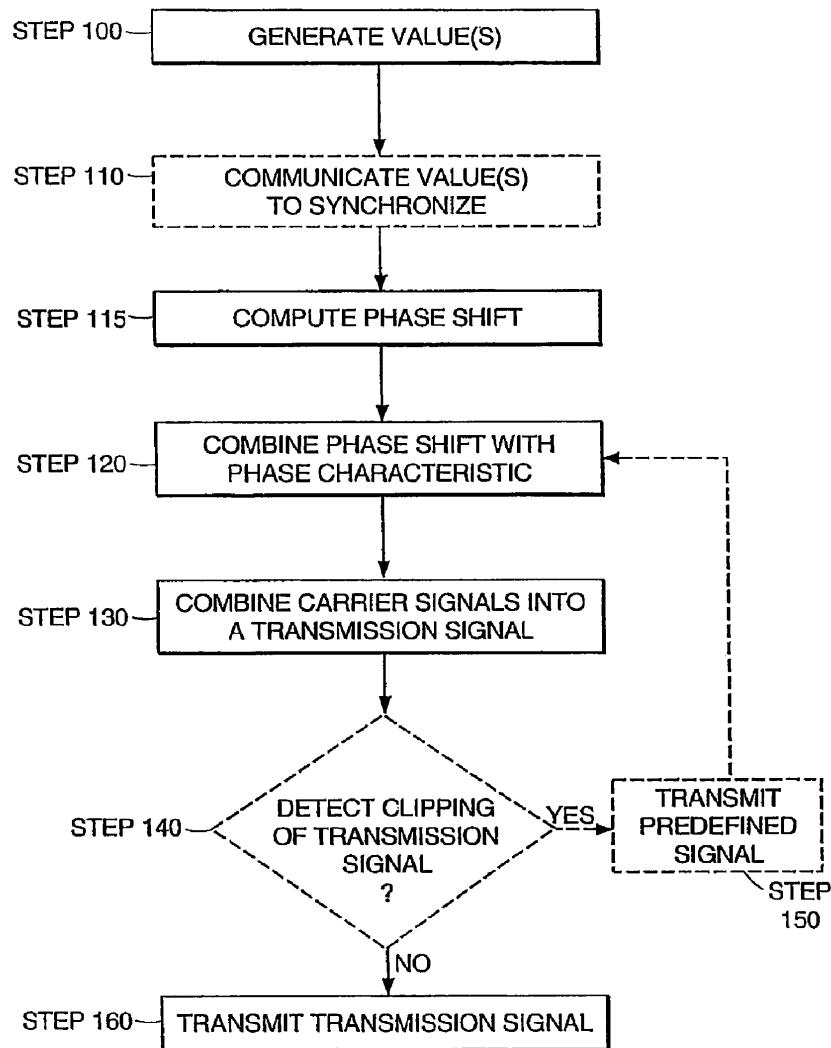


FIG. 2

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SYSTEM AND METHOD FOR SCRAMBLING THE PHASE OF THE CARRIERS IN A MULTICARRIER COMMUNICATIONS SYSTEM

RELATED APPLICATION

This application is a Continuation of U.S. patent application Ser. No. 12/255,713, filed Oct. 22, 2008, now U.S. Pat. No. 7,769,104, which is a Continuation of U.S. patent application Ser. No. 11/863,581, filed Sep. 28, 2007, now U.S. Pat. No. 7,471,721, which is a Continuation of U.S. application Ser. No. 11/211,535, filed Aug. 26, 2005, now U.S. Pat. No. 7,292,627, which is a Continuation of U.S. patent application Ser. No. 09/710,310, filed Nov. 9, 2000, now U.S. Pat. No. 6,961,369, which claims the benefit of the filing date of copending U.S. Provisional Application Ser. No. 60/164,134, filed Nov. 9, 1999, entitled "A Method For Randomizing The Phase Of The Carriers In A Multicarrier Communications System To Reduce The Peak To Average Power Ratio Of The Transmitted Signal," each of which are incorporated herein by reference in their entirety.

FIELD OF THE INVENTION

This invention relates to communications systems using multicarrier modulation. More particularly, the invention relates to multicarrier communications systems that lower the peak-to-average power ratio (PAR) of transmitted signals.

BACKGROUND OF THE INVENTION

In a conventional multicarrier communications system, transmitters communicate over a communication channel using multicarrier modulation or Discrete Multitone Modulation (DMT). Carrier signals (carriers) or sub-channels spaced within a usable frequency band of the communication channel are modulated at a symbol (i.e., block) transmission rate of the system. An input signal, which includes input data bits, is sent to a DMT transmitter, such as a DMT modem. The DMT transmitter typically modulates the phase characteristic, or phase, and amplitude of the carrier signals using an Inverse Fast Fourier Transform (IFFT) to generate a time domain signal, or transmission signal, that represents the input signal. The DMT transmitter transmits the transmission signal, which is a linear combination of the multiple carriers, to a DMT receiver over the communication channel.

The phase and amplitude of the carrier signals of DMT transmission signal can be considered random because the phase and amplitude result from the modulation of an arbitrary sequence of input data bits comprising the transmitted information. Therefore, under the condition that the modulated data bit stream is random, the DMT transmission signal can be approximated as having a Gaussian probability distribution. A bit scrambler is often used in the DMT transmitter to scramble the input data bits before the bits are modulated to assure that the transmitted data bits are random and, consequently, that the modulation of those bits produces a DMT transmission signal with a Gaussian probability distribution.

With an appropriate allocation of transmit power levels to the carriers or sub-channels, such a system provides a desirable performance. Further, generating a transmission signal with a Gaussian probability distribution is important in order to transmit a transmission signal with a low peak-to-average ratio (PAR), or peak-to-average power ratio. The PAR of a transmission signal is the ratio of the instantaneous peak value (i.e., maximum magnitude) of a signal parameter (e.g.,

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voltage, current, phase, frequency, power) to the time-averaged value of the signal parameter. In DMT systems, the PAR of the transmitted signal is determined by the probability of the random transmission signal reaching a certain peak voltage during the time interval required for a certain number of symbols. An example of the PAR of a transmission signal transmitted from a DMT transmitter is 14.5 dB, which is equivalent to having a 1E-7 probability of clipping. The PAR of a transmission signal transmitted and received in a DMT communication system is an important consideration in the design of the DMT communication system because the PAR of a signal affects the communication system's total power consumption and component linearity requirements of the system.

If the phase of the modulated carriers is not random, then the PAR can increase greatly. Examples of cases where the phases of the modulated carrier signals are not random are when bit scramblers are not used, multiple carrier signals are used to modulate the same input data bits, and the constellation maps, which are mappings of input data bits to the phase of a carrier signal, used for modulation are not random enough (i.e., a zero value for a data bit corresponds to a 90 degree phase characteristic of the DMT carrier signal and a one value for a data bit corresponds to a -90 degree phase characteristic of the DMT carrier signal). An increased PAR can result in a system with high power consumption and/or with high probability of clipping the transmission signal. Thus, there remains a need for a system and method that can effectively scramble the phase of the modulated carrier signals in order to provide a low PAR for the transmission signal.

SUMMARY OF THE INVENTION

The present invention features a system and method that scrambles the phase characteristics of the modulated carrier signals in a transmission signal. In one aspect, a value is associated with each carrier signal. A phase shift is computed for each carrier signal based on the value associated with that carrier signal. The value is determined independently of any input bit value carried by that carrier signal. The phase shift computed for each carrier signal is combined with the phase characteristic of that carrier signal to substantially scramble the phase characteristics of the carrier signals.

In one embodiment, the input bit stream is modulated onto the carrier signals having the substantially scrambled phase characteristic to produce a transmission signal with a reduced peak-to-average power ratio (PAR). The value is derived from a predetermined parameter, such as a random number generator, a carrier number, a DMT symbol count, a superframe count, and a hyperframe count. In another embodiment, a predetermined transmission signal is transmitted when the amplitude of the transmission signal exceeds a certain level.

In another aspect, the invention features a method wherein a value is associated with each carrier signal. The value is determined independently of any input bit value carried by that carrier signal. A phase shift for each carrier signal is computed based on the value associated with that carrier signal. The transmission signal is demodulated using the phase shift computed for each carrier signal.

In another aspect, the invention features a system comprising a phase scrambler that computes a phase shift for each carrier signal based on a value associated with that carrier signal. The phase scrambler also combines the phase shift computed for each carrier signal with the phase characteristic of that carrier signal to substantially scramble the phase characteristic of the carrier signals. In one embodiment, a modulator, in communication with the phase scrambler, modulates

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bits of an input signal onto the carrier signals having the substantially scrambled phase characteristics to produce a transmission signal with a reduced PAR.

DESCRIPTION OF THE DRAWINGS

The invention is pointed out with particularity in the appended claims. The advantages of the invention described above, as well as further advantages of the invention, may be better understood by reference to the following description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a block diagram of an embodiment of a digital subscriber line communications system including a DMT (discrete multitone modulation) transceiver, in communication with a remote transceiver, having a phase scrambler for substantially scrambling the phase characteristics of carrier signals; and

FIG. 2 is a flow diagram of an embodiment of a process for scrambling the phase characteristics of the carrier signals in a transmission signal.

DETAILED DESCRIPTION

FIG. 1 shows a digital subscriber line (DSL) communication system 2 including a discrete multitone (DMT) transceiver 10 in communication with a remote transceiver 14 over a communication channel 18 using a transmission signal 38 having a plurality of carrier signals. The DMT transceiver 10 includes a DMT transmitter 22 and a DMT receiver 26. The remote transceiver 14 includes a transmitter 30 and a receiver 34. Although described with respect to discrete multitone modulation, the principles of the invention apply also to other types of multicarrier modulation, such as, but not limited to, orthogonally multiplexed quadrature amplitude modulation (OQAM), discrete wavelet multitone (DWMT) modulation, and orthogonal frequency division multiplexing (OFDM).

The communication channel 18 provides a downstream transmission path from the DMT transmitter 22 to the remote receiver 34, and an upstream transmission path from the remote transmitter 30 to the DMT receiver 26. In one embodiment, the communication channel 18 is a pair of twisted wires that is one of a star quad cable, a Dieselhorst-Martin quad cable, and the like. In a wireless communication system wherein the transceivers 10, 14 are wireless modems, the communication channel 18 is the air through which the transmission signal 38 travels between the transceivers 10, 14.

By way of example, the DMT transmitter 22 shown in FIG. 1 includes a quadrature amplitude modulation (QAM) encoder 42, a modulator 46, a bit allocation table (BAT) 44, and a phase scrambler 66. The DMT transmitter 22 can also include a bit scrambler 74, as described further below. The remote transmitter 30 of the remote transceiver 14 comprises equivalent components as the DMT transmitter 22. Although this embodiment specifies a detailed description of the DMT transmitter 22, the inventive concepts apply also to the receivers 34, 24 which have similar components to that of the DMT transmitter 22, but perform inverse functions in a reverse order.

The QAM encoder 42 has a single input for receiving an input serial data bit stream 54 and multiple parallel outputs to transmit QAM symbols 58 generated by the QAM encoder 42 from the bit stream 54. In general, the QAM encoder 42 maps the input serial bit-stream 54 in the time domain into parallel

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QAM symbols 58 in the frequency domain. In particular, the QAM encoder 42 maps the input serial data bit stream 54 into N parallel quadrature amplitude modulation (QAM) constellation points 58, or QAM symbols 58, where N represents the number of carrier signals generated by the modulator 46. The BAT 44 is in communication with the QAM encoder 42 to specify the number of bits carried by each carrier signal. The QAM symbols 58 represent the amplitude and the phase characteristic of each carrier signal.

The modulator 46 provides functionality associated with the DMT modulation and transforms the QAM symbols 58 into DMT symbols 70 each comprised of a plurality of time-domain samples. The modulator 46 modulates each carrier signal with a different QAM symbol 58. As a result of this modulation, carrier signals have phase and amplitude characteristics based on the QAM symbol 58 and therefore based on the input-bit stream 54. In particular, the modulator 46 uses an inverse fast Fourier transform (IFFT) to change the QAM symbols 58 into a transmission signal 38 comprised of a sequence of DMT symbols 70. The modulator 46 changes the QAM symbols 58 into DMT symbols 70 through modulation of the carrier signals. In another embodiment, the modulator 46 uses the inverse discrete Fourier transform (IDFT) to change the QAM symbols 58 into DMT symbols 70. In one embodiment, a pilot tone is included in the transmission signal 38 to provide a reference signal for coherent demodulation of the carrier signals in the remote receiver 34 during reception of the transmission signal 38.

The modulator 46 also includes a phase scrambler 66 that combines a phase shift computed for each QAM-modulated carrier signal with the phase characteristic of that carrier signal. Combining phase shifts with phase characteristics, in accordance with the principles of the invention, substantially scrambles the phase characteristics of the carrier signals in the transmission signal 38. By scrambling the phase characteristics of the carrier signals, the resulting transmission signal 38 has a substantially minimized peak-to-average (PAR) power ratio. The phase scrambler 66 can be part of or external to the modulator 46. Other embodiments of the phase scrambler 66 include, but are not limited to, a software program that is stored in local memory and is executed on the modulator 46, a digital signal processor (DSP) capable of performing mathematical functions and algorithms, and the like. The remote receiver 34 similarly includes a phase descrambler 66' for use when demodulating carrier signals that have had their phase characteristics adjusted by the phase scrambler 66 of the DMT transceiver 10.

To compute a phase shift for each carrier signal, the phase scrambler 66 associates one or more values with that carrier signal. The phase scrambler 66 determines each value for a carrier signal independently of the QAM symbols 58, and, therefore, independently of the bit value(s) modulated onto the carrier signal. The actual value(s) that the phase scrambler 66 associates with each carrier signal can be derived from one or more predefined parameters, such as a pseudo-random number generator (pseudo-RNG), a DMT carrier number, a DMT symbol count, a DMT superframe count, a DMT hyperframe count, and the like, as described in more detail below. Irrespective of the technique used to produce each value, the same technique is used by the DMT transmitter 22 and the remote receiver 34 so that the value associated with a given carrier signal is known at both ends of the communication channel 18.

The phase scrambler 66 then solves a predetermined equation to compute a phase shift for the carrier signal, using the value(s) associated with that carrier signal as input that effects the output of the equation. Any equation suitable for comput-

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ing phase shifts can be used to compute the phase shifts. When the equation is independent of the bit values of the input serial bit stream 54, the computed phase shifts are also independent of such bit values.

In one embodiment (shown in phantom), the DMT transmitter 22 includes a bit scrambler 74, which receives the input serial bit stream 54 and outputs data bits 76 that are substantially scrambled. The substantially scrambled bits 76 are then passed to the QAM encoder 42. When the bit scrambler 74 is included in the DMT transmitter 22, the operation of the phase scrambler 66 further assures that the transmission signal 38 has a Gaussian probability distribution and, therefore, a substantially minimized PAR.

FIG. 2 shows embodiments of a process used by the DMT transmitter 22 for adjusting the phase characteristic of each carrier signal and combining these carrier signals to produce the transmission signal 38. The DMT transmitter 22 generates (step 100) a value that is associated with a carrier signal. Because the value is being used to alter the phase characteristics of the carrier signal, both the DMT transmitter 22 and the remote receiver 34 must recognize the value as being associated with the carrier signal. Either the DMT transmitter 22 and the remote receiver 34 independently derive the associated value, or one informs the other of the associated value. For example, in one embodiment the DMT transmitter 22 can derive the value from a pseudo-RNG and then transmit the generated value to the remote receiver 34. In another embodiment, the remote receiver 34 similarly derives the value from the same pseudo-RNG and the same seed as used by the transmitter (i.e., the transmitter pseudo-RNG produces the same series of random numbers as the receiver pseudo-RNG).

As another example, the DMT transmitter 22 and the remote receiver 34 can each maintain a symbol counter for counting DMT symbols. The DMT transmitter 22 increments its symbol counter upon transmitting a DMT symbol; the remote receiver 34 upon receipt. Thus, when the DMT transmitter 22 and the remote receiver 34 both use the symbol count as a value for computing phase shifts, both the DMT transmitter 22 and remote receiver 34 “know” that the value is associated with a particular DMT symbol and with each carrier signal of that DMT symbol.

Values can also be derived from other types of predefined parameters. For example, if the predefined parameter is the DMT carrier number, then the value associated with a particular carrier signal is the carrier number of that signal within the DMT symbol. The number of a carrier signal represents the location of the frequency of the carrier signal relative to the frequency of other carrier signals within a DMT symbol. For example, in one embodiment the DSL communication system 2 provides 256 carrier signals, each separated by a frequency of 4.3125 kHz and spanning the frequency bandwidth from 0 kHz to 1104 kHz. The DMT transmitter 22 numbers the carrier signals from 0 to 255. Therefore, “DMT carrier number 50” represents the 51st DMT carrier signal which is located at the frequency of 215.625 kHz (i.e., 51×4.3125 kHz).

Again, the DMT transmitter 22 and the remote receiver 34 can know the value that is associated with the carrier signal because both the DMT transmitter 22 and the remote receiver 34 use the same predefined parameter (here, the DMT carrier number) to make the value-carrier signal association. In other embodiments (as exemplified above with the transmitter pseudo-RNG), the DMT transmitter 22 can transmit the value to the remote receiver 34 (or vice versa) over the communication channel 18.

In other embodiments, other predefined parameters can be used in conjunction with the symbol count. One example of

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such a predefined parameter is the superframe count that increments by one every 69 DMT symbols. One exemplary implementation that achieves the superframe counter is to perform a modulo 68 operation on the symbol count. As another example, the DMT transmitter 22 can maintain a hyperframe counter for counting hyperframes. An exemplary implementation of the hyperframe count is to perform a modulo 255 operation on the superframe count. Thus, the hyperframe count increments by one each time the superframe count reaches 255.

Accordingly, it is seen that some predefined parameters produce values that vary from carrier signal to carrier signal. For example, when the predefined parameter is the DMT carrier number, values vary based on the frequency of the carrier signal. As another example, the pseudo-RNG generates a new random value for each carrier signal.

Other predefined parameters produce values that vary from DMT symbol 70 to DMT symbol 70. For example, when the predefined parameter is the symbol count, the superframe count, or hyperframe count, values vary based on the numerical position of the DMT symbol 70 within a sequence of symbols, superframes, or hyperframes. Predefined parameters such as the pseudo-RNG, symbol count, superframe count, and superframe can also be understood to be parameters that vary values over time. Any one or combination of the predefined parameters can provide values for input to the equation that computes a phase shift for a given carrier signal.

In one embodiment, the phase scrambling is used to avoid clipping of the transmission signal 38 on a DMT symbol 70 by DMT symbol 70 basis. In this embodiment, the DMT transmitter 22 uses a value based on a predefined parameter that varies over time, such as the symbol count, to compute the phase shift. It is to be understood that other types of predefined parameters that vary the values associated with carrier signals can be used to practice the principles of the invention. As described above, the transceivers 10, 14 may communicate (step 110) the values to synchronize their use in modulating and demodulating the carrier signals.

The DMT transmitter 22 then computes (step 115) the phase shift that is used to adjust the phase characteristic of each carrier signal. The amount of the phase shift combined with the phase characteristic of each QAM-modulated carrier signal depends upon the equation used and the one or more values associated with that carrier signal.

The DMT transmitter 22 then combines (step 120) the phase shift computed for each carrier signal with the phase characteristic of that carrier signal. By scrambling the phase characteristics of the carrier signals, the phase scrambler 66 reduces (with respect to unscrambled phase characteristics) the combined PAR of the plurality of carrier signals and, consequently, the transmission signal 38. The following three phase shifting examples, PS #1-PS #3, illustrate methods used by the phase scrambler 66 to combine a computed phase shift to the phase characteristic of each carrier signal.

Phase Shifting Example #1

Phase shifting example #1 (PS #1) corresponds to adjusting the phase characteristic of the QAM-modulated carrier signal associated with a carrier number N by

$$N \times \frac{\pi}{3},$$

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modulo (mod) 2π . In this example, a carrier signal having a carrier number N equal to 50 has a phase shift added to the phase characteristic of that carrier signal equal to

$$50 \times \frac{\pi}{3} (\text{mod} 2\pi) = \frac{2}{3}\pi.$$

The carrier signal with a carrier number N equal to 51 has a phase shift added to the phase characteristic of that carrier signal equal to

$$51 \times \frac{\pi}{3} (\text{mod} 2\pi) = \pi.$$

The carrier signal with the carrier number N equal to 0 has no phase shift added to the phase characteristic of that carrier signal.

Phase Shifting Example #2

Phase shifting example #2 (PS #2) corresponds to adjusting the phase characteristic of the QAM-modulated carrier signal associated with a carrier number N by

$$(N + M) \times \frac{\pi}{4},$$

mod 2π , where M is the symbol count. In this example, a carrier signal having a carrier number N equal to 50 on DMT symbol count M equal to 8 has a phase shift added to the phase characteristic of that carrier signal equal to

$$(50 + 8) \times \frac{\pi}{4} (\text{mod} 2\pi) = \frac{\pi}{2}.$$

The carrier signal with the same carrier number N equal to 50 on the next DMT symbol count M equal to 9 has a phase shift added to the phase characteristic of that carrier signal equal to

$$(50 + 9) \times \frac{\pi}{4} (\text{mod} 2\pi) = \frac{3\pi}{4}.$$

Phase Shifting Example #3

Phase shifting example #3 (PS #3) corresponds to adjusting the phase characteristic of the QAM-modulated carrier signal associated with a carrier number N by

$$(X_N) \times \frac{\pi}{6},$$

mod 2π , where X_N is an array of N pseudo-random numbers. In this example, a carrier signal having a carrier number N equal to 5 and X_N equal to [3, 8, 1, 4, 9, 5, ...] has a phase shift added to the phase characteristic of the carrier signal that is equal to

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$$(9) \times \frac{\pi}{6} (\text{mod} 2\pi) = \frac{3\pi}{2}$$

(Note that 9 is the 5th value in X_N .) The carrier signal with a carrier number N equal to 6 has a phase shift added to the phase characteristic of the carrier signal equal to

$$(5) \times \frac{\pi}{6} (\text{mod} 2\pi) = \frac{5\pi}{6}.$$

It is to be understood that additional and/or different phase shifting techniques can be used by the phase scrambler 66, and that PS #1, #2, and #3 are merely illustrative examples of the principles of the invention. The DMT transmitter 22 then combines (step 130) the carrier signals to form the transmission signal 38. If the transmission signal is not clipped, as described below, the DMT transmitter 22 consequently transmits (step 160) the transmission signal 38 to the remote receiver 34.

Clipping of Transmission Signals

A transmission signal 38 that has high peak values of voltage (i.e., a high PAR) can induce non-linear distortion in the DMT transmitter 22 and the communication channel 18. One form of this non-linear distortion of the transmission signal 38 that may occur is the limitation of the amplitude of the transmission signal 38 (i.e., clipping). For example, a particular DMT symbol 70 clips in the time domain when one or more time domain samples in that DMT symbol 70 are larger than the maximum allowed digital value for the DMT symbols 70. In multicarrier communication systems when clipping occurs, the transmission signal 38 does not accurately represent the input serial data bit signal 54.

In one embodiment, the DSL communication system 2 avoids the clipping of the transmission signal 38 on a DMT symbol 70 by DMT symbol 70 basis. The DMT transmitter 22 detects (step 140) the clipping of the transmission signal 38. If a particular DMT symbol 70 clips in the time domain to produce a clipped transmission signal 38, the DMT transmitter 22 substitutes (step 150) a predefined transmission signal 78 for the clipped transmission signal 38.

The predefined transmission signal 78 has the same duration as a DMT symbol 70 (e.g., 250 ms) in order to maintain symbol timing between the DMT transmitter 22 and the remote receiver 34. The predefined transmission signal 78 is not based on (i.e., independent of) the modulated input data bit stream 54; it is a bit value pattern that is recognized by the remote receiver 34 as a substituted signal. In one embodiment, the predefined transmission signal 78 is a known pseudo-random sequence pattern that is easily detected by the remote receiver 34. In another embodiment, the predefined transmission signal 78 is an "all zeros" signal, which is a zero voltage signal produced at the DMT transmitter 22 output (i.e., zero volts modulated on all the carrier signals). In addition to easy detection by the remote receiver 34, the zero voltage signal reduces the power consumption of the DMT transmitter 22 when delivered by the DMT transmitter 22. Further, a pilot tone is included in the predefined transmission signal 78 to provide a reference signal for coherent demodulation of the carrier signals in the remote receiver 34 during reception of the predefined transmission signal 78.

After the remote receiver 34 receives the transmission signal 38, the remote receiver 34 determines if the transmission signal 38 is equivalent to the predefined transmission signal 78. In one embodiment, when the remote receiver 34 identi-

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fies the predefined transmission signal 78, the remote receiver 34 ignores (i.e., discards) the predefined transmission signal 78.

Following the transmission of the predefined transmission signal 78, the phase scrambler 66 shifts (step 120) the phase characteristic of the QAM-modulated carrier signals (based on one of the predefined parameters that varies over time). For example, consider that a set of QAM symbols 58 produces a DMT symbol 70 comprising a plurality of time domain samples, and that one of the time domain samples is larger than the maximum allowed digital value for the DMT symbol 70. Therefore, because the transmission signal 38 would be clipped when sent to the remote receiver 34, the DMT transmitter 22 sends the predefined transmission signal 78 instead.

After transmission of the predefined transmission signal 78, the DMT transmitter 22 again attempts to send the same bit values that produced the clipped transmission signal 38 in a subsequent DMT symbol 70'. Because the generation of phase shifts in this embodiment is based on values that vary over time, the phase shifts computed for the subsequent DMT symbol 70' are different than those that were previously computed for the DMT symbol 70 with the clipped time domain sample. These different phase shifts are combined to the phase characteristics of the modulated carrier signals to produce carrier signals of the subsequent DMT symbol 70' with different phase characteristics than the carrier signals of the DMT symbol 70 with the clipped time domain sample.

DMT communication systems 2 infrequently produce transmission signals 38 that clip (e.g., approximately one clip every 10^5 time domain samples 70). However, if the subsequent DMT symbol 70' includes a time domain sample that clips, then the predefined transmission signal 78 is again transmitted (step 150) to the remote receiver 34 instead of the clipped transmission signal 38. The clipping time domain sample may be on the same or on a different carrier signal than the previously clipped DMT symbol 70. The DMT transmitter 22 repeats the transmission of the predefined transmission signal 78 until the DMT transmitter 22 produces a subsequent DMT symbol 70' that is not clipped. When the DMT transmitter 22 produces a DMT symbol 70' that is not clipped, the DMT transmitter 22 transmits (step 160) the transmission signal 38 to the remote receiver 34. The probability of a DMT symbol 70 producing a transmission signal 38 that clips in the time domain depends on the PAR of the transmission signal 38.

For example, the following phase shifting example, PST #4, illustrates the method used by the phase scrambler 66 to combine a different phase shift to the phase characteristic of each carrier signal to avoid the clipping of the transmission signal 38.

Phase Shifting Example #4

Phase shifting example #4 (PS #4) corresponds to adjusting the phase characteristic of the carrier signal associated with a carrier number N by

$$\frac{\pi}{3} \times (M + N),$$

mod 2π , where M is the DMT symbol count. In this example, if the DMT symbol 70 clips when the DMT symbol count M equals 5, the predefined transmission signal 78 is transmitted instead of the current clipped transmission signal 38. On the following DMT symbol period, the DMT count M equals 6,

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thereby causing a different set of time domain samples to be generated for the subsequent DMT symbol 70', although the QAM symbols 58 used to produce both DMT symbols 70, 70' are the same.

If this different set of time domain samples (and consequently the transmission signal 38) is not clipped, the DMT transmitter 22 sends the transmission signal 38. If one of the time domain samples in the different set of time domain samples 70 (and consequently the transmission signal 38) is clipped, then the DMT transmitter 22 sends the predefined transmission signal 78 again. The process continues until a DMT symbol 70 is produced without a time domain sample 70 that is clipped. In one embodiment, the transmitter 22 stops attempting to produce a non-clipped DMT symbol 70' for the particular set of QAM symbols 58 after generating a predetermined number of clipped DMT symbols 70'. At that moment, the transmitter 22 can transmit the most recently produced clipped DMT symbol 70' or the predetermined transmission signal 78.

The PAR of the DSL communication system 2 is reduced because the predefined transmission signal 78 is sent instead of the transmission signal 38 when the DMT symbol 70 clips. For example, a DMT communication system 2 that normally has a clipping probability of 10^{-7} for the time domain transmission signal 38 can therefore operate with a 10^{-5} probability of clipping and a lower PAR equal to 12.8 dB (as compared to 14.5 dB). When operating at a 10^{-5} probability of clipping, assuming a DMT symbol 70 has 512 time-domain samples 70, the DMT transmitter 22 experiences one clipped DMT symbol 70 out of every

$$\frac{10^5}{512},$$

or 195 DMT symbols 70. This results in the predefined (non-data carrying) transmission signal 78 being transmitted, on average, once every 195 DMT symbols. Although increasing the probability of clipping to 10^{-5} results in approximately a 0.5% (1/195) decrease in throughput, the PAR of the transmission signal 38 is reduced by 1.7 dB, which reduces transmitter complexity in the form of power consumption and component linearity.

While the invention has been shown and described with reference to specific preferred embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the following claims. For example, although the specification uses DSL to describe the invention, it is to be understood that various form of DSL can be used, e.g., ADSL, VDSL, SDSL, HDSL, HDSL2, or SHDSL. It is also to be understood that the principles of the invention apply to various types of applications transported over DSL systems (e.g., telecommuting, video conferencing, high speed Internet access, video-on demand).

What is claimed is:

1. A method for scrambling phase characteristics of carrier signals in a first multicarrier transceiver that uses a plurality of carrier signals for modulating a bit stream, wherein each carrier signal has a phase characteristic associated with the bit stream, the method comprising:

associating each carrier signal with a value determined independently of any bit value of the bit stream carried by that respective carrier signal, the value associated with each carrier signal determined using a pseudo-

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random number generator; computing a phase shift for each carrier signal based on the value associated with that carrier signal; and
 combining the phase shift computed for each respective carrier signal with the phase characteristic of that carrier signal so as to substantially scramble the phase characteristics of the plurality of carrier signals, wherein multiple carrier signals corresponding to the scrambled carrier signals are used by the first multicarrier transceiver to modulate the same bit value. 5
 2. The method of claim 1, wherein the first transceiver is a cable transceiver.
 3. The method of claim 1, wherein the first transceiver is a VDSL transceiver.
 4. The method of claim 1, wherein the bit stream is used to transport video.
 5. The method of claim 1, wherein the bit stream is used to transport high speed internet access.
 6. The method of claim 1, further comprising, in a second transceiver in communication with the first transceiver, independently deriving the values associated with each carrier using a second pseudo-random number generator in the second transceiver. 10
 7. The method of claim 6, wherein the first and second transceivers use a same seed for the pseudo-random number generator.
 8. The method of claim 6, wherein the first and second transceivers are wireless transceivers.
 9. The method of claim 6, wherein the first and second transceivers are cable transceivers. 15
 10. The method of claim 6, wherein the first and second transceivers are DSL transceivers connected using a pair of twisted wires of a telephone subscriber system.
 11. The method of claim 10, wherein the first and second transceivers are VDSL transceivers. 20
 12. The method of claim 6, wherein the bit stream is used to transport video.
 13. The method of claim 6, wherein the bit stream is used to transport high speed internet access.
 14. A multicarrier system including a first transceiver that uses a plurality of carrier signals for modulating a bit stream, wherein each carrier signal has a phase characteristic associated with the bit stream, the transceiver capable of:

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associating each carrier signal with a value determined independently of any bit value of the bit stream carried by that respective carrier signal, the value associated with each carrier signal determined using a pseudo-random number generator;
 computing a phase shift for each carrier signal based on the value associated with that carrier signal; and
 combining the phase shift computed for each respective carrier signal with the phase characteristic of that carrier signal to substantially scramble the phase characteristics of the plurality of carrier signals, wherein multiple carrier signals corresponding to the scrambled carrier signals are used by the first transceiver to modulate the same bit value.
 15. The system of claim 14, wherein the first transceiver is a cable transceiver.
 16. The system of claim 14, wherein the first transceiver is a VDSL transceiver.
 17. The system of claim 14, wherein the bit stream is used to transport video.
 18. The system of claim 14, wherein the bit stream is used to transport high speed internet access.
 19. The system of claim 14, further comprising a second transceiver in communication with the first transceiver, the second transceiver independently deriving the values associated with each carrier using a second pseudo-random number generator in the second transceiver.
 20. The system of claim 19, wherein the first and second transceivers use a same seed for the pseudo-random number generator.
 21. The system of claim 19, wherein the first and second transceivers are wireless transceivers.
 22. The system of claim 19, wherein the first and second transceivers are cable transceivers.
 23. The system of claim 19, wherein the first and second transceivers are DSL transceivers connected using a pair of twisted wires of a telephone subscriber system.
 24. The system of claim 23, wherein the first and second transceivers are VDSL transceivers.
 25. The system of claim 19, wherein the bit stream is used to transport video.
 26. The system of claim 19, wherein the bit stream is used to transport high speed internet access.

* * * * *

EXHIBIT 5

(12) **United States Patent**
Tzannes et al.

(10) **Patent No.:** **US 8,276,048 B2**
(45) **Date of Patent:** ***Sep. 25, 2012**

(54) **RESOURCE SHARING IN A
TELECOMMUNICATIONS ENVIRONMENT**

(75) Inventors: **Marcos C. Tzannes**, Orinda, CA (US);
Michael Lund, West Newton, MA (US)

(73) Assignee: **Aware, Inc.**, Bedford, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/901,699**

(22) Filed: **Oct. 11, 2010**

(65) **Prior Publication Data**
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Related U.S. Application Data

(63) Continuation of application No. 12/761,586, filed on Apr. 16, 2010, now Pat. No. 7,844,882, which is a continuation of application No. 11/246,163, filed on Oct. 11, 2005, now Pat. No. 7,831,890.

(60) Provisional application No. 60/618,269, filed on Oct. 12, 2004.

(51) **Int. Cl.**
H03M 13/00 (2006.01)
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G06F 13/00 (2006.01)
G06F 15/16 (2006.01)

(52) **U.S. Cl.** **714/774; 714/784; 375/222; 711/147; 711/157; 709/215**

(58) **Field of Classification Search** **714/774, 714/784; 375/222; 711/147, 157; 709/215**
See application file for complete search history.

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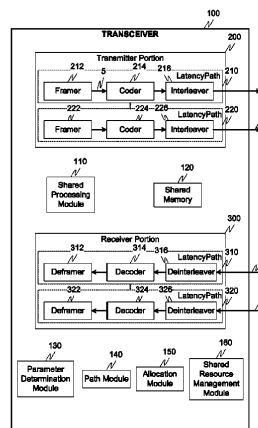
Primary Examiner — John J Tabone, Jr.

(74) *Attorney, Agent, or Firm* — Jason H. Vick; Sheridan Ross, PC

(57) **ABSTRACT**

A system allocates shared memory by transmitting/receiving a message specifying a maximum number of bytes of memory that are available to be allocated to an interleaver. The system determines an amount of memory required by the interleaver to interleave a first plurality of RS coded data bytes within a shared memory and allocates a first number of bytes of the shared memory to the interleaver to interleave the first plurality of RS coded data bytes for transmission at a first data rate. The system also allocates a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate and interleaves the first plurality of RS coded data bytes within the shared memory allocated to the interleaver and deinterleaves the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver.

8 Claims, 3 Drawing Sheets



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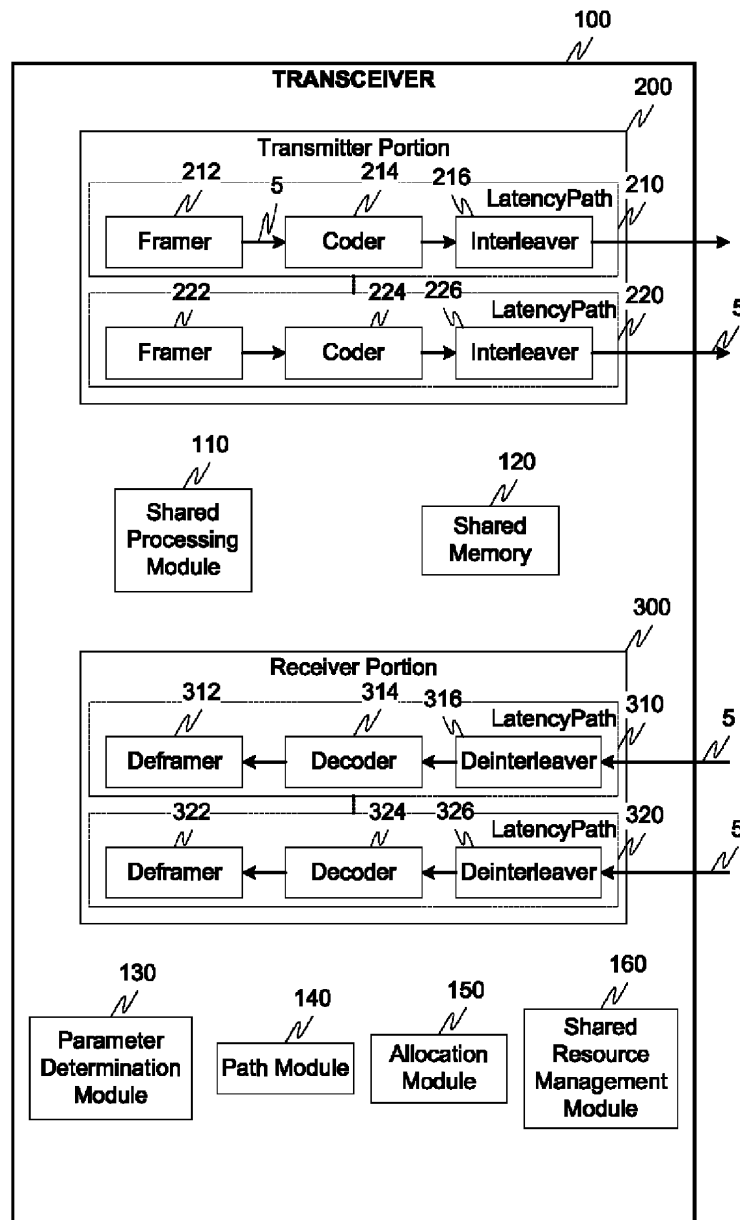


Fig. 1

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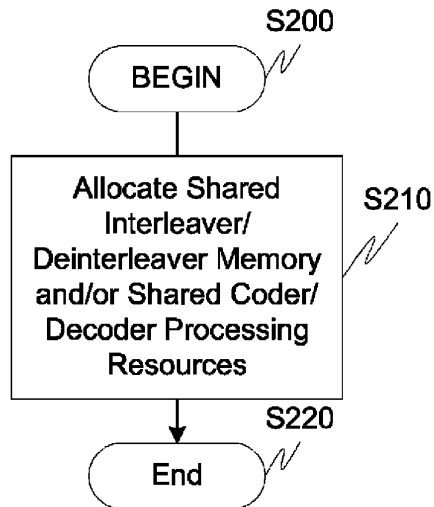


Fig. 2

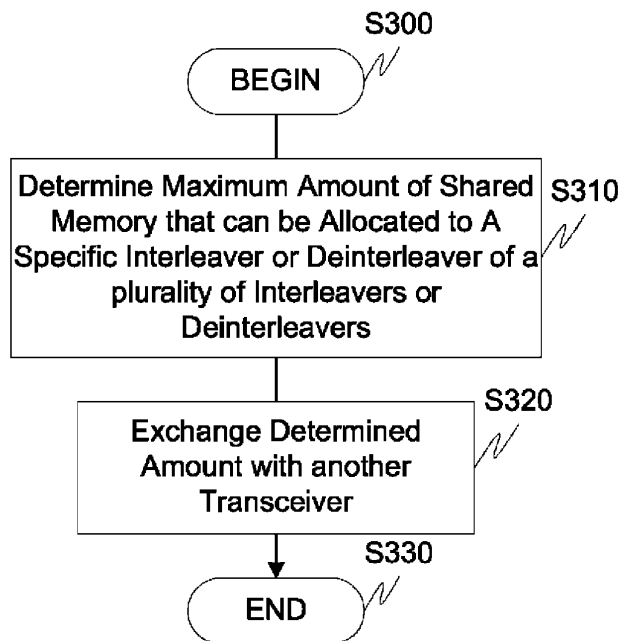


Fig. 3

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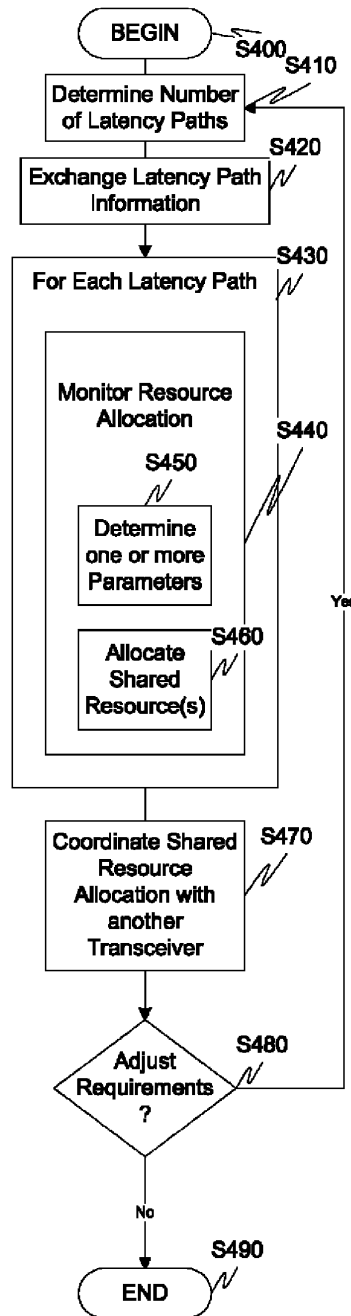


Fig. 4

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RESOURCE SHARING IN A TELECOMMUNICATIONS ENVIRONMENT

RELATED APPLICATION DATA

This application is a Continuation of U.S. application Ser. No. 12/761,586, filed Apr. 16, 2010, now U.S. Pat. No. 7,844,882, which is a Continuation of U.S. application Ser. No. 11/246,163 filed Oct. 11, 2005, now U.S. Pat. No. 7,831,890, which claims the benefit of and priority under 35 U.S.C. §119(e) to U.S. Patent Application No. 60/618,269, filed Oct. 12, 2004, entitled "Sharing Memory and Processing Resources in DSL Systems," each of which are incorporated herein by reference in their entirety.

BACKGROUND

1. Field of the Invention

This invention generally relates to communication systems. More specifically, an exemplary embodiment of this invention relates to memory sharing in communication systems. Another exemplary embodiment relates to processing or coding resource sharing in a communication system.

2. Description of Related Art

U.S. Pat. Nos. 6,775,320 and 6,778,596 describe DSL systems supporting multiple applications and multiple framer/coder/interleaver FCI blocks (an FCI block is also referred to as a latency path). DSL systems carry applications that have different transmission requirements with regard to, for example, data rate, latency (delay), bit error rate (BER), and the like. For example, video typically requires a low BER (<1E-10) but can tolerate higher latency (>20 ms). Voice, on the other hand, typically requires a low latency (<1 ms) but can tolerate BER (>1E-3).

As described in U.S. Pat. No. 6,775,320, different applications can use different latency paths in order to satisfy the different application requirements of the communication system. As a result a transceiver must support multiple latency paths in order to support applications such as video, Internet access and voice telephony. When implemented in a transceiver, each of the latency paths will have a framer, coder, and interleaver block with different capabilities that depend on the application requirements.

SUMMARY

One difficulty with implementing multiple latency paths in a transceiver is the fact that a latency path is a complicated digital circuit that requires a large amount of memory and processing power. An interleaver within a latency path can consume a large amount of memory in order to provide error correcting capability. For example, a typical DSL transceiver will have at least one latency path with approximately 16 kbytes of memory for the interleaver. Likewise, the coding block, for example, a Reed Solomon coder, consumes a large amount of processing power. In general, as the number of latency paths increase, the memory and processing power requirements for a communication system become larger.

Accordingly, an exemplary aspect of this invention relates to sharing memory between one or more interleavers and/or deinterleavers in a transceiver. More particularly, an exemplary aspect of this invention relates to shared latency path memory in a transceiver.

Additional aspects of this invention relate to configuring and initializing shared memory in a communication system. More particularly, an exemplary aspect of this invention

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relates to configuring and initializing interleaver/deinterleaver memory in a communication system.

Additional aspects of the invention relate to determining the amount of memory that can be allocated to a particular component by a communication system. More specifically, an exemplary aspect of the invention relates to determining the maximum amount of shared memory that can be allocated to one or more interleaves or deinterleavers.

According to another exemplary aspect of the invention, processing power is shared between a number of transceiver modules. More specifically, and in accordance with an exemplary embodiment of the invention, a coding module is shared between one or more coders and/or decoders.

Another exemplary embodiment of the invention relates to transitioning from a fixed memory configuration to a shared memory configuration during one or more of initialization and SHOWTIME (user data transmission).

An additional exemplary aspect of the invention relates to dynamically updating one or more of shared memory and processing resources based on changing communication conditions.

An additional exemplary aspect of the invention relates to updating one or more of shared memory and processing resources based on an updated communication parameter.

An additional exemplary aspect of the invention relates to updating the allocation of one or more of shared memory and processing resources based on an updated communication parameter(s).

Additional aspects of the invention relate to exchanging shared resource allocations between transceivers.

Additional exemplary aspects relate to a method of allocating shared memory in a transceiver comprising allocating the shared memory to a plurality of modules, wherein each of the plurality of modules comprise at least one interleaver, at least one deinterleaver or a combination thereof.

Still further aspects relate to the above method wherein the plurality of modules comprise interleavers.

Still further aspects relate to the above method wherein the plurality of modules comprise deinterleavers.

Still further aspects relate to the above method wherein the plurality of modules comprise at least one interleaver and at least one deinterleaver.

Additional exemplary aspects relate to a transceiver comprising a plurality of modules each including at least one interleaver, at least one deinterleaver or a combination thereof and a shared memory designed to be allocated to a plurality of the modules.

Still further aspects relate to the above transceiver wherein the plurality of modules comprise interleavers.

Still further aspects relate to the above transceiver wherein the plurality of modules comprise deinterleavers.

Still further aspects relate to the above transceiver wherein the plurality of modules comprise at least one interleaver and at least one deinterleaver.

These and other features and advantages of this invention are described in, or are apparent from, the following description of the embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the invention will be described in detail, with reference to the following figures, wherein:

FIG. 1 is a functional block diagram illustrating an exemplary transceiver according to this invention;

FIG. 2 is a flowchart outlining an exemplary method of sharing resources according to this invention;

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FIG. 3 is a flowchart outlining an exemplary method of determining a maximum amount of shared memory according to this invention; and

FIG. 4 is a flowchart outlining an exemplary resource sharing methodology according to this invention.

DETAILED DESCRIPTION

The exemplary embodiments of this invention will be described in relation to sharing resources in a wired and/or wireless communications environment. However, it should be appreciated, that in general, the systems and methods of this invention will work equally well for any type of communication system in any environment.

The exemplary systems and methods of this invention will also be described in relation to multicarrier modems, such as DSL modems and VDSL modems, and associated communication hardware, software and communication channels. However, to avoid unnecessarily obscuring the present invention, the following description omits well-known structures and devices that may be shown in block diagram form or otherwise summarized.

For purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the present invention. It should be appreciated however that the present invention may be practiced in a variety of ways beyond the specific details set forth herein.

Furthermore, while the exemplary embodiments illustrated herein show the various components of the system collocated, it is to be appreciated that the various components of the system can be located at distant portions of a distributed network, such as a telecommunications network and/or the Internet, or within a dedicated secure, unsecured and/or encrypted system. Thus, it should be appreciated that the components of the system can be combined into one or more devices, such as a modem, or collocated on a particular node of a distributed network, such as a telecommunications network. As will be appreciated from the following description, and for reasons of computational efficiency, the components of the system can be arranged at any location within a distributed network without affecting the operation of the system. For example, the various components can be located in a Central Office modem (CO, ATU-C, VTU-O), a Customer Premises modem (CPE, ATU-R, VTU-R), a DSL management device, or some combination thereof. Similarly, one or more functional portions of the system could be distributed between a modem and an associated computing device.

Furthermore, it should be appreciated that the various links, including communications channel 5, connecting the elements can be wired or wireless links, or any combination thereof, or any other known or later developed element(s) that is capable of supplying and/or communicating data to and from the connected elements. The term module as used herein can refer to any known or later developed hardware, software, firmware, or combination thereof that is capable of performing the functionality associated with that element. The terms determine, calculate and compute, and variations thereof, as used herein are used interchangeably and include any type of methodology, process, mathematical operation or technique. FCI block and latency path are used interchangeably herein as well as transmitting modem and transmitting transceiver. Receiving modem and receiving transceiver are also used interchangeably.

FIG. 1 illustrates an exemplary embodiment of a transceiver 100 that utilizes shared resources. It should be appreciated that numerous functional components of the transceiver have been omitted for clarity. However, the transceiver

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100 can also include the standard components found in typical communications device(s) in which the technology of the subject invention is implemented into.

According to an exemplary embodiment of the invention, memory and processing power can be shared among a plurality of transmitter and/or receiver latency paths, in a communications transceiver that carries or supports multiple applications. For example, the transmitter and/or receiver latency paths of the transceiver can share an interleaver/deinterleaver memory and the shared memory can be allocated to the interleaver and/or deinterleaver of each latency path. This allocation can be done based on the data rate, latency, BER, impulse noise protection requirements of the application, data or information being transported over each latency path, or in general any parameter associated with the communications system.

Likewise, for example, the transmitter and/or receiver latency paths can share a Reed-Solomon coder/decoder processing module and the processing power of this module can be allocated to each encoder and/or decoder. This allocation can be done based on the data rate/latency, BER, impulse noise protection requirements of the application data or information being transported over each latency path, or in general based on any parameter associated with the communication system.

In accordance with an exemplary operational embodiment, a first transceiver and a second transceiver transmit to one another messages during, for example, initialization which contain information on the total and/or shared memory capabilities of each transceiver and optionally information about the one or more latency paths. This information can be transmitted prior to determining how to configure the latency paths to support the application requirements. Based on this information, one of the modems can select an FCI configuration parameter(s) that meets the transmission requirements of each application being transported over each latency paths. While an exemplary of the embodiment of the invention will be described in relation to the operation of the invention and characteristics thereof being established during initialization, it should be appreciated that the sharing of resources can be modified and messages transmitted between a two transceivers at any time during initialization and/or user data transmission, i.e., SHOWTIME.

FIG. 1 illustrates an exemplary embodiment of a transceiver 100. The transceiver 100 includes a transmitter portion 200 and a receiver portion 300. The transmitter portion 200 includes one or more latency paths 210, 220, ... Similarly, the receiver portion 300 includes one or more latency paths 310, 320, ... Each of the latency paths in the transmitter portion 200 includes a framer, coder, and interleaver designated as 212, 214, 216 and 222, 224 and 226, respectively. Each of the latency paths in the receiver portion includes a deframer, decoder, and deinterleaver designated as 312, 314, 316 and 322, 324, and 326, respectively. The transceiver 100 further includes a shared processing module 110, a shared memory 120, a parameter determination module 130, a path module 140, an allocation module 150, and a shared resource management module 160, all interconnected by one or more links (not shown).

In this exemplary embodiment, the transceiver 100 is illustrated with four total transmitter portion and receiver portion latency paths, i.e., 210, 220, 310, and 320. The shared memory 120 is shared amongst the two transmitter portion interleavers 216 and 226 and two receiver portion deinterleavers 316 and 326. The shared processing module 110, such

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as a shared coding module, is shared between the two transmitter portion coders 214 and 224 and the two receiver portion decoders 314 and 324.

While the exemplary embodiment of the invention will be described in relation to a transceiver having a number of transmitter portion latency paths and receiver portion latency paths, it should be appreciated that this invention can be applied to any transceiver having any number of latency paths. Moreover, it should be appreciated that the sharing of resources can be allocated such that one or more of the transmitter portion latency paths are sharing a shared resource, one or more of the receiver portion latency paths are sharing a shared resource, or a portion of the transmitter portion latency paths and a portion of the receiver portion latency paths are sharing shared resources. Moreover, any one or more of the latency paths, or portions thereof, could also be assigned to a fixed resource while, for example, another portion of the latency path(s) assigned to a shared resource. For example, in latency path 210, the interleaver 216 could be allocated a portion of the shared memory 120, while the coder 214 could be allocated to a dedicated processing module, vice versa, or the like.

In accordance with the exemplary embodiment, a plurality of transmitter portion or receiver portion latency paths share an interleaver/deinterleaver memory, such as shared memory 120, and a coding module, such as shared processing module 110. For example, the interleaver/deinterleaver memory can be allocated to different interleavers and/or deinterleavers. This allocation can be based on parameters associated with the communication systems such as data rate, latency, BER, impulse noise protection, and the like, of the applications being transported. Similarly, a coding module, which can be a portion of the shared processing module 110, can be shared between any one or more of the latency paths. This sharing can be based on requirements such as data rate, latency, BER, impulse noise protection, and the like, of the applications being transported.

For example, an exemplary transceiver could comprise a shared interleaver/deinterleaver memory and could be designed to allocate a first portion of the shared memory 120 to an interleaver, such as interleaver 216 in the transmitter portion of the transceiver and allocate a second portion of the shared memory 120 to a deinterleaver, such as 316, in the receiver portion of the transceiver.

Alternatively, for example, an exemplary transceiver can comprise a shared interleaver/deinterleaver memory, such as shared memory 120, and be designed to allocate a first portion of shared memory 120 to a first interleaver, e.g., 216, in the transmitter portion of the transceiver and allocate a second portion of the shared memory to a second interleaver, e.g., 226, in the transmitter portion of the transceiver.

Alternatively, for example, an exemplary transceiver can comprise a shared interleaver/deinterleaver memory and be designed to allocate a first portion of the shared memory 120 to a first deinterleaver, e.g., 316, in the receiver portion of the transceiver and allocate a second portion of the shared memory to a second deinterleaver, e.g., 326, in the receiver portion of the transceiver. Regardless of the configuration, in general any interleaver or deinterleaver, or grouping thereof, be it in a transmitter portion or receiver portion of the transceiver, can be associated with a portion of the shared memory 120.

Establishment, configuration and usage of shared resources is performed in the following exemplary manner. First, and in cooperation with the path module 140, the number of transmitter and receiver latency paths (N) is determined. The parameter determination module 130 then analy-

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ses one or more parameters such as data rate, transmitter data rate, receiver data rate, impulse noise protection, bit error rate, latency, or the like. Based on one or more of these parameters, the allocation module 150 allocates a portion of the shared memory 120 to one or more of the interleaver and/or deinterleavers, or groupings thereof. This process continues until the memory allocation has been determined and assigned to each of the N latency paths.

Having determined the memory allocation for each of the latency paths, and in conjunction with the shared resource management 160, the transceiver 100 transmits to a second transceiver one or more of the number of latency paths (N), the maximum interleaver memory for any one or more of the latency paths and/or the maximum total and/or shared memory for all of the latency paths.

Three examples of sharing interleaver/deinterleaver memory and coding processing in a transceiver are described below. The latency paths in these examples can be in the transmitter portion of the transceiver or the receiver portion of the transceiver.

EXAMPLE #1

A first transmitter portion or receiver portion latency path may carry data from a video application, which needs a very low BER but can tolerate higher latency. In this case, the video will be transported using an latency path that has a large amount of interleaving/deinterleaving and coding (also known as Forward Error Correction (FEC) coding). For example, the latency path may be configured with Reed-Solomon coding using a codeword size of 255 bytes ($N=255$) with 16 checkbytes ($R=16$) and interleaving/deinterleaving using an interleaver depth of 64 ($D=64$). This latency path will require $N \times D = 255 \times 64 = 16$ Kbytes of interleaver memory at the transmitter (or deinterleaver memory at the receiver). This latency path will be able to correct a burst of errors that is less than 512 bytes in duration.

A second transmitter portion or receiver portion latency path may carry an internet access application that requires a medium BER and a medium amount of latency. In this case, the internet access application will be transported using a latency path that has a medium amount of interleaving and coding. For example, the latency path may be configured with Reed-Solomon coding using a codeword size of 128 bytes ($N=128$) with 8 checkbytes ($R=8$) and interleaving using an interleaver depth of 16 ($D=32$). This latency path will require $N \times D = 128 \times 32 = 4$ Kbytes of interleaver memory and the same amount of deinterleaver memory. This latency path will be able to correct a burst of errors that is less than 128 bytes in duration.

A third transmitter portion or receiver portion latency path may carry a voice telephony application, which needs a very low latency but can tolerate BER. In this case, the video will be transported using an latency path that has a large amount of interleaving and coding. For example, the third transmitter portion or receiver portion latency path may be configured with no interleaving or coding which will result in the lowest possible latency through the latency path but will provide no error correction capability.

According to the principles of this invention, a system carrying the three applications described above in Example #1, would have three latency paths that share one memory space containing at least $(16+4) = 20$ Kbytes. The three latency paths also share a common coding block that is able to simultaneously encode (in the transmitter portion) or decode (in a receiver portion) two codewords with $N=255/R=16$ and $N=128/R=8$.

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According to an exemplary embodiment of this invention, the latency paths can be reconfigured at initialization or during data transmission mode (also known as SHOWTIME in ADSL and VDSL transceivers). This would occur if, for example, the applications or application requirements were to change.

EXAMPLE #2

If instead of 1 video application, 1 internet application and 1 voice application, there were 3 internet access applications then the transmitter portion and/or receiver portion latency paths would be reconfigured to utilize the shared memory and coding module in a different way. For example, the system could be reconfigured to have 3 transmitter portion or receiver portion latency paths, with each latency path being configured with Reed-Solomon coding using a codeword size of 128 bytes ($N=128$) with 8 checkbytes ($R=8$) and interleaving using an interleaver depth of 16 ($D=32$). Each latency path will require $N \cdot D = 128 \cdot 32 = 4$ Kbytes of interleaver memory and each block will be able to correct a burst of errors that is less than 128 bytes in duration. Based on the example of carrying the three internet access applications described, the three latency path share one memory space containing at least $3 \cdot 4 = 12$ Kbytes. Also the three latency paths share a common coding block that is able to simultaneously encode (on the transmitter side) or decode (on the receiver side) three codewords with $N=128/R=16$, $N=128/R=8$ and $N=128/R=8$.

EXAMPLE #3

The system could be configured to carry yet another set of applications. For example, the latency paths could be configured to carry 2 video applications. In this case only 2 transmitter portion or receiver portion latency paths are needed, which means that the third latency path could be simply disabled. Also, assuming that the memory is constrained based on the first example above, then the maximum shared memory for these 2 latency paths is 20 Kbytes. In this case, the system could be reconfigured to have 2 latency paths, with each block being configured with Reed-Solomon coding using a codeword size of 200 bytes ($N=200$) with 10 checkbytes ($R=10$) and interleaving/deinterleaving using an interleaver depth of 50 ($D=50$). Each latency path will require $N \cdot D = 200 \cdot 50 = 10$ Kbytes of interleaver memory and each block will be able to correct a burst of errors that is less than 250 bytes in duration. This configuration results in 20K of shared memory for both latency paths, which is the same as in the first example. In order to stay within the memory constraints of the latency paths, the error correction capability for each latency path is decreased to 250 bytes from 512 bytes in Example #1.

Another aspect of this invention is the how FCI configuration information is transmitted between a first modem and a second modem. FCI configuration information will depend on the requirements of the applications being transported over the DSL connection. This information may need to be forwarded during initialization in order to initially configure the DSL connection. This information may also need to be forwarded during SHOWTIME in order to reconfigure the DSL connection based on a change in applications or the application requirements.

According to one embodiment, a first modem determines the specific FCI configuration parameters, e.g., N , D , R as defined above, needed to meet specific application requirements, such as latency, burst error correction capability, etc. In order to determine the FCI configuration parameters, the

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first modem must know what are the capabilities of a second modem. For example, the first modem must know how many latency paths (FCI blocks) the second modem can support. Also the first modem must know the maximum amount of interleaver memory for each transmitter latency path. In addition, since the transmitter latency paths may share a common memory space the first modem must know the total shared memory for all transmitter latency paths. This way the first modem will be able to choose a configuration that can meet application requirements and also meet the transmitter portion latency path capabilities of the second modem.

For example, using values from examples above, a first transceiver could send a message to a second transceiver during initialization or during SHOWTIME containing the following information:

Number of supported transmitter and receiver latency paths=3

Max Interleaver Memory for latency path #1=16 Kbytes

Max Interleaver Memory for latency path #2=16 Kbytes

Max Interleaver Memory for latency path #3=16 Kbytes

Maximum total/shared memory for all latency paths=20 Kbytes

Based on this information, and the application requirements, the first transceiver would select latency path settings. For example, if the applications are 1 video, 1 internet access and 1 voice application, the first transceiver could configure 3 latency paths as follows:

latency path #1—Video: $N=255$, $R=16$, $D=64$

latency path #2—Video: $N=128$, $R=8$, $D=32$

latency path #3—Video: $N=0$, $R=0$, $D=1$ (no coding or interleaving)

This would result in a total interleaver memory of 20 Kbytes.

Alternatively, if for example, there are only 2 video applications, the first transceiver could configure 2 latency paths as follows:

latency path #1—Video: $N=200$, $R=10$, $D=50$

latency path #2—Video: $N=200$, $R=10$, $D=50$

latency path #3—Video: $N=0$, $R=0$, $D=1$ (no coding or interleaving)

This would also result in a total interleaver memory of 20 Kbytes.

Alternatively, the second transceiver can determine the specific FCI configuration parameters, e.g., N , D , R as defined above, needed to meet specific application requirements, such as latency, burst error correction capability, etc. As described above for the first transceiver, in order to determine the FCI configuration parameters, the second transceiver must first know what are the capabilities of the first transceiver. In this case, the first transceiver would send a message to the second transceiver containing the information described above and based on this information and the application requirements the second transceiver would select latency path settings.

FIG. 2 outlines an exemplary method of allocating shared memory in a transceiver. More specifically, control begins in step S200 and continues to step S210. In step S210, one or more of shared interleaver/deinterleaver memory and/or shared coder/decoder processing resources are allocated to one or more latency paths, in a transceiver. Control then continues to step S220 where the control sequence ends.

FIG. 3 outlines an exemplary method of exchanging shared resource allocations according to an exemplary embodiment of this invention. In particular, control begins in step S310. In step S310, a maximum amount of shared memory that can be allocated to a specific interleaver or deinterleaver of a plurality of interleavers or deinterleavers in a transceiver is deter-

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mined. Next, in step S320, the determined maximum amount for one or more of the deinterleavers and/or interleavers is transmitted to another transceiver. Messages containing additional information can also be transmitted to the other transceiver and/or received from the other transceiver. Control then continues to step S330 where the control sequence ends.

FIG. 4 outlines an exemplary procedure for resource sharing according to an exemplary embodiment of this invention. In particular, control begins in step S400 and continues to step S410. In step S410, the number of latency paths are determined. Then, in step S420, the latency path information (FCI block information) is transmitted to another transceiver. Messages containing additional information can also be transmitted to the other transceiver and/or received from the other transceiver. Moreover, the messages received from the other transceiver could specify what the memory allocation is to be based on, for example, the number of latency paths, memory allocation in the remote transceiver and required applications. Control then continues to step S430.

In step S430, and for each latency path, the steps in step 440 are performed.

In step S440, and while monitoring of allocation of resources is being performed, steps 450 and 460 are performed. More specifically, in step S450, one or more parameters associated with the communication system are determined. Then, in step S460, shared resources are allocated based on one or more of the communication parameters. Control then continues to step S470.

In step S470, the allocation of shared resources is communicated to another transceiver. Next, in step S480, a determination is made as to whether there is a change in communications that would require the adjustment of the shared resource allocation. Examples of changes in communications conditions include a change in applications being transported over the system and/or changes in the channel condition, etc. If adjustments are required, control jumps back to step S410. Otherwise, control jumps to step S490 where the control sequence ends.

The above-described system can be implemented on wired and/or wireless telecommunications devices, such as a modem, a multicarrier modem, a DSL modem, an ADSL modem, an XDSL modem, a VDSL modem, a linecard, test equipment, a multicarrier transceiver, a wired and/or wireless wide/local area network system, a satellite communication system, a modem equipped with diagnostic capabilities, or the like, or on a separate programmed general purpose computer having a communications device or in conjunction with any of the following communications protocols: CDSL, ADSL2, ADSL2+, VDSL1, VDSL2, HDSL, DSL Lite, IDSL, RADSL, SDSL, UDSL or the like.

Additionally, the systems, methods and protocols of this invention can be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element(s), an ASIC or other integrated circuit, a digital signal processor, a hard-wired electronic or logic circuit such as discrete element circuit, a programmable logic device such as PLD, PLA, FPGA, PAL, a modem, a transmitter/receiver, any comparable means, or the like. In general, any device capable of implementing a state machine that is in turn capable of implementing the methodology illustrated herein can be used to implement the various communication methods, protocols and techniques according to this invention.

Furthermore, the disclosed methods may be readily implemented in software using object or object-oriented software

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development environments that provide portable source code that can be used on a variety of computer or workstation platforms. Alternatively, the disclosed system may be implemented partially or fully in hardware using standard logic circuits or VLSI design. Whether software or hardware is used to implement the systems in accordance with this invention is dependent on the speed and/or efficiency requirements of the system, the particular function, and the particular software or hardware systems or microprocessor or microcomputer systems being utilized. The communication systems, methods and protocols illustrated herein can be readily implemented in hardware and/or software using any known or later developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

Moreover, the disclosed methods may be readily implemented in software that can be stored on a storage medium, executed on programmed general-purpose computer with the cooperation of a controller and memory, a special purpose computer, a microprocessor, or the like. In these instances, the systems and methods of this invention can be implemented as program embedded on personal computer such as an applet, JAVA® or CGI script, as a resource residing on a server or computer workstation, as a routine embedded in a dedicated communication system or system component, or the like. The system can also be implemented by physically incorporating the system and/or method into a software and/or hardware system, such as the hardware and software systems of a communications transceiver.

It is therefore apparent that there has been provided, in accordance with the present invention, systems and methods for sharing resources. While this invention has been described in conjunction with a number of embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable arts. Accordingly, it is intended to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and scope of this invention.

The invention claimed is:

1. A system that allocates shared memory comprising: a transceiver that is capable of:

- transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver;
- determining an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within the shared memory;
- allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes specified in the message;
- allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate; and
- interleaving the first plurality of RS coded data bytes within the shared memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver, wherein the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver.

2. The system of claim 1, wherein the determining is based on an impulse noise protection requirement.

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3. The system of claim 1, wherein the determining is based on a latency requirement.

4. The system of claim 1, wherein the determining is based on a bit error rate requirement.

5. A system that allocates shared memory comprising: 5
a transceiver that is capable of:

transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver;

determining an amount of memory required by the 10
deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within the shared memory;

allocating a first number of bytes of the shared memory 15
to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message;

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allocating a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes received at a second data rate; and

deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver, wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver.

6. The system of claim 5, wherein the determining is based on an impulse noise protection requirement.

7. The system of claim 5, wherein the determining is based on a latency requirement.

8. The system of claim 5, wherein the determining is based on a bit error rate requirement.

* * * * *

EXHIBIT 6



US008462835B2

(12) **United States Patent**
Tzannes

(10) **Patent No.:** **US 8,462,835 B2**
(45) **Date of Patent:** **Jun. 11, 2013**

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(65)	Prior Publication Data	2009/0086800	A1	4/2009	Cioffi
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(60)	Provisional application No. 60/549,804, filed on Mar. 3, 2004, provisional application No. 60/555,982, filed on Mar. 24, 2004.	

(Continued)

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(58)	Field of Classification Search	
	USPC 375/219, 224, 285, 346; 714/774, 714/786	
	See application file for complete search history.	

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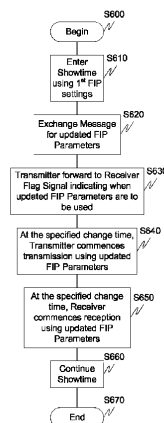
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Primary Examiner — Jean B Corrielus
(74) *Attorney, Agent, or Firm* — Jason H. Vick; Sheridan Ross, PC

(57) **ABSTRACT**

Evaluation of the impact of impulse noise on a communication system can be utilized to determine how the system should be configured to adapt to impulse noise events. Moreover, the system allows for information regarding impulse noise events, such as length of the event, repetition period of the event and timing of the event, to be collected and forwarded to a destination. The adaptation can be performed during one or more of Showtime and initialization, and can be initiated and determined at either one or more of a transmitter and a receiver.

32 Claims, 7 Drawing Sheets



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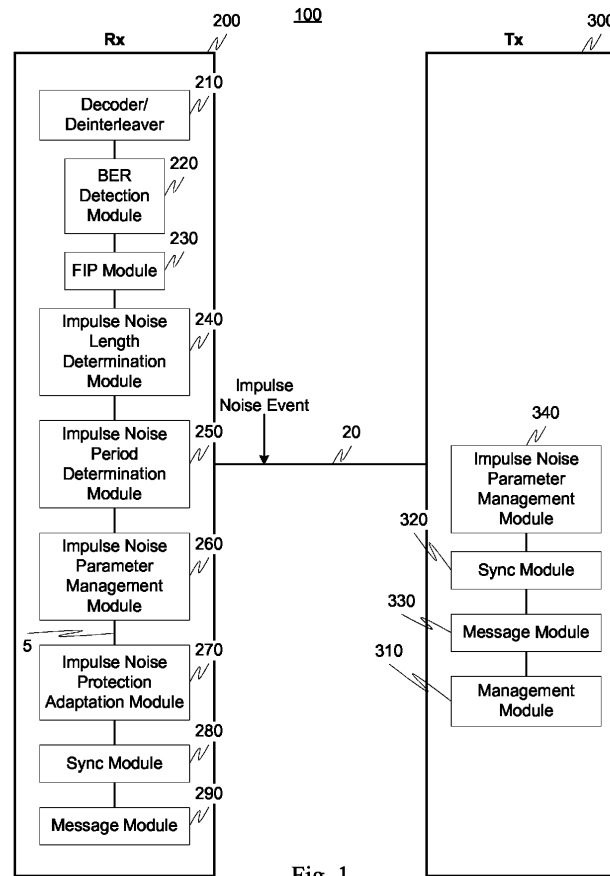


Fig. 1

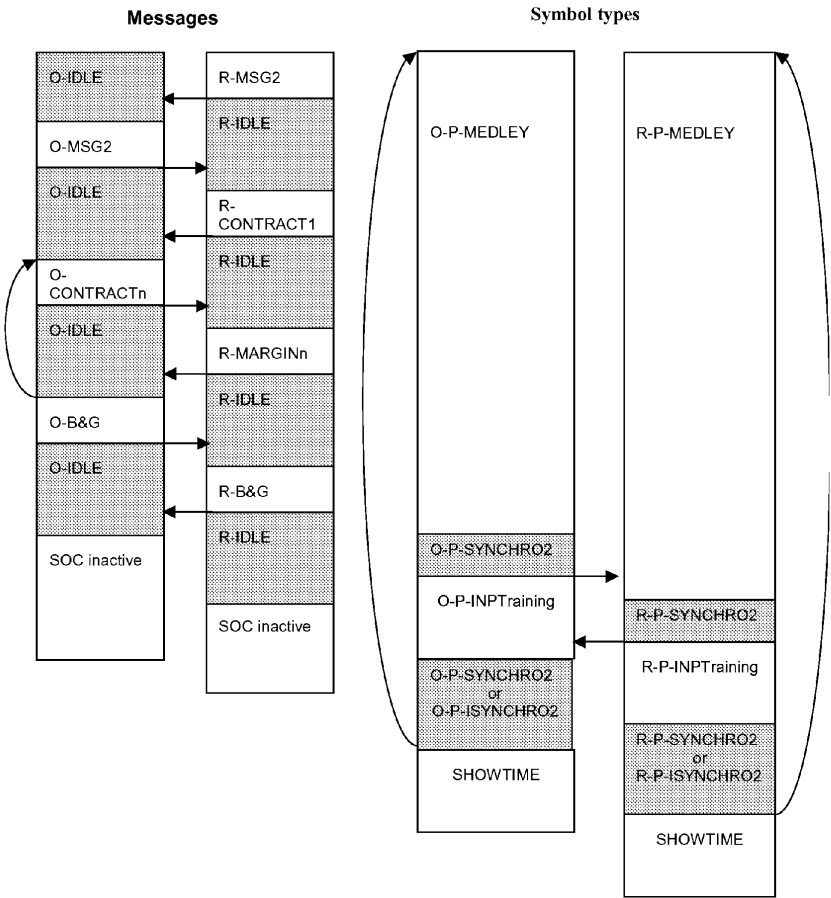


Fig. 2

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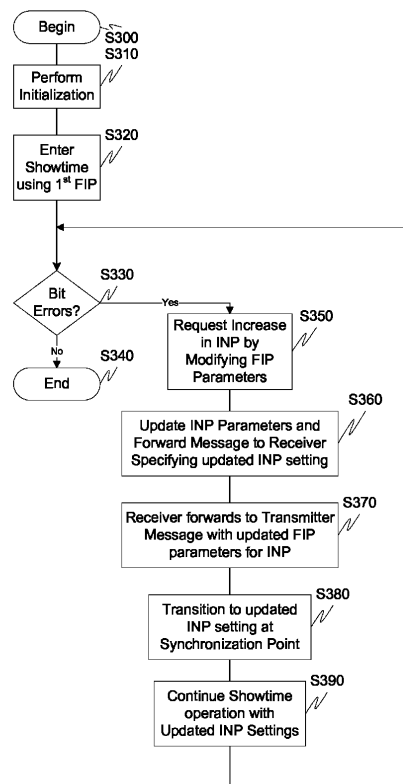


Fig. 3

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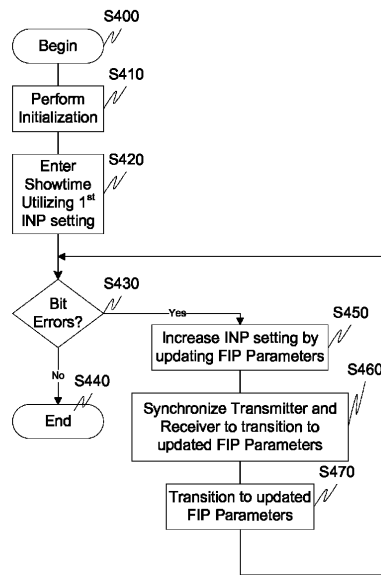


Fig. 4

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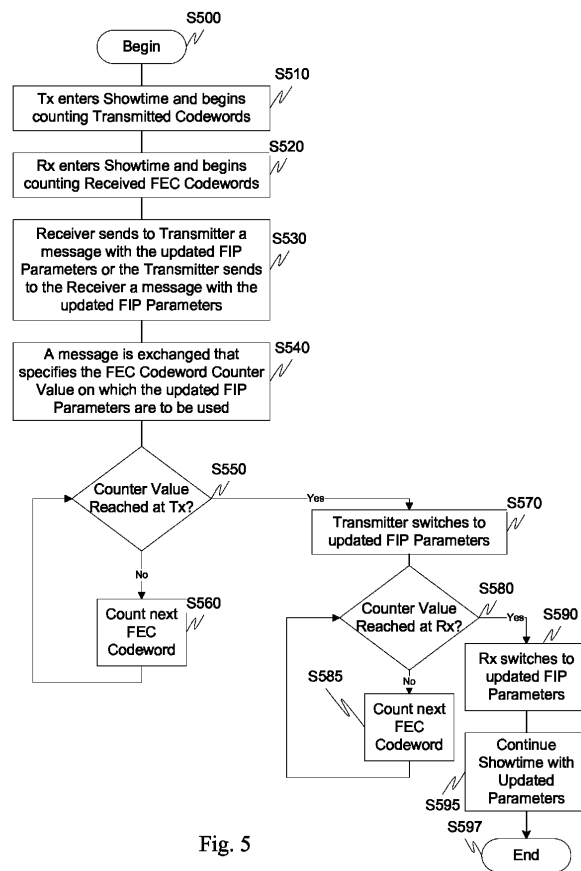


Fig. 5

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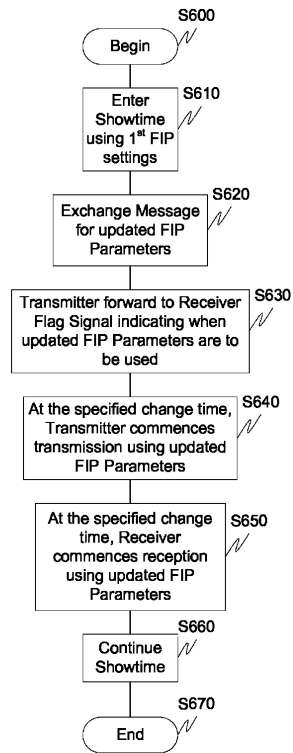


Fig. 6

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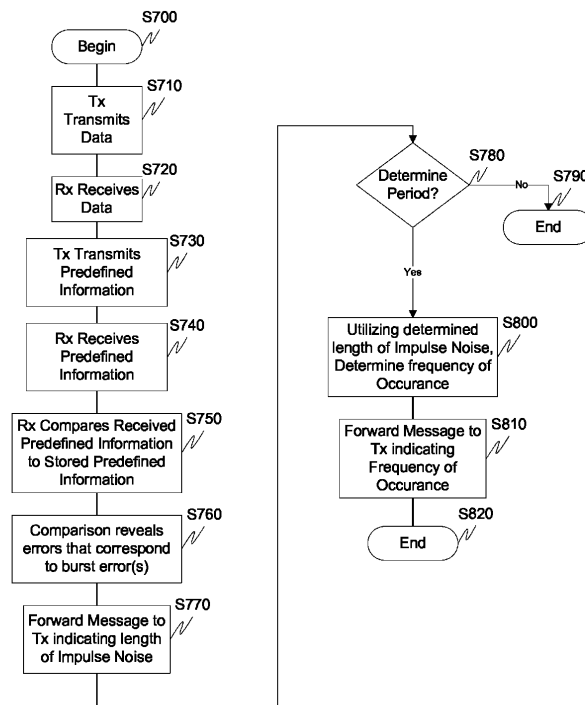


Fig. 7

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IMPULSE NOISE MANAGEMENT**RELATED APPLICATION DATA**

This application is a continuation of U.S. application Ser. No. 10/597,482, filed Jul. 27, 2006 now abandoned, which is a national stage application under 35 U.S.C. 371 of PCT Application No. PCT/US2005/006842, filed Mar. 3, 2005, which claims the benefit of and priority under 35 U.S.C. §119(e) to U.S. Provisional Application No. 60/549,804, entitled "On-Line Impulse Noise Protection (INP) Adaptation," filed Mar. 3, 2004, and U.S. Provisional Application No. 60/555,982, entitled "Impulse Noise Protection (INP) Training," filed Mar. 24, 2004, each of which are incorporated herein by reference in their entirety.

BACKGROUND**1. Field of the Invention**

This invention generally relates to communication systems. In particular, an exemplary aspect of this invention relates to impulse noise protection adaptation. Another exemplary aspect of this invention relates to impulse noise length and period determination and use thereof for impulse noise protection adaptation.

2. Description of Related Art

Communications systems often operate in environments that produce impulse noise. Impulse noise is a short-term burst of noise that is higher than the normal noise that typically exists in a communication channel. For example, DSL systems operate on telephone lines and experience impulse noise from many external sources including telephones, AM radio, HAM radio, other DSL services on the same line or in the same bundle, other equipment in the home, etc. It is standard practice for communications systems to use interleaving in combination with Forward Error Correction (FEC) to correct the errors caused by impulse noise. Standard initialization procedures in ADSL and VDSL systems are designed to optimize performance (data rate/reach) in the presence "stationary" crosstalk or noise. Impulse noise protection is handled with interleaving and FEC, but the current xDSL procedure at least does not provide specific states to enable training for the selection of the appropriate interleaving and FEC parameters.

An exemplary problem associated with traditional communication systems is that they use traditional Signal to Noise Ratio (SNR) measurement techniques to determine the SNR of the channel. These traditional techniques assume that the noise is stationary and does not contain non-stationary components such as impulse noise. The most common method for measuring the SNR is to calculate the mean-square error of the received signal based on a known transmitted signal, which is described in the ADSL series of ITU G.992.x standards and the VDSL series of ITU G.993.x standards, which are incorporated herein by reference in their entirety. These traditional methods for measuring SNR do not correctly measure the impact of impulse noise and do not have the noise capability to determine how the system should be configured to handle impulse noise.

There has been proposed that there is a need in ADSL and VDSL systems to provide robust error-free performance in the presence of high, real-world impulse noise. A specific proposal recommends that the standard impulse noise protection (INP) values are extended to values of 4, 8, 16 and 32 in order to handle high levels of impulse noise. Impulse noise protection is defined in the ADSL2 Standard G.992.3, which is incorporated herein by reference in its entirety, as the num-

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ber of impulse noise corrupted DMT symbols that can be corrected by the FEC and interleaving configuration. Specifically, G.992.3 defines the following variables:

$$INP = 1/2 * (S * D) * R / N$$

$$S = 8 * N / L$$

$$\text{Latency (or delay)} = S * D / 4$$

$$\text{Line Rate (in kbps)} = L * 4$$

where N is the codeword size in bytes, R is the number of parity (or redundancy) bytes in a codeword, D is the interleaver depth in number of codewords, and L is the number of bits in a DMT symbol.

If K is the number of information bytes in a codeword then:

$$N = K + R$$

and the user data rate is approximately equal to:

$$L * 4 * K / N.$$

In general, DSL systems (such as the one defined in ADSL G.992.x or VDSL G.993.x) use the FEC and Interleaving Parameters (FIP) characterized by the set of parameters (N, K, R, D). Using these parameters, the Burst Error Correction Capability (BECC) in bytes can be simply calculated as:

$$BECC = D * R / 2 \text{ bytes}$$

where BECC is defined as the number of consecutive byte errors that can be corrected by the receiver. Note that if the receiver uses more intelligent decoding schemes, such as erasure detection, it is possible to correct even more than $D * R / 2$ bytes. It also follows from above that $INP = BECC / L$.

The proposal further recommends that the higher INP values are achieved by increasing the amount of FEC redundancy while keeping the same system latency and the same interleaver memory at the expense of user data rate or excess margin. Since, on phone lines without excess margin, there is clearly a trade-off between high impulse noise protection values and user data rate, it would be advantageous to try to maximize the user data rate by finding the minimum impulse noise protection value that can provide adequate impulse noise protection. The current technique includes the steps of an operator, or service provider, configuring the ADSL connection with a specific noise protection value, the ADSL connection is initialized and the transceivers enter into steady state data transmission (i.e., Showtime), and if the connection is stable, i.e., error-free, then the service is acceptable and the process ends. If there are bit errors, then the process is repeated with the operator, or service provider, configuring the ADSL connection with another specific INP value.

One exemplary problem with this approach is that it is time consuming and can result in sub-optimum user rates. This is illustrated with reference to the following examples:

Example 1: Assume that for a particular DSL connection there is high impulse noise and the required INP is 8. As a result, if the service provider uses a first INP configuration of 2, the DSL connection will not be error free. Therefore, the service provider needs to configure a higher INP value and reinitialize the connection. If a value of 4 is used as a second INP value, it still will not provide adequate impulse noise protection and bit errors will occur. Again, the service provider will need to configure a higher INP value until the correct value of 8 is configured. Clearly, the connection needs to be re-initialized every time there is a new INP configuration chosen and this trial and error technique proves to be very time consuming

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Example 2: Assume that for a particular DSL connection there is high-impulse noise and the required INP is 4. As a result, if the service provider uses a first INP configuration of 2, the connection will not be error free. Therefore, the service provider needs to configure a higher INP value and reinitialize the connection. In order to save time and not go through the number of initializations has occurred in Example 1, the service provider simply configures the system to the maximum INP value of 32. Obviously, there will be no bit errors with INP=32 since this connection needs only an INP value of 4. As a result, user data throughput is greatly degraded since the additional FEC redundancy will be three times higher than what is actually needed. For example, if the INP of 4 requires 10 percent FEC redundancy, an INP of 32 requires 40 percent FEC redundancy which results in a 30 percent decrease in user data rate.

SUMMARY

In addition to the above drawbacks, the related systems do not have the ability to actually measure the length or repetition period of impulse noise which can both be used to determine an appropriate impulse noise protection setting.

Exemplary aspects of this invention relate to determining the impact of impulse noise on a communication system and the capability to determine how the system should be configured to handle the impulse noise event.

An exemplary aspect of this invention determines the impact of impulse noise by transmitting and receiving using a plurality of different FEC and interleaving parameter settings. For each FEC and Interleaving Parameter (FIP) setting, the received signal quality is determined by, for example, detecting if there are bit errors after the receiver performs the FEC decoding and deinterleaving. Based on this, the appropriate FIP setting is selected and used for transmission and reception.

A plurality of FIP settings can be used for transmission and reception. In accordance with one particular aspect of this invention, the system can transition from one FIP setting to another FIP setting without going through the startup initialization procedure such as the startup initialization sequence utilized in traditional xDSL systems. For example, an xDSL system that implements the systems and methods described herein could start using an FIP setting of (N=255, K=247, R=8, D=64) and then transition to an FIP setting of (N=255, K=239, R=16, D=64) without re-executing the startup initialization procedure.

Knowing that the first FIP setting has a BECC=256 bytes and the second setting has a BECC=512 bytes, means, for example, that the second setting can correct an impulse that causes twice as many bit errors as the first FIP setting. On the other hand, the first FIP setting has less FEC parity (overhead) which results in a higher information (net) data rate for the user during Showtime. This is also illustrated by the fact that K, the number of information bytes per code word, is higher for the first FIP setting. For each of the FIP settings, the receiver detects whether there are bit errors after the decoding and deinterleaving process. This detection can be done by, for example, by performing a cyclic redundancy check (CRC) after the decoding and deinterleaving process is complete as defined in the ITU standard G.992.x. In general, the CRC is a well-known method for detecting bit errors. Since impulse noise occurs at random times, this system can operate using a particular FIP setting for a period of time that is sufficient to encounter the impulse noise. In the simple example illustrated above, only the K and R values were modified. It should be appreciated however, that the systems and methods of this

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invention are not limited thereto but rather can be extended to include the modification of any one or more FIP parameter(s).

The process of determining the impact of impulse noise by transmitting and receiving using a plurality of FIP settings can be done while in steady-state transmission, i.e., Showtime for DSL systems, when user information bits are being transmitted.

The process of determining the impact of impulse noise by transmitting and receiving using a plurality of FIP settings, can be done during a special impulse noise training period during which the system is not actually transmitting user data. In accordance with this exemplary aspect of the invention, the standard xDSL procedure is modified to include the capability of measuring the effectiveness of a chosen impulse noise protection (INP) setting during initialization and having receiver-controlled updates of transmission parameters that control the INP setting, e.g., FEC parameters and interleaving parameters, during initialization.

A new initialization state is included in the xDSL initialization procedure that provides the capability to measure the effectiveness of the current INP settings. The new initialization state will be referred to as the INPTraining state and it can, for example, follow the exchange of the Showtime transmission parameters such as the bi/gi table, trellis coding, tone reordering, FEC/interleaving parameters, etc. It is important to note that steady-state transmission during which user information is transmitted is known as "Showtime" in xDSL systems and that standard ITU G.992.3 ADSL systems and ITU VDSL G.993.3 systems include an exchange phase in initialization during which the Showtime parameters are exchanged, see, for example, G.992.3 and G.993.1.

During this INPTraining state, the transceivers transmit and receive using at least one of the standard Showtime functions using the Showtime parameters, e.g., bi/gi table, FEC/interleaving parameters, etc., that are exchanged during the previous exchange phase. These functions include at least one of Showtime PMD functions, e.g., bi/gi table, trellis coding, tone reordering, etc., PMS-TC functions, such as framing and FEC/interleaving, and TPS-TC functions. During the INP-Training state, the TPS-TC can transmit idle ATM cells, HDLC flags, or 64/65 idle packets depending on the TPS-TC type.

At the receiver, the CRC, the FEC, the TPS-TC error detection capabilities, and other receiver functions can be used to determine whether the INP setting is adequate for the current impulse noise conditions on the line. The receiver can also use these receiver functions to automatically and dynamically determine what the correct INP setting should be. If the current INP setting is not adequate, a new set of Showtime transmission parameters can be exchanged and the process repeated by reentering the INPTraining state using the newly exchanged Showtime transmission parameters. If, on the other hand, the current INP setting is adequate, the transceivers can enter into Showtime.

An exemplary advantage associated with this aspect of the invention is that the receiver can measure the effectiveness of the current INP setting and can make updates to the INP setting based on these measurements during initialization. This is important because the receiver generally has the most knowledge of channel conditions, receiver functionality, and processing capability. In general, the receiver has the best capability to make the necessary trade offs between data rate, latency, excess margin, FEC redundancy, coding gain, and the like. Current related ADSL systems have the operator servicing lines that are experiencing high impulse noise by trying various INP settings in an attempt to find an error-free operating mode. However, since the operator is not capable of

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making the receiver trade offs stated above, such as the data rate, latency, and the like, the process will often lead to a sub-optimum result.

Another exemplary aspect of this invention relates to determining the length and/or repetition period of impulse noise events in order to select an appropriate INP setting.

For example, the transceivers can transmit and receive using at least one of the standard Showtime functions and parameters such as the bi/gi table, FEC/interleaving parameters, and the like. These functions include the Showtime PMD functions, such as the bi/gi table, trellis coding, tone reordering and the like, PMS-TC functions (such as framing and FEC interleaving) and TPS-TC functions. The TPS-TC may transmit ATM cells, HDLC packets, or 64/65 packets depending on, for example, the TPS-TC type.

At the receiver, the CRC, the FEC, the TPS-TC error detection capabilities, and other receiver functions can be used to determine the length and the period of the impulse noise and whether an INP setting is adequate for the current impulse noise conditions on the line.

For example, the receiver can determine the length of an impulse noise event. The length of impulse noise events can be determined in a number of ways. For example, they can be determined as:

1. The length of the impulse in time, e.g., how many microseconds the impulse power is above a specific noise level (e.g. the above the stationary channel noise)
2. The number received bits that are affected by the impulse noise, e.g. how many received bits are in error in a specific sliding time window or how many consecutive bits are in error in a stream
3. The number of received ATM cells that are affected by the impulse noise, e.g. how many ATM cells contain bits that are in error. This may be detected using a standard ATM HEC, which is a CRC that covers the ATM header bits. Alternatively this may be detected by checking the ATM payload bits by, for example, transmitting a predefined bit pattern that is known by the receiver
4. The number of 64/65 packets that are affected by the impulse noise, e.g. how many packets contain bits that are in error (the 64/65 CRC can be used for this)
5. The number of received DMT symbols that are affected by the impulse noise, e.g., the measured noise in a DMT symbol is above a predefined threshold which results in most (if not all) the bits in that DMT symbol being in error
6. The number of FEC codewords that are affected by the impulse noise, e.g., how many codewords have an uncorrectable number of bit errors, i.e., the number of bit errors in a codeword exceeds the number of bit that are correctable by the FEC code

In accordance with one exemplary aspect, the FEC correction capability and interleaving is turned off when trying to determine the length of the impulse noise. For example, the FEC may be configured so that there are no parity bits (i.e., R=0) or the FEC may be disabled altogether (i.e., no codewords are sent). Additionally, for example, the interleaving may be disabled by setting the interleaver depth to 1 (i.e., D=1). Disabling the FEC and interleaving is beneficial when trying to determine the length of the impulse noise based on affected bits, affected code words and/or affected packets. This is true since when the FEC/interleaving is enabled, the impulse noise event will be spread over a large time period and it will be more difficult to determine the length of the original impulse.

The exemplary techniques discussed herein that are used to determine the length of the impulse event can also be

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extended to determining the repetition period of the impulse noise event, i.e., how often is impulse noise occurring. The repetition period can be important, because the period has an effect on the FIP setting that is used. For example, if the interleaving spreads an impulse noise event over a period of time that exceeds the impulse period, then the interleaver could combine multiple impulse noise events together. As a result, the FEC correction capability may have to be increased. In order to determine the repetition period of an impulse noise event, the receiver can first detect the impulse noise event as discussed above and then determine how often the impulse noise events occur. For example, periodic impulse noise due to AC power lines occurs at a 120 Hz reception rate, or approximately every 8 ms.

In the case where the impulse noise does not have a fixed length, i.e., where the impulse noise varies over time, the receiver can attempt to determine the maximum impulse noise length. This involves measuring several impulse noise events and determining the impulse noise event with the maximum length. In practice, it is likely that the impulse noise will have varying length and it is important that the FEC/interleaving settings be configured to handle the maximum, e.g., worst case, impulse noise event.

Once the receiver determines the (maximum) length of the impulse noise and/or the repetition period of the impulse noise, this information can be sent to the transmitting modem. In particular, when the receiving modem, such as a Customer-Premises (CPE) modem determines the (maximum) length of the impulse and/or the repetition period of the impulse, the CPE modem could send the information to a Central Office (CO) modem in a message. The length of the impulse length event can be defined and specified in the message in terms of time, received bits, ATM cells, 64/65 packets, DMT symbols, or the like. The CO modem could then, for example, provide this information to the CO-MIB, which is the management interface that is used by the operator or service provider to configure the modems. For example, based on this information, the operator may configure the modems to a different INP value, data rate, latency, or the like. This process could also be automated such that the message received by the CO modem allows automatic reconfiguration to adjust, for example, INP values, data rate, latency, or the like.

The exemplary aspects of the invention that are used to determine the length and/or repetition period of the impulse noise event can be performed during initialization and/or Showtime. During initialization, the method can perform during an INPTraining state such as the one described herein. During Showtime the method can be performed, for example, during a Showtime INP adaptation phase as described herein.

These and other features and advantages of this invention are described in, or are apparent from, the following description of the embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of this invention will be described in relation to the figures, wherein:

FIG. 1 is a functional block diagram illustrating an exemplary impulse noise adaptation system according to this invention;

FIG. 2 illustrates an exemplary initialization state machine that includes an INPTraining state according to this invention;

FIG. 3 is a flowchart outlining an exemplary method for impulse noise protection adaptation during Showtime according to this invention;

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FIG. 4 is a flowchart illustrating an exemplary receiver optimized method for impulse noise protection adaptation according to this invention;

FIG. 5 is a flowchart illustrating an exemplary method for forward error correction synchronization according to this invention;

FIG. 6 is a flowchart illustrating an exemplary method for flag signal synchronization according to this invention; and

FIG. 7 is a flowchart illustrating an exemplary method for determining impulse noise length and period according to this invention.

DETAILED DESCRIPTION

The exemplary embodiments of this invention will be described in relation to adapting impulse noise parameters as well as measuring impulse noise length and repetition period within an xDSL environment. However, it should be appreciated that, in general, the systems and methods of this invention can be applied and will work equally well with any type of communication system in any environment.

The exemplary systems and methods of this invention will be described in relation to xDSL modems and associated communication hardware, software, and communication channels. However, to avoid unnecessarily obscuring the present invention, the following description omits well-known structures and devices that may be shown in block diagram form or otherwise summarized.

For purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the present invention. It should be appreciated however, that the present invention may be practiced in a variety of ways beyond the specific details set forth herein. For example, the systems and methods of this invention can generally be applied to any type of system within any environment in which the impulse noise length and/or period is desired, or for which impulse noise adaptation is desired.

Furthermore, while the exemplary embodiments illustrated herein show the various components of the system collocated in specific locations, it is to be appreciated that the various components of the system can be located or relocated at distant portions of a distributed network, such as a telecommunications network and/or the Internet, or within a dedicated secure, unsecured and/or encrypted system. Thus, it should be appreciated that the components of the system can be combined into one or more devices, such as a modem, or collocated on a particular node of a distributed network, such as a telecommunications network. As will be appreciated from the following description, and for reasons of computational efficiency, the components of the system can be arranged at any location within a distributed network without effecting the operation of the system. For example, the various components can be located in a central office (CO or ATU-C) modem, a customer premises modem (CPE or ATU-R), or some combination thereof. Similarly, the functionality of the system could be distributed between one or more of the modems and an associated computing device.

Furthermore, it should be appreciated that the various links, including communications link 20, connecting the elements can be wired or wireless links, or any combination thereof or any other known or later-developed element(s) that is capable of supplying and/or communicating data to and from the connected elements. The term module as used herein can refer to any known or later-developed hardware, software, or combination of hardware and software that is capable of performing the functionality associated with that element. Furthermore, as used herein, the term “transmitter” has the

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same meaning as the term “transmitting modem” or “transmitting transceiver” and the term “receiver” has the same meaning as “receiving modem” or “receiving transceiver.”

FIG. 1 illustrates an exemplary embodiment of an impulse noise adaptation system 100 according to an exemplary embodiment of this invention. In particular, the system 100 comprises a receiving modem 200 and a transmitting modem 300. The exemplary receiving modem 200 comprises a decoder/deinterleaver 210, a bit error rate (BER) detection module 220, a forward error correction and interleaving parameter (FIP) module 230, an impulse noise length determination module 240, an impulse noise period determination module 250, an impulse noise parameter management module 260, an impulse noise protection adaptation module 270, a synchronization module 280, a message module 290 and a controller and memory (not shown) all interconnected by a link 5. The exemplary transmitting modem 300 comprises a management module 310, a synchronization module 320, a message module 330, and may optionally include an impulse noise parameter management module 340.

In operation, the exemplary communication system adapts the impulse noise parameters on-line by operating using a series of different FIP settings. For each FIP setting, the system can dynamically determine if the appropriate amount of impulse noise protection is being provided. Based on these determinations, the system can select a particular FIP setting for regular, i.e., Showtime, operation. As will be discussed in greater detail hereinafter, this impulse noise protection adaptation can be performed during Showtime and/or during initialization.

Impulse noise protection adaptation during Showtime includes the following exemplary steps. First, the DSL system, i.e., the transmitting and receiving modems, completes regular initialization and commences transmission and reception using a first FIP setting. For DSL systems, this first FIP setting is selected by the receiver 200 and is based on the minimum/maximum data rate, maximum latency, and minimum INP parameters as configured by, for example, the service provider via the management module 310. A detailed explanation of this procedure can be seen in G.992.3.

The system will use this first FIP setting for a period of time T1. During this period, and in conjunction with the BER detection module 220, the receiver 200 detects if bit errors have occurred using this first FIP setting for the decoding and deinterleaving performed by the decoder/deinterleaver 210. For example, the receiver 200 can use a CRC to detect bit errors. If there are no bit errors, then the current INP setting is adequate and there is no need to modify the INP setting and Showtime communication can continue as normal.

However, if bit errors have been detected by the BER detection module 220, an adjustment to the INP setting may be appropriate. For example, a service provider, a user, or the system can choose an updated INP setting. Since bit errors have been detected, the INP setting could be increased by an on-line modification to the FIP parameters. Specifically, the transmitter 300, and for example the management module 310, in response to an indication from the receiver 200 that bit errors have been detected, can send a message to the receiver 200 to initiate a change in the INP settings. The receiver 200, in cooperation with the message module 290, the FIP module 230, the impulse noise parameter management module 260 and impulse noise protection adaptation module 270, can return a message to the transmitter 300 that specifies a newly determined FIP setting that satisfies the new INP requirement.

The transmitter 300 and receiver 200 can then transition to the new INP setting by starting to use the new FIP parameters

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for transmission and reception, respectively, at a synchronized point in time. This synchronization can be done in accordance with a number of exemplary methods that are discussed hereinafter.

Upon synchronization, the system **100** continues communication using the updated FIP settings for a second period of time **T2**. If the receiver detects that bit errors are occurring using this updated FIP setting during the decoding and deinterleaving performed by the decoder/deinterleaver **210** the steps can be repeated with the selection of another updated INP setting. However, if there are no bit errors detected by the receiver **200** during the time period **T2**, then the new INP setting is adequate and there is no need for further change at which point the INP adaptation procedure can end.

This Showtime-based INP adaptation process can be repeated as many times as necessary until an INP setting is obtained that provides the required impulse noise immunity and/or bit error rate.

One advantage of this technique is that the transition between different FIP settings can be accomplished without reinitializing the transceivers using the lengthy standard initialization procedure that is typically used in ADSL and VDSL systems. In contrast, the transition can occur without the standard initialization since the transition between FIP settings can be synchronized between the transmitter and the receiver such that the receiver **200** can determine when to start FEC decoding using the new FIP settings for **K** and **R**. As will be discussed hereinafter, this transition can be synchronized using a number of different exemplary methods.

The transition can also be accomplished without synchronization in which case the receiver **200** will determine when the new FIP settings are used by some alternative means. For example, the receiver could determine when the new FIP settings are being used by FEC decoding using both the old and updated FIP settings and determining which one is currently being utilized by the transmitter by determining with which FIP setting the codeword is correct. Other receiver functions such as CRCs, ATM HEC errors and the like could also be used.

This impulse noise protection adaptation procedure can be performed during regular steady-state transmission, i.e., Showtime in ADSL, using actual user data or, for example, idle ATM cells. This methodology can also be performed during a special impulse noise training period during which the system is not actually transmitting user data. For example, this impulse noise training period could utilize transmitted predefined pseudorandom bit streams or, for example, idle ATM cells or HDLC flags for determining an appropriate INP value.

The length of the time periods **T1**, **T2**, . . . can be controlled by, for example, the receiving modem **200**. The receiving modem **200** could control the length of these time periods by, for example, sending a message that specifies how long the transmitter should transmit using a particular FIP setting. This length can be defined, for example, in terms of the number of DMT symbols or the number of FEC codewords. For example, a message could indicate that 200 DMT symbols should be sent for all FIP settings or 300 FEC code words should be sent for all FIP settings. Alternately, the message can indicate a different number of DMT symbols or FEC code words for each FIP setting. This technique could further be used to aid in determining an appropriate INP setting by forwarding a predetermined number of DMT symbols at a first FIP value, followed by a second number of DMT symbols at a second FIP value, and so on. For each of these sets of DMT symbols and associated FIP values, the receiver could determine the bit error rate, with the cooperation of the BER

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detection module **220**, and then forward a message, with the cooperation of the message module **290**, to the transmitter **300** specifying which FIP setting provided the appropriate impulse noise protection.

Similarly, the transmitting modem **300** and receiving modem **200** could cooperate such that an optimum impulse noise protection value is converged upon. For example, the transmitting modem **300**, with the cooperation of the message module **330**, could forward a message to the receiving modem **200** specifying a first INP setting. If there are no bit errors, a message could be sent via the message module **290** to the transmitting modem **300** indicating that there are no bit errors and a lower INP value could be attempted. The impulse noise parameter management module **260** and FIP module **230** could then determine an appropriate lower INP setting and forward it to the transmitter **300**. As discussed above, since a lower INP value is inversely proportional to the user data rate, it is advantageous to optimize the INP value based on detected errors. The transmitting modem **300**, in cooperation with the message module **330**, could then send another message to the receiving modem **200** indicating that the lower INP value will be transitioned to at which point the procedure repeats itself through detection of bit errors in cooperation with the bit error rate detection module **220** and the decoder/deinterleaver **210**. This reduction in the INP parameters can continue until bit errors are detected at which point a message is sent, with the cooperation of the message module **290**, to the transmitting modem **300** indicating a higher INP value is required since bit errors were detected. Then, for example, based on an evaluation of a convergence of bit errors vs. impulse noise protection parameters, an optimum INP value can be determined and transitioned to by the receiver **300** and transmitter **200**. This procedure could also be used to increase the INP parameters in a similar fashion.

The length of the time periods **T1**, **T2**, . . . can also be controlled by the transmitter **300**. For example, the transmitter **300** could control the length of these time periods, by, for example, sending a message to the receiver **200** that specifies the length of time the transmitter will transmit using a particular FIP setting. This length could be defined in terms of the number of DMT symbols or, for example, the number of FEC codewords. The exemplary message could indicate that, for example, 200 DMT symbols would be sent for all FIP settings or 300 FEC codewords will be sent for all FIP settings. The message could also indicate a different number of DMT symbols or FEC codewords for each FIP setting. In general, the message could contain any type of information relating to how long the transmitter will be using a specific FIP setting(s).

The length of the time periods **T1**, **T2**, . . . can also be controlled by, for example, a service provider or a user. For example, the service provider could configure through the management module **310** a minimum time **X=10** seconds to be used for testing each FIP setting. The service provider could use the knowledge of the nature of the impulse noise, such as how often impulse noise event occurs, to determine the times. However, and in general, the length of the time periods could be configured to be any length of time as appropriate.

As discussed above, when a determination is made that there are bit errors and an increase in the INP setting is desirable, the receiving modem **200** can determine the new INP settings. However, it should be appreciated that the transmitting modem **300**, in cooperation with the impulse noise parameter management module **340** could also determine updated INP settings. For example, either modem could con-

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tinually adapt the INP values as discussed above until no bit errors that are the result of impulse noise are detected by the BER detection module 220.

As alluded to above, the receiver and transmitter can synchronize the modification of the FEC and interleaving parameters such that the both the transmitter and receiver start using the parameters at the same instant in time. This synchronization can be based on, for example, a synchronization using FEC codeword counters or a flag signal.

For synchronization using FEC codeword counters, the receiver 200 and transmitter 300 can synchronize the change in cooperation with the sync modules 280 and 320, by counting the FEC codewords from the beginning of Showtime and the transition would occur when a specific FEC codeword counter value that is known by both the transmitter 300 and the receiver 200 is reached. Prior to the transition point, the transmitter 300 or receiver 200 in cooperation with the message module 290 and message module 330, would send a message indicating the FEC codeword count value on which the FIP parameters will be updated. For example, the transmitting modem 300 can enter into Showtime and the synchronization module 320 commences counting the number of transmitted FEC codewords. For example, the first codeword transmitted has a count value of 0, the second transmitted codeword has a count value of 1 The counter can optionally be defined as having a finite length, for example, 0 to 1023 (10 bits) such that when the value of 1023 is reached, on the next FEC code word that is transmitted, the counter restarts at the value of 0.

Similarly, the receiving modem 200 upon entering Showtime starts a counter in cooperation with the synchronization module 280 that counts the number of received FEC codewords. The first received FEC codeword has a count value of 0, the second received FEC codeword to the count value of 1 As with the synchronization module 320, the synchronization module 280 can have a counter with a finite length, for example 0-1023, such that when the value of 1023 is reached, on the next FEC codeword the counter restarts at 0.

At some point, for example, based on detected bit errors, the user, a service provider, or the like, it is determined that an updated FIP setting is needed. The receiving modem 200 can send a message, via the message module 290, to the transmitting modem 300, and in particular the message module 330 and impulse noise parameter management module 340. The updated FIP setting can alternatively be sent from the transmitting modem to the receiving modem.

The synchronization module 280 and message module 290 then cooperate to send a message to the transmitting modem 300 specifying the FEC codeword counter value on which the new FIP settings are to be used for transmission and reception. Alternatively, the transmitting modem, in cooperation with the message module 330, can send a message to the receiving modem indicating the FEC codeword counter value on which the FIP settings are to be used for transmission and reception. For example, the message can indicate that when the code word counter equals 501, the new FIP setting will be used for transmission and reception.

When the transmitter FEC codeword counter equals the value indicated in the message, the synchronization module 220 instructs the transmitting modem 300 to transition to the new FIP settings. Similarly, when the synchronization module 280 in the receiving modem 200 counts the FEC codeword that equals the value indicated in the message, the receiving modem 200 transitions to using the new FIP settings for reception.

Synchronization can also be performed through the use of a flag signal (sync flag). For this exemplary embodiment, the

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receiving modem 200 and transmitting modem 300, in cooperation with the synchronization module 280 and synchronization module 320, synchronize the change in FIP settings using a flag or marker signal that is similar to that used in the ADSL2 G.992.3 ORL protocol. This protocol may be more desirable than using an FEC codeword counter because, for example, it has greater impulse noise immunity.

For synchronization using a flag signal, the receiver and transmitter would start using updated FEC and interleaving parameters on a pre-defined FEC codeword boundary following the sync flag. For example, while transmitting using a first INP setting, a determination is made by, for example, the BER detection module 220 that a new FIP setting is needed due to the presence of impulse noise on the line. This determination can be performed by the receiving modem, in cooperation with the FIP module 230, the transmitting modem, a user, a service provider, or the like. The receiving modem 200, in cooperation with the message module 290, sends a message to the transmitting modem 300 indicating the new FIP settings to be used for transmission and reception. Alternatively, the transmitting modem, in cooperation with the message module 330, prepares and sends a message to the receiving modem indicating the updated FIP settings to be used for transmission and reception.

The transmitting modem then sends a flag or marker signal to the receiving modem 200 indicating that the new FIP settings are to be used on a predetermined number of DMT symbols following the transmission of the flag or marker signal. For example, the flag signal could be an inverted sync symbol, or sync FLAG, as used in the ADSL2 G.992.3 OLR protocol. The transmitting modem 300 then starts using the new FIP settings for transmission on the predetermined number of DMT symbols following the transmission of the flag or marker signal. Similarly, the receiving modem starts using the new FIP settings for reception once the predetermined number of DMT symbols following the receipt of the flag or marker signal have been received.

EXAMPLE 1

On-Line INP Adaptation FIP Setting

This section describes an example of FIP settings for On-Line INP adaptation for DSL. In this example only the number of information bytes in a codeword (K) and the number of parity bytes in a codeword (R) are updated on-line. The Codeword Size (N) and Interleaver Depth (D) are not changed. This means that the latency (and interleaver memory size) and the line rate are not modified on-line. Since $N=K+R$ this places restrictions on the allowed values for K and R.

1st Setting—{Approximate User Data Rate=3.968 Mbps, Line Rate=4.096 Mbps, N=128, K=124, R=4, S=1, D=64, Latency=16 msec, INP=1}

2nd Setting—{Approximate User Data Rate=3.840 Mbps, Line Rate=4.096 Mbps, N=128, K=120, R=8, S=1, D=64, Latency=16 msec, INP=2}

3rd Setting—{Approximate User Data Rate=3.584 Mbps, Line Rate=4.096 Mbps, N=128, K=112, R=16, S=1, D=64, Latency=16 msec, INP=4}

The On-line INP adaptation process is restricted to only modify the number of information bytes in a codeword (K) and the number of parity bytes in a codeword (R). The FEC Codeword Size ($N=K+R$) and Interleaver Depth (D) are not changed. This means that the latency (or interleaver memory size) and the line rate are not modified on-line. However the user data rate will change during the process since K is being modified. Also since the line rate and the FEC codeword size

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are not modified, the S value does not change in the process. It is important to note that with these constraints, the On-line INP adaptation process can be done in a seamless manner (no bit errors and service interruption). This means provided that the modification if the FIP setting is restricted to K and R, the transition between FIP settings can be done in a seamless manner. This is the case because if the codeword size N and the interleaver depth D are not modified, the transition can happen without the problem of "interleaving memory flushing." Interleaver memory flushing is a well-known problem in which errors occur because interleaver and deinterleaver memory locations are overwritten due to on-line changes in the codeword size (N) and or interleaver depth (D).

EXAMPLE 2

On-Line INP Adaptation FIP Setting

This section describes an example of FIP settings for On-Line INP adaptation for DSL. In this example only the Codeword Size (N) and the number of parity bytes in a codeword (R) are updated on line. The number of information bytes in a codeword (K) and Interleaver Depth (D) are not changed and therefore the user data rate does not change. This means that the latency (and interleaver memory size) and the line rate are modified on-line. Since $N=K+R$ this places restrictions on the allowed values for K and R.

1st Setting—{Approximate User Data Rate=3.968 Mbps, Line Rate=4.096 Mbps, N=128, K=124, R=4, S=1, D=64, Latency=16 msec, INP=1}

2nd Setting—{Approximate User Data Rate=3.968 Mbps, Line Rate=4.224 Mbps, N=132, K=124, R=8, S=1, D=64, Latency=16 msec, INP=2}

3rd Setting—{Approximate User Data Rate=3.968 Mbps, Line Rate=4.480 Mbps, N=128, K=124, R=16, S=1, D=64, Latency=16 msec, INP=4}

In this example the Line Rate is modified on-line. For this reason it is necessary to also complete a rate adaptation process in order to complete this On-Line INP adaptation. A method for Seamless Rate Adaptation is described in U.S. Pat. No. 6,498,808.

While these examples restrict the changes to a subset of the FIP parameters, they can obviously be extended to cover any combination of the FIP parameters (N, K, R and D). For example, the value of D could also be modified in addition to the values of K, R and N. This could result in a change in the required interleaver memory and latency. In order to keep the memory and latency constant it is necessary to change the codeword size (N) accordingly when changing the interleaver depth (D). For example, if the interleaver depths is changed from D=64 to D=128, the Codeword size would have to be decreased by a factor of 2 so that overall latency is constant.

FIG. 2 illustrates an exemplary modified initialization state machine that includes the INPTraining state prior to Showtime. This state machine is based on the VDSL G.993.1 ITU standard. As defined in G.993.1, VTU-O is the VDSL Transceiver Unit at the Optical Network Unit (ONU) and VTU-R is the VDSL Transceiver Unit at the Remote terminal. The Initialization state machine in FIG. 2 is an example of how INPTraining states could be included in a modified VDSL initialization procedure. While exemplary FIG. 1 includes the INPTraining state at a specific time in the initialization sequence, the INPTraining state can be included at any time during initialization provided that it is preceded by a state during which Showtime parameters are exchanged between the transceivers.

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O-P-INPTrain

During the O-P-INPTrain State the VTU-O transmitter transmits DMT Symbols using the standard PMD, PMS-TC and TPS-TC SHOWTIME functions with parameters exchanged during the previous Exchange Phase. During this state, the TPS-TC transmits idle ATM cells, HDLC flags or 64/65 idle packets. SOC is inactive during this state.

This state is used by the VTU-R to determine the correct DS INP setting based on Impulse Noise conditions on the line. For example, the downstream CRC, FEC error detection, TPS-TC error detection capabilities, and other receiver functions can be used to determine whether the INP setting is adequate. The receiver can also use these receiver functions to determine the correct INP setting.

If the VTU-R determines that the current INP setting is not adequate, the VTU-R transmits the R-P-ISYNCHRO2 signal to indicate the need to transition back to the Exchange Phase in order to exchange new transmission parameters.

If the VTU-R determines that the current INP setting is not adequate, the VTU-R transmits the R-P-SYNCHRO2 signal to indicate that it is OK to transition to Showtime with the current transmission parameters.

R-P-INPTrain

During the R-P-INPTrain State the VTU-R transmitter transmits DMT Symbols using the standard PMD, PMS-TC and TPS-TC Showtime functions with parameters exchanged during the previous Exchange Phase. During this state, the TPS-TC transmits idle ATM cells, HDLS flags or 64/65 idle packets. SOC is inactive during this state.

This state is used by the VTU-O to determine the correct US INP setting based on Impulse Noise conditions on the line. For example, the upstream (US) CRC, FEC error detection, TPS-TC error detection capabilities, and other receiver functions can be used to determine whether the INP setting is adequate. The receiver can also use these receiver functions to determine the correct INP setting.

If the VTU-O determines that the current INP setting is not adequate, the VTU-O transmits the O-P-ISYNCHRO2 signal to indicate the need to transition back to the Exchange Phase in order to exchange new transmission parameters.

If the VTU-O determines that the current INP setting is not adequate, the VTU-O transmits the O-P-SYNCHRO2 signal to indicate that it is OK to transition to Showtime with the current transmission parameters.

O-P-SYNCHRO2

The O-P-SYNCHRO2 is the same as defined in the current VDSL1. As in VDSL1, the VTU-O transmitter enters Showtime after transmitting the O-P-SYNCHRO2 signal.

But, if the VTU-R has not also entered into Showtime, the VTU-O waits for receipt of the R-P-SYNCHRO2 or R-P-ISYNCHRO2. If the VTU-O receives the R-P-SYNCHRO2 it continues in Showtime. If the VTU-O receives the R-P-ISYNCHRO2, the VTU-O transmitter transitions back to the beginning of the O-P-MEDLEY state.

R-P-SYNCHRO2

The O-P-SYNCHRO2 is the same as defined in the current VDSL1. As in VDSL1, the VTU-R transmitter enters Showtime after transmitting the R-P-SYNCHRO2 signal.

But, if the VTU-O has not also entered into Showtime, the VTU-R waits for receipt of the O-P-SYNCHRO2 or O-P-ISYNCHRO2. If the VTU-R receives the O-P-SYNCHRO2 it continues in Showtime. If the VTU-R receives the O-P-ISYNCHRO2, the VTU-R transmitter transitions back to the beginning of the R-P-MEDLEY state.

O-P-ISYNCHRO2

The O-P-ISYNCHRO2 is phase-inverted version of the O-P-SYNCHRO2, i.e., a subcarrier-by-subcarrier 180

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degrees phase reversal. The VTU-O transmitter transitions to the beginning of the O-P-MEDLEY state after transmitting the O-P-ISYNCHRO2 signal.

R-P-ISYNCHRO2

The R-P-ISYNCHRO2 is phase-inverted version of the R-P-SYNCHRO2, i.e., a subcarrier-by-subcarrier 180 degrees phase reversal. The VTU-R transmitter transitions to the beginning of the R-P-MEDLEY state after transmitting the R-P-ISYNCHRO2 signal

Exemplary Overview State Transition Rules Based on SYNCHRO2 and the ISYNCHRO2 signals:

If either the VTU-O or the VTU-R transmits the ISYNCHRO2 signal then both VTU-R and VTU-O transition back to beginning of the MEDLEY state.

If both the VTU-O and the VTU-R transmit the SYNCHRO2 signal then both the VTU-R and the VTU-O transition into Showtime.

There are several important points regarding this exemplary embodiment. First, the receiver can measure the efficiency of the plurality of INP settings without completing a new initialization procedure such as is used in ADSL and VDSL systems. Second, the length of the time of the O-P-INPTrain and R-P-INPTrain states can be controlled by the VTU-R and VTU-O respectively. In this way the receivers have adequate time to determine if the current INP setting is correct. In order to accomplish this, prior to entering the R-P-INPTrain state, the VTU-O can transmit a message to the VTU-R indicating the minimum length of the R-P-INPTrain state. Likewise, prior to entering the O-P-INPTrain state, the VTU-R can transmit a message to the VTU-O indicating the minimum length of the O-P-INPTrain state. For example, the message could indicate that a minimum of 20000 DMT symbols should be sent during the O-P-INPTrain state. Additionally, the length of the time of the O-P-INPTrain and R-P-INPTrain states could be set by the DSL service provider in order to make sure that the initialization does not take too long or because the service provider may have some knowledge of the statistics of the impulse noise which require setting the length of the INPTrain states. In this exemplary case a message could be sent from the VTU-O to the VTU-R indicating the minimum and/or maximum length of the O-P-INPTrain and/or the R-P-INPTrain states. For example, the message could indicate that a minimum of 20000 DMT symbols should be sent during the R-P-INPTrain state. Also, for example, the message could indicate that a maximum of 40000 DMT symbols should be sent during the R-P-INPTrain state.

The length of the time of the O-P-INPTrain and R-P-INPTrain states could also be controlled by the VTU-O and VTU-R respectively. In this case, the transmitters will have control of the state lengths. In order to accomplish this, prior to entering the R-P-INPTrain state, the VTU-R can transmit a message to the VTU-O indicating the minimum length of the R-P-INPTrain state. Likewise, prior to entering the O-P-INPTrain state, the VTU-O can transmit a message to the VTU-R indicating the minimum length of the O-P-INPTrain state. For example, the message could indicate that a minimum of 20000 DMT symbols should be sent during the O-P-INPTrain state.

As discussed above, another exemplary aspect of this invention relates to determining the length and/or repetition period of impulse noise events in order to select an appropriate INP setting.

The INP length can be determined using any one of a plurality of metrics. For example, the INP length can be determined based on one or more of:

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- 1) The length of the impulse in time
- 2) The number of received bits that are affected by the impulse noise
- 3) The number of received ATM cells that are affected by the impulse noise
- 4) The number of 64/65 packets that are affected by the impulse noise
- 5) The number of received DMT symbols that are affected by the impulse noise
- 6) The number of FEC codewords that are affected by the impulse noise

As an example, assume that length of the impulse noise is 700 microseconds (Example 1). At a data rate of 1 Mbps this could correspond to an impulse noise length of 700 bits (Example 2) assuming that all impulse noise was high enough to affect all 700 bits in the 700 microsecond period. This also could correspond to a impulse noise length of $700/(53*8) = 1.65$ ATM cells since there are 53 bytes in a ATM cell (Example 3). This also could correspond to an impulse noise length of $700/(65*8) = 1.35$ 64/65 packets since there are 65 bytes in a 64/65 packet (Example 4). This also could correspond to an impulse noise length of $700/(250) = 2.8$ DMT symbols (INP=2.8) assuming the DMT symbol rate is 4 kHz (250 microseconds DMT symbol length) (Example 5).

As an example, the determination of the INP length with the number of received bits that are affected by impulse noise can be performed in accordance with the following procedure. Initially, the transmitting modem 300 transmits data using at least one of the Showtime functions. In accordance with a first exemplary embodiment, at least the bit allocation table is used. In addition, or alternatively, the trellis coder, framer, and TPS-TC functions may also be used. Additionally, or alternatively still, the interleaving and FEC may also be used.

The receiving modem 200 receives data using at least one of the Showtime functions, such as the bit allocation table as discussed above. Similarly, the trellis coder, framer, TPS-TC and/or interleaving and FEC can be used.

The transmitter 300 then transmits a predefined bit pattern that is used for determining or measuring the impulse noise length based on detected erroneous bits. The receiving modem 200 compares, with the assistance of the impulse noise length determination module 240, the predefined bit pattern to the received bit pattern in order to detect bit errors. Since impulse noise events typically cause a burst of errors in a bit stream, the receiving modem 200 determines the length of the impulse noise event by detecting and determining the length of the error burst.

Once the receiver 200 determines the length of the impulse noise, the receiving modem 200, in cooperation with the message module 290, sends a message to the transmitter 300 that indicates the determined length of the impulse noise.

In accordance with an exemplary embodiment, the FEC correction capability and interleaving is turned off when trying to determine the length of the impulse noise, e.g., R=0 and D=1. Disabling the FEC and interleaving is beneficial when trying to determine the length of the impulse noise based on affected bits, affected code words, or affected packets. This is the case because if the FEC/interleaving is enabled, the impulse event can be spread over a large time period which makes it more difficult to determine the length of the original impulse.

The exemplary methodology discussed above can also be used to determine the length of the impulse event using other metrics. For example, a predefined bit pattern could be used in the payload of the ATM cells or the 64/65 packets. Idle packets or cells, which carry a predefined pattern, could also be used. In these cases, the receiver would compare the received

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data to the predefined data to determine the length of the impulse or to determine if an INP setting is adequate. Alternatively, the CRC of the ATM cell or 64/65 packet could be used to determine the length of the impulse noise. This would provide a coarser measurement of the impulse noise length since it would be an integer number of packets or cells. In this example, a 700 bit impulse would cause CRC errors in two ATM cells so the length of the impulse noise would be two ATM cells, as opposed to the more precise measurement of 1.64 above. Likewise, in this example, a 700 bit impulse would cause CRC errors in two 64/65 packets so the length of the impulse noise would be two packets, as opposed to the more precise measure of 1.35 above.

Likewise, a predefined bit pattern could also be used to modulate the carriers in the DMT symbols so that the receiver would know what DMT symbols were transmitted. In this case, the receiver 200 would determine how many DMT symbols were corrupted by comparing the received signal with a known transmitted signal.

The exemplary techniques used to determine the length of the impulse noise event could also be extended to determine the repetition rate of the impulse noise event in cooperation with the impulse noise period determination module 250. In order to determine the repetition period of an impulse noise event, the receiver 200 detects the impulse noise event as discussed above and then determines how often they occur. For example, periodic impulse noise due to AC power lines occur at 120 Hz reception rates or approximately every 8 ms. The receiver 200 could, for example, also store information about past impulse noise events and compare detected impulse noise events to historical events. The impulse noise period determination module 250 could then determine which events of a similar duration are occurring at what interval. This information could then be used in determining an appropriate INP setting.

Once the receiver 200 determines the (maximum) length of the impulse and/or the repetition period of the impulse, the information, with the cooperation of the message module 290 can be sent to the transmitting modem. For example, when the receiving modem 200 determines the (maximum) length of the impulse and/or the repetition period of the impulse, the impulse noise period determination module 250, in cooperation with the message module 290 can forward information to the transmitting modem that quantifies this period. The transmitting modem 300 could provide this information to, for example, the management module 310, that would allow, for example, an operator or service provider to configure the modems. For example, based on the period information contained in the message, the operator may configure the modems to different INP values, data rates, latency, or the like.

The receiver 200 could also test a specific INP setting by detecting how many received bits are errored in a specific time period. For example, if the specific INP setting enables the correction of 100 bits in an 8 msec. time period then the receiver 200 could detect how many bits are errored in a sliding 8 msec. window. If less than 100 bits are detected in error in the 8 ms sliding window, then the INP setting is adequate.

If more than 100 bits are detected in error in a sliding window, then the INP setting is not adequate, and the FEC/interleaving needs to be changed to provide more error correction capability.

Likewise, instead of using the received number of bits that are effected by the impulse noise, the receiver could test a specific INP setting by detecting how many received ATM

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cells, 64/65 packets, DMT symbols, and/or FEC corrections are affected in a specific time period.

FIG. 3 outlines an exemplary method for performing impulse noise protection adaptation during Showtime according to this invention. In particular, control begins in step S300 and continues to step S310. In step S310, traditional DSL initialization occurs. Next, in step S320, Showtime is entered between the two modems using the first FIP setting that was determined during the initialization in step S310. Then, in step S330, a determination is made whether bit errors are occurring using the first FIP setting. If bit errors are not occurring, control continues to step S340 where the control sequence ends. Otherwise, control jumps to step S350.

In step S350, a determination is made that an increase of the INP setting is required that requires modification of the FIP parameters. Next, in step S360, updated INP parameter is determined and a message forwarded to the receiver specifying the new INP setting. Then, in step S370, the receiver forwards to the transmitter updated FIP parameters for the new impulse noise protection requirements. Control then continues to step S380.

In step S380, the transmitter and receiver transition to using the updated INP parameters at a synchronization point. Next, in step S390 Showtime operation continues. Control then continues back to step S330.

FIG. 4 outlines an exemplary method for receiver optimized impulse noise protection adaptation during Showtime. In particular, control begins in step S400 and continues to step S410. In step S410, the DSL system completes regular initialization. In particular, control begins in step S400 and continues to step S410. In step S410, the DSL system completes startup initialization and continues into Showtime in step S420 using a first FIP setting. Control then continues to step S430 where a determination is made whether bit errors are occurring using the first FIP setting. If bit errors are not occurring, control continues to step S440 where the control sequence ends.

Otherwise, control jumps to step S450 where the receiver increases the impulse noise protection by modifying the FIP parameters. Next, in step S460, a synchronization point is determined between the transmitter and receiver, and when the synchronization point is reached both the transmitter and the receiver transition to the updated FIP setting in step S470 and Showtime communications continue and control returns back to step S430.

FIG. 5 illustrates an exemplary method for synchronization of the modified FEC and interleaving parameters according to this invention. In particular, control begins in step S500 and continues to step S510. In step S510, the transmitter enters Showtime and counts the number of transmitted FEC codewords. Next, in step S520, the receiver enters Showtime and counts the number of received FEC codewords. Then, in step S530, after a determination is made that an updated FIP setting is needed, the receiving modem sends a message to the transmitting modem indicating a new FIP setting that is to be used for transmitting and reception or, alternatively, the transmitting modem sends a message to the receiving modem indicating the new FIP setting to be used for transmission and reception. Control then continues to step S540.

In step S540, a message with the FEC codeword counter value on which the new FIP values are to be used is exchanged. Next, in step S550, a determination is made whether the counter value has been reached at the transmitter. If the counter value has not been reached, the next codeword is counted in step S560 and control continues back to step S550.

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Otherwise, if the counter value has been reached, control jumps to step S570. In step S570, the transmitter transitions to the new FIP setting. Next, in step S580, a determination is made whether the counter value has been reached at the receiving modem. If the counter value has not been reached, the next received FEC codeword is counted in step S585 and control continues back to step S580. However, when the counter value has been reached in the receiving modem, control jumps to step S590 where the receiving modem switches to the new FIP value. Control then continues to step S595 where the modems continue Showtime communication and control continues to step S597 where the control sequence ends.

FIG. 6 illustrates an exemplary method of synchronization using a flag signal according to this invention. In particular, control begins in step S600 and continues to step S610. In step S610, the modems enter Showtime using the first FIP parameters. Next, in step S620, a message is exchanged indicating the new FIP settings. Then, in step S630, the transmitter forwards to the receiver a flag signal indicating when the new FIP settings are to be used.

At step S640, and at a predefined change time following the transmission of the flag signal, the transmitter begins transmission using the new FIP parameters. Next, at step S650, at the predefined change time following the reception of the flag signal, the receiver commences reception utilizing the new FIP parameters. Control then continues to step S660 where Showtime communication continues with the control sequence ending at step S670.

FIG. 7 illustrates an exemplary method of impulse noise length and period determination. In particular, control begins in step S700 and continues to step S710. In step S710, the transmitter transmits data using at least one Showtime function. Next, in step S720, the receiver receives data using at least one Showtime function. Then, in step S730, the transmitter transmits predefined information to the receiver. Control then continues to step S740.

In step S740, the receiver receives the predefined information from the transmitter. Next, in step S750, the receiver compares the received predefined information to the predefined information and determines the differences (i.e., errors) between the two. Then, in step S760, and based on the detected errors, the length of the burst error is determined. Next, in step S770, a message is forwarded to the transmitter indicating the length of the impulse noise event. Control then continues to step S780 where a determination is made whether the period of the impulse noise event is also to be determined. If the period is not to be determined, control continues to step S790 where the control sequence ends. Otherwise, control jumps to step S800.

In step S800, and once the length of the impulse noise event is known, the receiver detects how often the impulse noise events occur. For example, historical information regarding the length and timing of previous impulse noise events can be stored in a memory (not shown). Then, a comparison can be made with the aid of a processor (not shown) to compare an impulse noise event to the historical information to determine the period of repetition (if any) of similar impulse noise events and, for example, a message indicating the period as well as the timing forwarded to, for example, another transceiver, the CO, or in general any destination as appropriate. Thus, in a similar manner, this information can be forwarded in step S810 to, for example, the transmitter in a message specifying the repetition frequency of the impulse noise event. Control then continues to step S820 where the control sequence ends.

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The above-described system can be implemented on wired and/or wireless telecommunications device(s), such as a modem, a multicarrier modem, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a linecard, test equipment, a multicarrier transceiver, a wired and/or wireless wide/local area network system, a satellite communication system, a modem equipped with diagnostic capabilities, or the like, or on a separate programmed general purpose computer having a communications device.

Additionally, the systems, methods and protocols of this invention can be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element(s), an ASIC or other integrated circuit, a digital signal processor, a hard-wired electronic or logic circuit such as discrete element circuit, a programmable logic device such as PLD, PLA, FPGA, PAL, modem, transmitter/receiver, or the like. In general, any device capable of implementing a state machine that is in turn capable of implementing the methodology illustrated herein can be used to implement the various communication methods, protocols and techniques according to this invention.

Furthermore, the disclosed methods may be readily implemented in software using object or object-oriented software development environments that provide portable source code that can be used on a variety of computer or workstation platforms. Alternatively, the disclosed system may be implemented partially or fully in hardware using standard logic circuits or VLSI design. Whether software or hardware is used to implement the systems in accordance with this invention is dependent on the speed and/or efficiency requirements of the system, the particular function, and the particular software or hardware systems or microprocessor or microcomputer systems being utilized. The communication systems, methods and protocols illustrated herein however can be readily implemented in hardware and/or software, or any means, using any known or later developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

Moreover, the disclosed methods may be readily implemented in software, that can be stored on a storage medium, and executed on programmed general-purpose computer, a special purpose computer, a microprocessor, or the like. In these instances, the systems and methods of this invention can be implemented as a program embedded on personal computer such as JAVA® or CGI script, as a resource residing on a server or computer workstation, as a routine embedded in a dedicated communication system or system component, or the like. The system can also be implemented by physically incorporating the system and/or method into a software and/or hardware system, such as the hardware and software systems of a communications transceiver.

It is therefore apparent that there has been provided, in accordance with the present invention, systems and methods for impulse noise adaptation. While this invention has been described in conjunction with a number of embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable arts. Accordingly, it is intended to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and scope of this invention.

The invention claimed is:

1. In a transceiver, a method of adapting forward error correction and interleaver parameter (FIP) settings of the transceiver during steady-state communication or initialization comprising:

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transmitting, by the transceiver, a signal using a first FIP setting;

transmitting, by the transceiver, a flag signal; and
switching, by the transceiver, to using, for transmitting, a
second FIP setting following transmission of the flag
signal,
wherein:

the first FIP setting comprises at least one first FIP value,
the second FIP setting comprises at least one second FIP
value, different than the first FIP value, and
the switching occurs on a pre-defined forward error cor-
rection codeword boundary following the flag signal.

2. The method of claim 1, wherein a first forward error
correction parameter value of the first FIP setting is different
than a second forward error correction parameter value of the
second FIP setting.

3. The method of claim 1, wherein a first interleaver param-
eter value of the first FIP setting is different than a second
interleaver parameter value of the second FIP setting.

4. The method of claim 1, wherein the adapting of the FIP
settings is based on a service provider configuration.

5. The method of claim 1, further comprising transmitting
the flag signal on a telephone line that experiences impulse
noise from external sources including one or more of AM
radio, HAM radio and AC power lines.

6. The method of claim 1, wherein the method is performed
in a linecard that includes a management interface that is used
by an operator or service provider to configure a service.

7. The method of claim 1, wherein the method is performed
in a Customer Premises Equipment (CPE) that includes a
management interface that is used by an operator, a service
provider or service user.

8. An apparatus configurable to adapt forward error cor-
rection and interleaver parameter (FIP) settings during
steady-state communication or initialization comprising:

a transceiver, including a processor, configurable to:
transmit a signal using a first FIP setting,
transmit a flag signal, and
switch to using for transmission, a second FIP setting
following transmission of the flag signal,
wherein:

the first FIP setting comprises at least one first FIP value,
the second FIP setting comprises at least one second FIP
value, different than the first FIP value, and
the switching occurs on a pre-defined forward error cor-
rection codeword boundary following the flag signal.

9. The apparatus of claim 8, wherein a first forward error
correction parameter value of the first FIP setting is different
than a second forward error correction parameter value of the
second FIP setting.

10. The apparatus of claim 8, wherein a first interleaver
parameter value of the first FIP setting is different than a
second interleaver parameter value of the second FIP setting.

11. The apparatus of claim 8, wherein the adapting of the
FIP settings is based on a service provider configuration.

12. The apparatus of claim 8, wherein the transceiver is
operable to transmit the flag signal on a telephone line that
experiences impulse noise from external sources including
one or more of AM radio, HAM radio and AC power lines.

13. The apparatus of claim 8, wherein the transceiver is
located in a linecard that includes a management interface
that is usable by an operator or service provider to configure
a service.

14. The apparatus of claim 8, wherein the transceiver is
located in a Customer Premises Equipment (CPE) that
includes a management interface that is usable by an operator,
a service provider or service user.

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15. The apparatus of claim 8, wherein the transceiver
includes at least one digital signal processor.

16. The apparatus of claim 8, wherein the transceiver
includes at least one ASIC.

17. In a transceiver, a method of adapting forward error
correction and interleaver parameter (FIP) settings of the
transceiver during steady-state communication or initializa-
tion comprising:

receiving, by the transceiver, a signal using a first FIP
setting;

receiving, by the transceiver, a flag signal; and

switching, by the transceiver, to using, for receiving, a
second FIP setting following reception of the received
flag signal,

wherein:

the first FIP setting comprises at least one FIP value,

the second FIP setting comprises at least one second FIP
value, different than the first FIP value, and

the switching occurs on a pre-defined forward error cor-
rection codeword boundary following the flag signal.

18. The method of claim 17, wherein a first forward error
correction parameter value of the first FIP setting is different
than a second forward error correction parameter value of the
second FIP setting.

19. The method of claim 17, wherein a first interleaver
parameter value of the first FIP setting is different than a
second interleaver parameter value of the second FIP setting.

20. The method of claim 17, wherein the adapting of the
FIP settings is based on a service provider configuration.

21. The method of claim 17, further comprising receiving
the flag signal over a telephone line that experiences impulse
noise from external sources including one or more of AM
radio, HAM radio and AC power lines.

22. The method of claim 17, wherein the method is per-
formed in a linecard that includes a management interface
that is used by an operator or service provider to configure a
service.

23. The method of claim 17, wherein the method is per-
formed in a Customer Premises Equipment (CPE) that
includes a management interface that is used by an operator,
a service provider or service user.

24. An apparatus configurable to adapt forward error cor-
rection and interleaver parameter (FIP) settings during
steady-state communication or initialization comprising:

a transceiver, including a processor, configurable to:

receive a signal using a first FIP setting,

receive a flag signal, and

switch to using for reception, a second FIP setting fol-
lowing reception of the flag signal,

wherein:

the first FIP setting comprises at least one first FIP value,

the second FIP setting comprises at least one second FIP
value, different than the first FIP value, and

the switching occurs on a pre-defined forward error cor-
rection codeword boundary following the flag signal.

25. The apparatus of claim 24, wherein a first forward error
correction parameter value of the first FIP setting is different
than a second forward error correction parameter value of the
second FIP setting.

26. The apparatus of claim 24, wherein a first interleaver
parameter value of the first FIP setting is different than a
second interleaver parameter value of the second FIP setting.

27. The apparatus of claim 24, wherein the adapting of the
FIP settings is based on a service provider configuration.

28. The apparatus of claim 24, wherein the transceiver is
operable to receive the flag signal over a telephone line that

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experiences impulse noise from external sources including one or more of AM radio, HAM radio and AC power lines.

29. The apparatus of claim 24, wherein the transceiver is located in a linecard that includes a management interface that is usable by an operator or service provider to configure a service. 5

30. The apparatus of claim 24, wherein the transceiver is located in a Customer Premises Equipment (CPE) that includes a management interface that is usable by an operator, a service provider or service user. 10

31. The apparatus of claim 24, wherein the transceiver includes at least one digital signal processor.

32. The apparatus of claim 24, wherein the transceiver includes at least one ASIC.

* * * * *

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EXHIBIT 7



US008468411B2

(12) **United States Patent**
Tzannes

(10) **Patent No.:** **US 8,468,411 B2**
(45) **Date of Patent:** ***Jun. 18, 2013**

(54) **PACKET RETRANSMISSION**

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(75) Inventor: **Marcos C. Tzannes**, Orinda, CA (US)

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(73) Assignee: **TQ Delta, LLC**, Austin, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 158 days.

This patent is subject to a terminal disclaimer.

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(21) Appl. No.: **12/783,765**

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(60) Continuation of application No. 12/760,728, filed on Apr. 15, 2010, which is a division of application No. 12/295,828, filed as application No. PCT/US2007/066522 on Apr. 12, 2007, now Pat. No. 8,335,956.

Primary Examiner — Sam Rizk

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(74) Attorney, Agent, or Firm — Jason H. Vick; Sheridan Ross, PC

(51) **Int. Cl.**
G08C 25/02 (2006.01)
H04L 1/18 (2006.01)

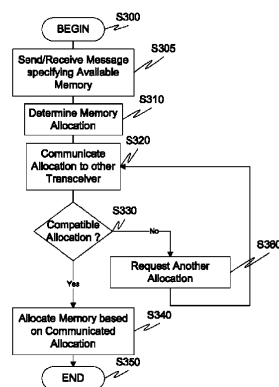
(52) **U.S. Cl.**
USPC **714/748**; 375/130

(58) **Field of Classification Search**
USPC 714/748; 375/130
See application file for complete search history.

(57) **ABSTRACT**

Through the identification of different packet-types, packets can be handled based on an assigned packet handling identifier. This identifier can, for example, enable forwarding of latency-sensitive packets without delay and allow error-sensitive packets to be stored for possible retransmission. In another embodiment, and optionally in conjunction with retransmission protocols including a packet handling identifier, a memory used for retransmission of packets can be shared with other transceiver functionality such as, coding, decoding, interleaving, deinterleaving, error correction, and the like.

25 Claims, 4 Drawing Sheets



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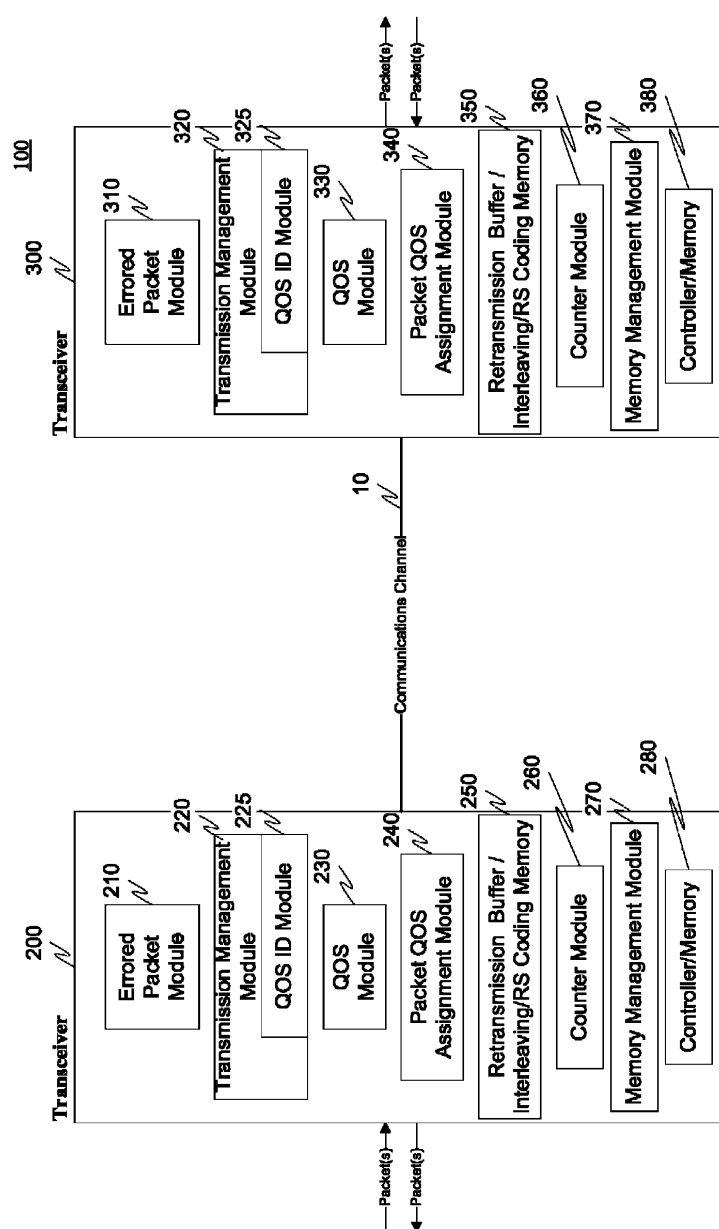


Fig. 1

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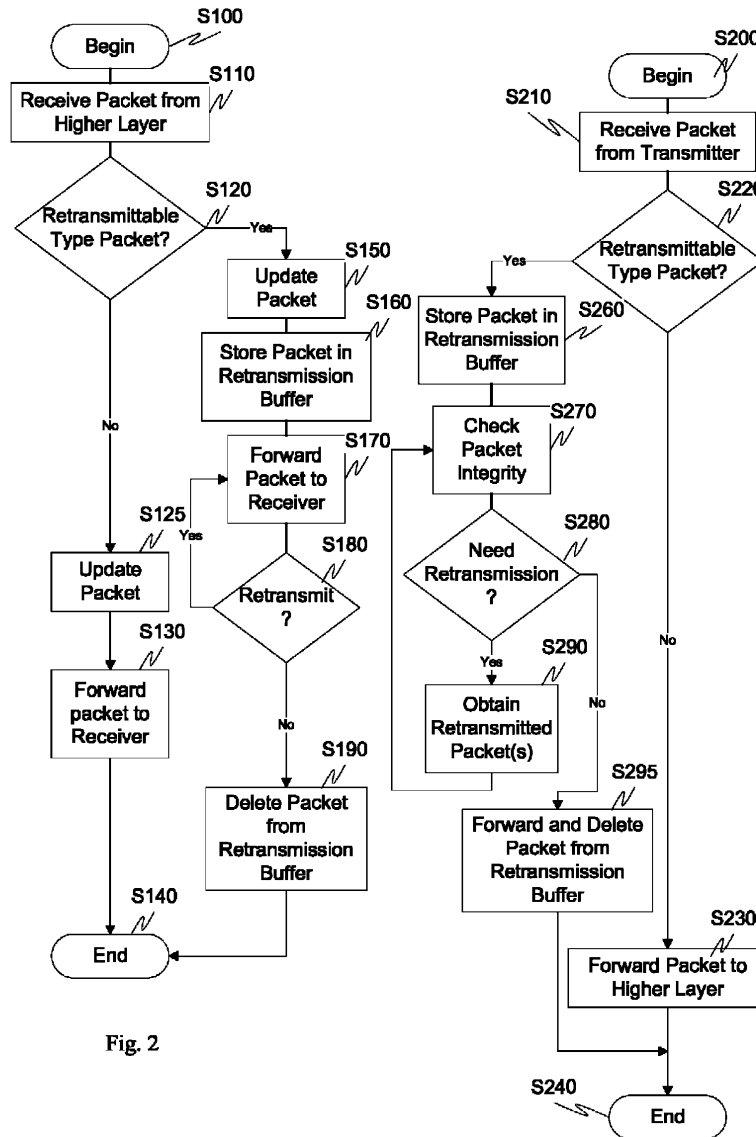


Fig. 2

Fig. 3

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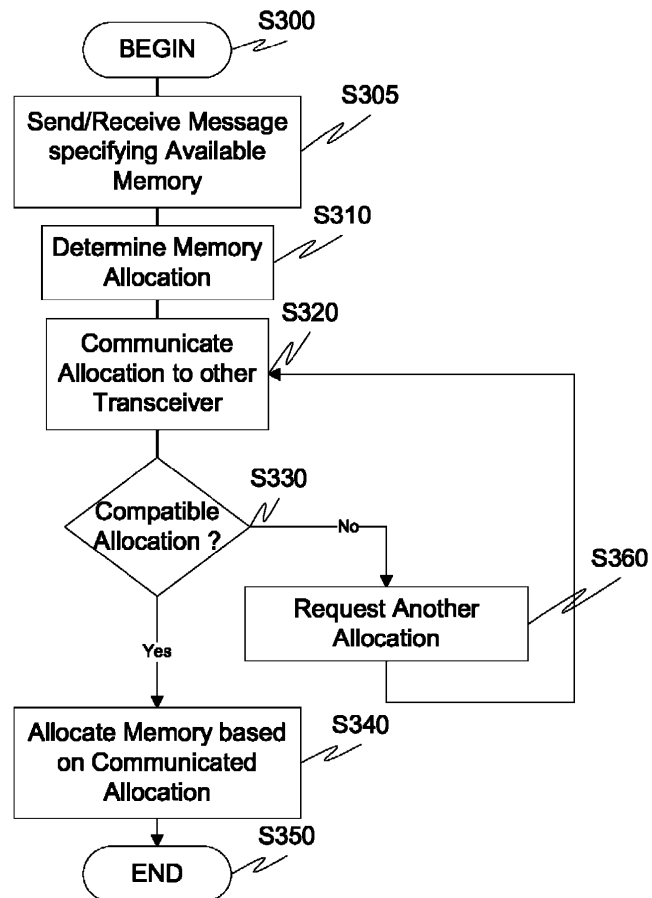


Fig. 4

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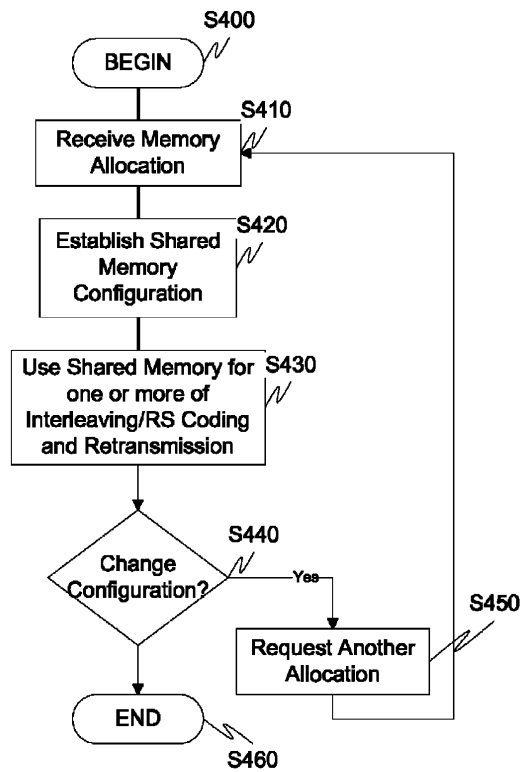


Fig. 5

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PACKET RETRANSMISSION

RELATED APPLICATION DATA

This application is a Continuation of U.S. patent application Ser. No. 12/760,728, filed Apr. 15, 2010, which is a Divisional of U.S. patent application Ser. No. 12/295,828, filed Oct. 2, 2008, now U.S. Pat. No. 8,335,956 which is a national stage application under 35 U.S.C. 371 of PCT Application No. PCT/US2007/066522 having an international filing date of Apr. 12, 2007, which designated the United States, which PCT application claims the benefit of and priority under 35 U.S.C. §119(e) to U.S. Patent Application Nos. 60/792,236, filed Apr. 12, 2006, entitled "xDSL Packet Retransmission Mechanism," and 60/849,650, filed Oct. 5, 2006, entitled "xDSL Packet Retransmission Mechanism with Examples," each of which are incorporated herein by reference in their entirety.

BACKGROUND

Field of the Invention

This invention generally relates to communication systems. More specifically, an exemplary embodiment of this invention relates to retransmission of packets in a communication environment. An exemplary embodiment of this invention also relates to memory sharing between transmission functions and other transceiver functions.

SUMMARY

Exemplary aspects of the invention relate to handling of packets and the assignment of a packet handling identifier. Exemplary aspects relate to sharing of resources between retransmitted packets and other transceiver functions. In addition, exemplary aspects relate to sharing of resources between packets associated with the packet handling identifier and other transceiver functions.

More specifically, aspects of the invention relate to assigning a packet handling identifier to one or more packets. Based on the packet handling identifier, a packet can either be, for example, forwarded directly to another communication device (or layer) or, alternatively, held for possible retransmission protocols. For example, packets received from, for example, a higher-layer of a communication device, can be designated to have a specific packet handling identifier, such as a Quality of Service (QOS) level. The QOS level of a packet indicates the importance of certain service metrics (or characteristics) of one or more packets.

Two exemplary QOS metrics are delay (or latency) and Packet Error Rate (PER). While these two metrics are used for illustrative purposes herein, it should be appreciated that other metrics can also be used with this invention. For example, other QOS metrics could include one or more of a Bit Error Rate (BER), data rate, delay variation (or jitter), packet loss rate, time between error events (TBE), or the like.

As an example, in the case where the two QOS metrics are latency and PER, packets containing, for example, video information (such as IPTV) may have the requirement for a very low packet error rate but can often tolerate higher delay. In contrast, voice or data (e.g., gaming) traffic may have very low latency requirements but can tolerate a higher packet error rate. For this particular example, the video packets could be designated as "low-PER" QOS packets and the voice or data packets could be designated as "low-latency" QOS packets. For example, a specific QOS identifier could be assigned

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to the low-latency packets while a different QOS identifier could be assigned to the low-PER packets. The low-latency packets could be forwarded directly to another transceiver, or a higher layer, while the low-PER packets can be stored in a retransmission buffer, e.g., memory, that can be used to reduce packet error.

As mentioned above, exemplary aspects also relate to sharing of resources between a retransmission function and other transceiver functions.

The exemplary systems and methods of this invention can utilize memory, such as a retransmission buffer, for the storing of packets for retransmission functions. Since other transceiver functions may also require memory to perform certain functionality, an exemplary aspect of this invention also relates to sharing the memory for retransmission functions with the memory required for other transceiver functions. For example, memory can be dynamically allocated based on configuration settings or noise conditions and, for example, the memory divided between one or more of interleaving/deinterleaving, RS Coding/Decoding functionality and the functionality used retransmission.

Aspects of the invention thus relate to identification of one or more packets.

Additional aspects of the invention relate to identifying one or more packets that can be retransmitted.

Still further aspects of the invention relate to identifying one or more packets that should not be retransmitted.

Aspects of the invention also relate to retransmission of one or more of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-data frame, a PTM-TC codeword, and RS codeword and a DMT symbols.

Still further aspects of the invention relate to appending an identifier to a packet.

Still further aspects of the invention relate to appending a sequence identifier to at least one packet.

Aspects of the invention also relate to routing one or more packets based on a packet handling identifier.

Aspects of the invention also relate to retransmitting a packet.

Aspects of the invention further relate to retransmit a packet based on a retransmission request.

Still further aspects of the invention relate to sharing memory between a retransmission function and one or more of an interleaver, deinterleaver, coder, decoder and other transceiver functionalities.

Other more specific aspects of the invention relate to sharing memory between a retransmission buffer (or memory) and interleaving/deinterleaving and/or coding/decoding functionality.

Additional exemplary, non-limiting aspects of the invention are:

1. A method of packet retransmission comprising: transmitting or receiving a plurality of packets; identifying at least one packet of the plurality of packets as a packet that should not be retransmitted.

2. The method of aspect 1, wherein the packet is any grouping of bytes.

3. The method of aspect 1, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

4. The method of aspect 1, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

5. The method of aspect 4, wherein the identifying step comprises using a special value for a sequence identifier (SID).

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6. The method of aspect 4, wherein the appended bit field comprises a dedicated CRC.

7. The method of aspect 1, wherein the at least one packet is not stored for retransmission.

8. The method of aspect 1, wherein the at least one packet is passed immediately to a high layer.

9. A packet retransmission module capable of transmitting or receiving a plurality of packets and capable of identifying at least one packet of the plurality of packets as a packet that should not be retransmitted.

10. The module of aspect 9, wherein the packet is any grouping of bytes.

11. The module of aspect 9, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

12. The module of aspect 9, wherein the module is capable of appending a bit field comprising a sequence identifier (SID) to each packet.

13. The module of aspect 12, wherein the identifying comprises using a special value for the SID.

14. The module of aspect 12, wherein the appended bit field comprises a dedicated CRC.

15. The module of aspect 9, wherein the at least one packet is not stored by the module for retransmission.

16. The module of aspect 9, wherein the at least one packet is passed by the module immediately to a high layer.

17. The module of aspect 9, wherein the module is implemented in one or more of a wireless transceiver, a wireless LAN station, a wired transceiver, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a multicarrier transceiver, a general purpose computer, a special purpose computer, a programmed microprocessor, a microcontroller and peripheral integrated circuit element(s), an ASIC, a digital signal processor, a hard-wired electronic or logic circuit and a programmable logic device.

18. The module of aspect 9, wherein the module is implemented in one or more of a PTM-TC, ATM-TC, PMD and PMS-TC.

19. A method comprising sharing memory between an interleaving and/or deinterleaving memory and a packet retransmission memory.

20. A method comprising allocating a first portion of shared memory for retransmission and a second portion of the shared memory for interleaving and/or deinterleaving.

21. The method of aspect 20, further comprising transmitting or receiving a message indicating how to allocate the shared memory.

22. The method of aspect 19 or 20, further comprising transmitting or receiving a message indicating how to share the memory.

23. A memory capable of being shared between an interleaving and/or deinterleaving buffer and a packet retransmission buffer.

24. A module capable of allocating a first portion of shared memory for retransmission and a second portion of the shared memory for interleaving and/or deinterleaving.

25. The module of aspect 24, wherein the module is capable of transmitting or receiving a message indicating how to allocate the shared memory.

26. The module of aspect 24, wherein the module is capable of transmitting or receiving a message indicating how to share the memory.

27. The module of aspect 24, wherein the module is one or more of a wireless transceiver, a wireless LAN station, a wired transceiver, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a multicarrier transceiver, a general

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purpose computer, a special purpose computer, a programmed microprocessor, a microcontroller and peripheral integrated circuit element(s), an ASIC, a digital signal processor, a hard-wired electronic or logic circuit and a programmable logic device.

28. A method of packet retransmission comprising:

transmitting or receiving a plurality of packets;

identifying at least one packet of the plurality of packets as a packet that should be retransmitted and at least one packet of the plurality of packets as a packet that should not be retransmitted.

29. The method of aspect 28, wherein the packet is any grouping of bytes.

30. The method of aspect 28, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

31. The method of aspect 28, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

32. The method of aspect 31, wherein the identifying step comprises using a special value for a sequence identifier (SID).

33. The method of aspect 31, wherein the appended bit field comprises a dedicated CRC.

34. The method of aspect 28, wherein at least one packet is stored for retransmission.

35. The method of aspect 28, wherein at least one packet is passed immediately to a high layer.

36. A packet handling method comprising:

receiving a stream of packets;

identifying a first number of packets in the stream of packets as low-latency packets;

identifying a second number of packets in the stream of packets as low-error packets;

forwarding the low-latency and low-error packets to a transceiver or a higher layer; and

storing the low-error packets for error correction.

37. The method of aspect 36, further comprising appending the low-error packets with an identifier.

38. A method of allocating memory in a transceiver comprising:

analyzing one or more communication parameters;

identifying a memory allocation; and

allocating memory based on the memory allocation to a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding.

39. A memory sharing method in a transceiver comprising:

receiving a memory allocation;

establishing a shared memory for one or more of interleaving, deinterleaving, RS coding, RS decoding and packet retransmission functions; and

sharing the shared memory between a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functions.

40. The method of aspect 39, further comprising determining a compatibility of the memory allocation.

41. The method of aspect 39, wherein the compatibility of the memory allocation is based on channel performance metrics.

42. Means for performing the functionality of any of the aforementioned aspects.

43. An information storage media comprising information that when executed performs the functionality of any of the aforementioned aspects.

44. Any one or more of the features as substantially described herein.

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45. Means for packet retransmission comprising:
means for transmitting or receiving a plurality of packets;
means for identifying at least one packet of the plurality of
packets as a packet that should not be retransmitted.

46. The means of aspect 45, wherein the packet is any
grouping of bytes.

47. The means of aspect 45, wherein the packet is one of an
IP packet, an Ethernet packet, an ATM cell, a PTM packet, an
ADSL Mux-Data Frame, a PTM-TC codeword, an RS code-
word and a DMT symbol.

48. The means of aspect 45, wherein a bit field comprising
a sequence identifier (SID) is appended to each packet.

49. The means of aspect 48, wherein the means for identi-
fying comprises using a special value for a sequence identifier
(SID).

50. The means of aspect 48, wherein the appended bit field
comprises a dedicated CRC.

51. The means of aspect 45, wherein the at least one packet
is not stored for retransmission.

52. The means of aspect 45, wherein the at least one packet
is passed immediately to a high layer.

53. Means for sharing memory between an interleaving
and/or deinterleaving function and a packet retransmission
function.

54. Means for allocating a first portion of shared memory
for retransmission and a second portion of the shared memory
for interleaving and/or deinterleaving.

55. The means of aspect 54, further comprising means for
transmitting or receiving a message indicating how to allocate
the shared memory.

56. The means of aspect 54, further comprising means for
transmitting or receiving a message indicating how to share
the memory.

57. Means for sharing a memory between an interleaving
and/or deinterleaving function and a packet retransmission
function.

58. Means for packet retransmission comprising:
means for transmitting or receiving a plurality of packets;
means for identifying at least one packet of the plurality of
packets as a packet that should be retransmitted and at
least one packet of the plurality of packets as a packet
that should not be retransmitted.

59. The means of aspect 58, wherein the packet is any
grouping of bytes.

60. The means of aspect 58, wherein the packet is one of an
IP packet, an Ethernet packet, an ATM cell, a PTM packet, an
ADSL Mux-Data Frame, a PTM-TC codeword, an RS code-
word and a DMT symbol.

61. The means of aspect 58, wherein a bit field comprising
a sequence identifier (SID) is appended to each packet.

62. The means of aspect 61, wherein the means for identi-
fying comprises using a special value for the sequence iden-
tifier (SID).

63. The means of aspect 58, wherein the appended bit field
comprises a dedicated CRC.

64. The means of aspect 58, wherein at least one packet is
stored for retransmission.

65. The means of aspect 58, wherein at least one packet is
passed immediately to a high layer.

66. A packet handling means comprising:
means for receiving a stream of packets;
means for identifying a first number of packets in the
stream of packets as low-latency packets;
means for identifying a second number of packets in the
stream of packets as low-error packets;
means for forwarding the low-latency and low-error pack-
ets to a transceiver or higher layer; and

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means for storing the low-error packets for error correc-
tion.

67. The means of aspect 66, further comprising means for
appending the low-error packets with an identifier.

68. Means for allocating memory in a transceiver compris-
ing:

means for analyzing one or more communication param-
eters;

means for identifying a memory allocation; and

means for allocating memory based on the memory allo-
cation to a retransmission function and one or more of an
interleaving, deinterleaving, RS coding and RS decod-
ing function.

69. Means for memory sharing in a transceiver comprising:
means for receiving a memory allocation;

means for establishing a shared memory for one or more of
interleaving, deinterleaving, RS coding, RS decoding
and packet retransmission function; and

means for sharing the shared memory between a retran-
smission function and one or more of interleaving,
deinterleaving, RS coding and RS decoding functional-
ity.

70. The means of aspect 69, further comprising means for
determining a compatibility of the memory allocation.

71. The means of aspect 69, wherein the compatibility of
the memory allocation is based on channel performance met-
rics.

72. A transceiver capable of performing packet retransmis-
sion comprising:

a transmission management module configurable to trans-
mit or receive a plurality of packets; and

a QOS module configurable to identify at least one packet
of the plurality of packets as a packet that should not be
retransmitted.

73. The transceiver of aspect 72, wherein the packet is any
grouping of bytes.

74. The transceiver of aspect 72, wherein the packet is one
of an IP packet, an Ethernet packet, an ATM cell, a PTM
packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an
RS codeword and a DMT symbol.

75. The transceiver of aspect 72, wherein a bit field com-
prising a sequence identifier (SID) is appended to each
packet.

76. The transceiver of aspect 75, wherein the QOS module
uses a special value for a sequence identifier (SID).

77. The transceiver of aspect 75, wherein the appended bit
field comprises a dedicated CRC.

78. The transceiver of aspect 72, wherein the at least one
packet is not stored for retransmission.

79. The transceiver of aspect 72, wherein the at least one
packet is passed immediately to a high layer.

80. A memory capable of being shared between interleav-
ing and/or deinterleaving and packet retransmission.

81. A memory management module capable of allocating a
first portion of shared memory for retransmission and capable
of allocating a second portion of the shared memory to one or
more of interleaving and deinterleaving functionality.

82. The module of aspect 81, further comprising a module
for transmitting or receiving a message indicating how to
allocate the shared memory.

83. The module of aspect 81, further comprising a module
for transmitting or receiving a message indicating how to
share the memory.

84. A module capable of being shared between interleaving
and/or deinterleaving and packet retransmission.

85. A transceiver capable of performing packet retransmis-
sion comprising:

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a transmission management module configurable to transmit or receive a plurality of packets; and
 QOS module configurable to identify at least one packet of the plurality of packets as a packet that should be retransmitted and at least one packet of the plurality of packets

as a packet that should not be retransmitted.
 86. The transceiver of aspect 85, wherein the packet is any grouping of bytes.

87. The transceiver of aspect 85, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

88. The transceiver of aspect 85, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

89. The transceiver of aspect 88, wherein the identifying step comprises using a special value for a sequence identifier (SID).

90. The transceiver of aspect 88, wherein the appended bit field comprises a dedicated CRC.

91. The transceiver of aspect 85, wherein at least one packet is stored for retransmission.

92. The transceiver of aspect 85, wherein at least one packet is passed immediately to a high layer.

93. A transceiver capable of handling a stream of packets comprising:

a QOS module capable of identifying a first number of packets in the stream of packets as low-latency packets and a second number of packets in the stream of packets as low-error packets;

a transmission management module capable of forwarding the low-latency and low-error packets to another transceiver; and

a buffer module capable of storing the low-error packets for error correction.

94. The transceiver of aspect 93, further comprising a packet QOS assignment module capable of appending the low-error packets with an identifier.

95. A transceiver capable of having an allocatable memory comprising:

a controller capable of analyzing one or more communication parameters; and

a memory management module capable of identifying a memory allocation and allocating a shared memory based on the memory allocation to a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functions.

96. A transceiver capable of sharing memory comprising: a controller capable of receiving a memory allocation; and a memory management module capable of establishing a shared memory for a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functions.

97. The transceiver aspect 96, wherein the memory management module further determines a compatibility of the memory allocation.

98. The transceiver of aspect 96, wherein the memory allocation is based on one or more communication channel performance metrics.

99. In a communication environment where packets are being transmitted, a method for allocating a first portion of shared memory for retransmission of packets and a second portion of the shared memory for interleaving and/or deinterleaving.

100. The method of aspect 99, wherein all errored packets are retransmitted.

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101. The method of aspects 19, 20 and 99, wherein a retransmission function identifies packets that should not be retransmitted.

102. The method of aspect 99, wherein all packets are being transmitted without an assigned a QOS level.

103. A packet communication method comprising:
 in a first mode of operation:

transmitting or receiving a plurality of packets;

identifying at least one packet of the plurality of packets as a packet that should not be retransmitted;

in a second mode of operation:

transmitting or receiving a plurality of packets;

allocating a first portion of shared memory for retransmission of packets and a second portion of the shared memory for one or more of interleaving, deinterleaving, coding, decoding and error correction; and

in a third mode of operation:

transmitting or receiving a plurality of packets;

identifying at least one packet of the plurality of packets as a retransmittable-type packet;

identifying at least one packet of the plurality of packets as a non-retransmittable-type packet;

allocating a first portion of shared memory for retransmission of the retransmittable-type packets and a second portion of the shared memory for one or more of interleaving, deinterleaving, coding, decoding and error correction.

104. The method of aspect 103, wherein the retransmittable-type packet is a low-latency packet.

105. The method of aspect 103, wherein the retransmittable-type packet is a low-error packet.

These and other features and advantages of this invention are described in, or are apparent from, the following detailed description of the exemplary embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The exemplary embodiments of the invention will be described in detail, with reference to the following figures wherein:

FIG. 1 illustrates an exemplary communication system according to this invention.

FIG. 2 is a flowchart outlining an exemplary method for packet retransmission according to this invention.

FIG. 3 is a flowchart outlining an exemplary method for retransmitted packet reception according to this invention.

FIG. 4 is a flowchart outlining an exemplary method for memory allocation according to this invention.

FIG. 5 is a flowchart outlining an exemplary method for memory sharing according to this invention.

DETAILED DESCRIPTION

The exemplary embodiments of this invention will be described in relation to packet retransmission and/or memory sharing in an xDSL environment. However, it should be appreciated, that in general, the systems and methods of this invention will work equally well for any type of communication system in any environment.

The exemplary systems and methods of this invention will also be described in relation to multicarrier modems, such as xDSL modems and VDSL modems, and associated communication hardware, software and communication channels. However, to avoid unnecessarily obscuring the present invention, the following description omits well-known structures and devices that may be shown in block diagram form or otherwise summarized.

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For purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the present invention. It should be appreciated however that the present invention may be practiced in a variety of ways beyond the specific details set forth herein.

Furthermore, while the exemplary embodiments illustrated herein show the various components of the system collocated, it is to be appreciated that the various components of the system can be located at distant portions of a distributed network, such as a communications network and/or the Internet, or within a dedicated secure, unsecured and/or encrypted system. Thus, it should be appreciated that the components of the system can be combined into one or more devices, such as a modem, or collocated on a particular node of a distributed network, such as a telecommunications network. As will be appreciated from the following description, and for reasons of computational efficiency, the components of the system can be arranged at any location within a distributed network without affecting the operation of the system. For example, the various components can be located in a Central Office modem (CO, ATU-C, VTU-O), a Customer Premises modem (CPE, ATU-R, VTU-R), an xDSL management device, or some combination thereof. Similarly, one or more functional portions of the system could be distributed between a modem and an associated computing device.

Furthermore, it should be appreciated that the various links, including communications channel 10, connecting the elements (not shown) can be wired or wireless links, or any combination thereof, or any other known or later developed element(s) that is capable of supplying and/or communicating data to and from the connected elements. The term module as used herein can refer to any known or later developed hardware, software, firmware, or combination thereof that is capable of performing the functionality associated with that element. The terms determine, calculate and compute, and variations thereof, as used herein are used interchangeably and include any type of methodology, process, mathematical operation or technique. Transmitting modem and Transmitting transceiver as well as Receiving modem and Receiving transceiver are used interchangeably herein.

Moreover, while some of the exemplary embodiments described herein are directed toward a transmitter portion of a transceiver performing interleaving and/or coding on transmitted information, it should be appreciated that a corresponding deinterleaving and/or decoding is performed by a receiving portion of a transceiver. Thus, while perhaps not specifically illustrated in every example, this disclosure is intended to include this corresponding functionality in both the same transceiver and/or another transceiver.

Communication system 100 comprises a portion of a transceiver 200 and a portion of a transceiver 300. The transceiver 200, in addition to well known componentry, comprises an errored packet module 210, a transmission management module 220, a QOS ID module 225, a QOS module 230, a packet QOS assignment module 240, a retransmission buffer/interleaving/deinterleaving/RS coding/RS Decoding memory 250, a counter module 260, a memory management module 270 and a controller/memory 280.

Connected via communication channel 10 to transceiver 200 is transceiver 300. The transceiver 300, in addition to well known componentry, comprises an errored packet module 310, a transmission management module 320, a QOS ID module 325, a QOS module 330, a packet QOS assignment module 340, a retransmission buffer/interleaving/deinterleaving/RS coding/RS Decoding memory 350, a counter module 360, a memory management module 370 and a controller/memory 380.

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As discussed above, the systems, methods and protocols discussed herein will be described in relation to xDSL systems, such as those specified in ADSL2 ITU-T G.992.3, ADSL2+ITU G.992.5, and VDSL2 ITU G.993.2, which are incorporated herein by reference in their entirety.

In operation, a first aspect of the invention relates to retransmission of one or more packets, the retransmission identifier being implemented at any transmission layer where packet boundaries are defined. For example, it can be implemented in the Packet Transmission Mode TC (PTM-TC) of xDSL systems. For reference, "Annex A" which is of record in the identified provisional filing and incorporated by reference herein contains the PTM-TC of ADSL2 and VDSL2 systems as specified in the ITU-T G.992.3 ADSL2 standard.

As discussed herein, the invention will generally be described in relation to the retransmission mechanism being incorporated as part of the PTM-TC however, it should be appreciated that it can also be implemented inside other layer(s) of a communication device, such as an xDSL transceiver, such as within the PMD or PMS-TC.

The retransmission techniques disclosed herein can also be performed at a layer above the PTM-TC, for example, in a new layer between the PTM-TC and the next higher layer, or at any layer above the physical layer, e.g., layers 2, 3, 4, 5, etc.

Additionally, while "packet" is used herein, the term "packet" includes any basic data unit, i.e., a grouping of bytes. For example, a packet could be an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data frame, a PTM-TC codeword, an RS Codeword, a DMT symbol, or, in general, any grouping of data bytes or information. A packet could also be a combination of one or more of the above. For example, a packet could be constructed by concatenating any number of ATM cells to create a larger grouping of bits. For example, five 53-byte ATM cells could be combined into a 265 byte packet or four 65 PTM-TC codewords could be combined into a 260 byte packet. A packet could also be based on dividing any of the above groupings of bytes. For example, larger IP or Ethernet packets could be divided into smaller groups of bytes to be used as a "packet" with the retransmission functionality described herein. For example, a 1500 byte IP packet could be divided into three 500 byte packets and used by the retransmission protocol. If the retransmission function is implemented as part of the PTM-TC, packets are received from a higher-layer in the xDSL transmitter PTM-TC and sent via the xDSL transmitter PMS-TC and PMD over the communication channel to the xDSL receiver. The xDSL receiver PMD and PMS-TC process the received signal and pass the results to the PTM-TC, which processes the information and passes the received packet up to a higher layer(s).

Packets received from the higher layer at the xDSL transmitter PTM-TC can be designated to have a QOS level. The QOS level of a packet can indicate the importance of certain service metrics (or characteristics) of this (or more) packet(s). Two exemplary QOS metrics are delay (or latency) and PER. Although, as discussed above, these two characteristics are the focus of the invention, any number of different QOS metrics could also be used.

As an example, in the case where the 2 QOS metrics are latency and PER, a first set of packets carrying certain information may have a requirement for very low PER but may be able to tolerate higher delay. Other packets containing information such as voice or data traffic may have very low delay requirements but can tolerate a higher PER. According to an exemplary embodiment of this invention, the first set of packets would be designated as "low-PER" QOS packets whereas voice or data packets would be designated as "low-latency"

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QOS packets. The QOS level (or metric) of a packet could be designated in a number of ways. For example:

i) Certain bit fields in the header of data portions of each packet could contain certain values that specify the QOS requirements a packet. For example, the packet header could contain bit fields that indicate if the packet has a “low-PER” QOS requirement or a “low-latency” QOS requirement. These fields could be read by the transmitting modem and/or receiving modem to determine the QOS level of each packet.

ii) When sending packets from higher layer to the PTM-TC, the higher layer could indicate on a packet by packet basis the QOS requirements of each packet. For example, there could be a separate signal on the interface that indicates if a packet being transferred has a “low-PER” QOS requirement or a “low-latency” QOS requirement.

iii) When sending packets from higher layer to the PTM-TC, there could be a separate interface (or channel) for packets with different QOS requirements. For example, one channel could be used to transfer packets that have a “low-PER” QOS requirement and a second channel could be used to transfer packets that have a “low-latency” QOS requirement. This general concept could also be scaled to accommodate a plurality of different QOS requirements and a plurality of channels.

iv) As in the case of Pre-Emption in the PTM-TC (see Annex A), two logically separated γ -interfaces could be used for the transport of a low-PER and low-latency packet flow through a single bearer channel. This general idea could then be scaled to support any number of packet types.

Other mechanisms can also be used to designate the QOS level of a packet-provided the transmitter and/or receiver retransmission protocol is capable of knowing the QOS level for one or more packets.

Once the QOS level is known by the PTM-TCs, an efficient packet retransmission can be designed. The exemplary packet retransmission methods and protocols can be designed to include any one or more of the following system level characteristics:

All packets are received from the higher layer and passed to the higher layers in the correct order.

“Low-latency” QOS packets will not incur any extra delay due to retransmission.

Only packets with “low-PER” QOS should be retransmitted, and therefore only low-PER packets will incur the extra delay due to the retransmission mechanism.

Flow control can be minimized such that the transmitter can generally accept all packets from the higher layer at the required data rate without holding-off (or “blocking”) packets from the higher layer during the retransmission process.

Packet delay-variation/jitter can be minimal

A “DRR-like” functionality in a single bearer without requiring latency/interleaver OLR.

The transceiver 200, in cooperation with the QOS module 230, receives packets from a higher-layer. In cooperation with the packet QOS assignment module 240, a packet Sequence ID (SID) is appended to the received packets. The packets, in cooperation with the transmission management module 220, can then be transmitted in the order in which they were received.

The QOS Module 230, if not already performed by a high layer, also identifies packets based on the QOS requirement of the packet(s). Then, in cooperation with the packet QOS assignment module 240, a QOS identifier is associated with the packet as discussed hereinafter.

If, for example, the packet is identified as a low-PER packet, and assigned such an identifier by the QOS module

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230, when the transmission management module 220 receives the packet, the packet is identified by the QOS ID module 225 as being a low-PER packet and the packet is forwarded for storage in the retransmission buffer 250. Alternatively, if the packet has been labeled as a low-latency packet, and identified as such by the by the QOS ID module 225, the packet can be transmitted to the receiving modem in cooperation with the transmission management module 220.

The low-PER packets can be stored for a sufficient amount of time to wait for a retransmission message from the receiver PTM-TC. During this time, the transmitting modem can continue to receive packets from one or more higher layers, label these packets, if needed, and store these packets, if they are identified as low-PER packets, in the same way. The resulting minimum storage requirements for the transmitter PTM-TC are estimated below.

For successful retransmission, the receiving modem should be able to inform the transmitting modem which packet, or packets, need to be retransmitted. One exemplary way of performing this is by transmitting packets with an appended bit field that contains a counter indicating the place of each packet in a stream of packets. This counter value is also known as a Sequence ID (SID). For example, a bit field containing a 16-bit counter could be appended to each packet and the counter module 260 would be incremented by one after each packet was transmitted. In cooperation with the packet assignment module 240, a packet counter field could be appended to the packet in a number of places, for example, at the beginning or end of the packet, or at the beginning or end of the packet header.

Packets received from a higher-layer may already have information in a header or data field of the packet that contains the packet count, or sequence, information. In addition, the packet counter field may be appended with an additional CRC field that contains a cyclic redundancy check that is computed on the packet counter field bits only. This CRC can be used by the receiver to determine if the packet counter field is received correctly, i.e., without bit errors. This CRC can be in addition to the standard CRC inserted by the standard PTM-TC (the standard packet PTM-TC CRC is a CRC that covers all bits in a packet). The standard packet CRC may also cover the new packet counter field in its CRC as well. This helps if the receiving modem uses the presence or absence of the packet counter field in a packet to detect if the packet has a low-PER or low-latency requirement (discussed below).

Alternatively, or in addition, the packet counter field (with or without a dedicated CRC) can be appended only to the packets with a specific QOS requirement, whereas all other packets can be transmitted without modification. For example, all video packets with low-PER QOS could contain the appended packet counter field whereas all the voice/data low-latency packets could be transmitted unchanged. One exemplary benefit of this is that the overhead (rate loss) due to adding the packet counter field is incurred only when transmitting low-PER packets.

Alternatively, or in addition, all low-PER and low-latency packets can be transmitted with the low packet counter field (with or without a dedicated CRC). In this case, the packet counter field of the low-latency packets may contain a special value indicating that a packet is not a low-PER packet. Also, the packet counter field of the low-latency packet may not even contain a count value, since the low-latency packets are not intended to be retransmitted. In this case, the packet counter field could contain a counter value only for low-PER packets and the counter value would only be incremented when a low-PER packet was transmitted. As an example, if the packet counter field is 16 bits, the special value of all zeros

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could be used to indicate that a packet is a low-latency packet. In this case, low-PER packets could contain counter values from one up to $2^{16}-1$, but not including all zeros, since this special zero value can be used to indicate a low-latency packet.

The receiving modem, e.g., receiver PTM-TC, which in this case is illustrated as the transceiver 300 and includes comparable functionality to that described in relation to transceiver 200, receives packets from the transmitting modem via the PMS-TC. If the received packet is identified as a low-latency packet by the QOS ID module 325, the packet is passed to a higher-layer. If a received packet is identified by the QOS ID module 325 as a low-PER packet, the packet is forwarded, with the cooperation of the transmission management module 320, to the retransmission buffer 350 for a minimum amount of time before passing to a higher-layer.

The storage time in the retransmission buffer 350 helps ensure that the retransmission protocol provides a constant delay, e.g., no delay variation seen by the upper layers. This way, if a packet needs to be retransmitted, the receiving modem can continue to provide packets to the higher-layers at a constant rate while waiting for the retransmitted packet(s) to arrive from the transmitting modem. The resulting minimum memory (or storage) requirements for the receiving PTM-TC are estimated below.

Alternatively, low-PER packets without errors may not be stored for a minimum amount of time before passing to a higher-layer. The error-free low-PER packets can be passed to the higher-layer immediately just like the low-latency packets. However, when a low-PER packet is in error, it is stored along with all of the following low-PER packets before passing to a higher-layer in order to wait for the retransmitted packet(s) to arrive. This will cause a delay variation on the low-PER packets whenever a retransmission occurs. However, this delay variation would not apply to the low-latency packets.

The QOS ID module 325 can detect that a packet is either low-PER or low-latency using several different methods. For example, if all low-PER and low-latency packets contain the appended packet counter field, then the receiving modem, in cooperation with the counter module 360, detects a low-latency packet when a packet counter field contains the designated special value, which was inserted by the transmitting modem, indicating the packet is a low-latency packet.

Alternatively, or in addition, the receiver could detect a low-PER packet when the packet counter field contains a valid packet counter value. Additionally, if a dedicated CRC is appended to the packet counter field, the CRC could be used to detect if the packet counter field bits are in error.

If the packet counter field, including the CRC, is only appended to low-PER packets, the absence or presence of this field in a packet can be used by the receiving modem, and in particular the QOS ID module, to detect a low-delay packet. For example, the receiving modem can examine the position in the packet where the packet counter field would be, if it was a low-PER packet, and if the packet counter field CRC fails while the standard whole packet CRC is correct, the receiving modem could determine that the packet is a low-delay packet, since it does not contain the packet counter field. Likewise, for example, the receiving modem can examine the position in the packet where the packet counter field would be, if it was a low-PER packet, and if the packet counter field CRC is correct, the receiving modem would determine that the packet is a low-PER packet, regardless of the status of the standard whole packet CRC.

The receiving modem, in cooperation with the retransmission buffer 350, and the errored packet module 310, can be

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used to detect missing or errored packets in a number of exemplary ways. For example, the errored packet module 310 can detect bit errors in the packet using the standard/whole packet PTM-TC CRC. Alternatively, or in addition, the errored packet module 310 can detect bit errors in the packet counter field if the transmitting modem appended a dedicated CRC to the packet counter field. This CRC is valuable because it can be used by the errored packet module in the receiving modem to determine if a packet has the correct packet number, even if the standard whole packet CRC happens to be in error.

Alternatively, or in addition, the errored packet module 310, can detect an errored or missing packet by receiving a packet with a correct CRC, either in the standard or packet counter field, which contains a packet counter number that is not the expected packet counter number. For example, if the errored packet module 310, in cooperation with the counter module 360, detects the receipt of a packet with a counter number equal to 5, wherein the errored packet module 310 is expecting to receive a packet with a counter equal to 3, the errored packet module 310 can determine that two packets, namely packets numbered 3 and 4, were lost due to errors.

Once a packet(s) is found to be in error, there are several exemplary ways in which a receiving modem can communicate information to the transmitting modem indicating that a retransmission of one or more packets is required. For example, the receiving modem, in cooperation with the errored packet module 310, can send an acknowledgment (ACK) message to the transmitting modem for every correctly received message or every predetermined number of packets. As long as the transmitting modem, and in particular the errored packet module 210, receives messages acknowledging receipt of packets in sequential order, there is no need for retransmission of information to the receiving modem. However, if the transmitting modem, and in particular the errored packet module 210, receives a message from the receiving modem, and in particular the errored packet module 310, indicating that a packet was correctly received with a counter value that is out of order, a retransmission by the transmitting modem is required. In the above example, where the receiving modem received a packet with a counter value equal to 5, without receiving packets numbered 3 and 4, the transmitting modem could receive an ACK for the packet with counter value of 2 and then an ACK for the packet with a counter value of 5. The transmitting modem would then determine that it was necessary to retransmit packets with counter values of 3 and 4 since they were not received.

Alternatively, or in addition, a timeout value could be specified for the transmitting modem. This timeout value could correspond to the amount of time that the transmitting modem should wait for an ACK for particular packet before retransmitting the packet. The timeout value could be set to be at least as long as the round-trip delay required for the transmitting modem to send a packet to the receiving modem and for the receiving modem to send an ACK back to the transmitting modem. If an ACK is not received by the timeout value, the transmitting modem could retransmit the packet.

Alternatively, or in addition, a negative acknowledgment (NAK) could be sent to the transmitting modem when a packet is detected as errored or missing. In the above example, when the receiving modem received the packet with a counter value of 5, while expecting a counter value of 3, the receiving modem could send a NAK message to the transmitting modem indicating that packets with counter values of 3 and 4 were not correctly received and needed to be retransmitted.

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Alternatively, or in addition, if a packet was received with a correct packet counter CRC and a valid packet counter value α and an incorrect standard whole packet CRC, the receiving modem could send a NAK message to the transmitting modem indicating that a packet with a value of α was incorrectly received and needed to be retransmitted.

Assuming that errored packets are infrequent, any methodology that sends an ACK for each correctly received packet can require a larger amount of data rate in the message channel that communicates this information back to the transmitting modem. In this case, sending only NAKs has the benefit that it requires sending a message only when an errored or missing packet is detected. Depending on the data rate capabilities of the message channel, and the PER, a retransmission system may use only ACKs, only NAKs, or both ACKs and NAKs at the same time.

The ACK and NAK messages sent back to the transmitting modem can be transmitted over the same physical channel i.e., phone line, in the opposite direction as the received packets. Since the channel has a limited data rate and is not necessarily error-free, it is important to make sure that these messages are as robust as possible and consume the least amount of data rate. Additionally, since the transmit and receive retransmission memory requirements depend on the round-trip latency of the connection, is important to minimize latency requirements for the message channel. There are several ways these requirements can be addressed.

The messages can be sent over a separate "low-latency" or "fast" path between the xDSL transceivers. This fast path could include little or even no delay due to interleaving and can be specified to have a latency that is less than 2 ms.

Alternatively, or in addition, the messages can be sent with increasing robustness by repeating transmission of each message a number of times. For example, the message could be repeated x times in order to make sure that even if $x-1$ messages were corrupted by the channel, at least one message would be received correctly.

Alternatively, or in addition, the messages can be sent such that each message is repeated a number of times and each repeated message is sent in a different DMT symbol. For example, the message can be repeated x times and each message sent in one of x DMT symbols. This way, even if $x-1$ DMT symbols were corrupted by the channel, at least one message would be received correctly.

Alternatively, or in addition, the messages can be sent such that each message is repeated a number of times and each repeated message is sent in different DMT symbols. For example, the message could be repeated x times and each message sent in one of x DMT symbols. This way, even if $x-1$ DMT symbols were corrupted by the channel, at least one message would be received correctly.

Alternatively, or in addition, the messages can be sent such that each message is repeated a number of times and each repeated message is sent a plurality of times in each DMT symbol. For example, the message could be repeated x times and each repeated message sent y times in one of x DMT symbols. This way, even if $x-1$ DMT symbols were corrupted by the channel and/or large portions of a DMT symbol were corrupted by a channel, the least one message would be received correctly.

Alternatively, or in addition, the messages can include multiple packet count values in order to reduce the data rate requirements. For example, if packets with counter values of 3-9 are correctly (or incorrectly) received an ACK (or NAK) message would be sent to indicate these packet values. For example, the message could contain the values 3 and 9 and the

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receiver of the message would automatically know that all intermediate values (4, 5, 6, 7, 8) are also been indicated in the message.

Alternatively, or in addition, the DMT sub-carriers that modulate these messages could operate with a much higher SNR margin e.g., 15 dB, as compared to the normal 6 dB margin of xDSL systems. This way, the messages would have a higher immunity to channel noise.

Alternatively, or in addition, a receiving modem may need to send an additional ACK or NAK message after already in the process of sending a repeated message. For example, a receiving modem may detect that packets with values 3 to 9 have been correctly received and send an ACK message back to the transmitting modem indicating this information. This message can be repeated x times with each repeated message being transmitted (at least once) on different DMT symbols. While sending the second repeated message on the second DMT symbol, the receiver could detect that packets with values 10 to 17 have now also been correctly received. In this case, the receiving modem could just append this information to the previous message or, alternatively, send a new separate message that is repeated as well x times with each repeated message being transmitted (at least once) on a different DMT symbol.

Alternatively, or in addition, when repeating a message x times on x DMT symbols, each repeated message can be modulated on a different set of DMT sub-carriers on each DMT symbol. This way, if one or more sub-carriers have a low SNR, the message will still be correctly received.

For low-PER packets, the delay due to this retransmission protocol is equal to the delay that results from storing these packets at the receiving modem (RX PTM-TC) to pass in the packets to a higher layer. Low-latency packets do not incur extra delay.

The transmitting modem must store a packet for retransmission for a time equal to the round trip delay from when the packet is sent to when the retransmission message is received. During this time the transmitting modem continues to receive packets from the higher layer and continues to store these packets in the same way. Therefore the storage requirements in octets can be computed as:

$$\text{Minimum TX memory(octets)} = \text{roundtripdelay} * \text{datarate},$$

where the roundtripdelay is the time equal to the round trip delay from when the packet is sent to when the retransmission message is received, and the datarate is the data rate of the connection that is transferring the packets.

For ITU-T G.993.2 VDSL2, which is incorporated herein by reference, this can be computed using the VDSL2 profile parameters as:

$$\text{Minimum TX memory(octets)} = (DS + US \text{ Interleaving Delay in octets}) + (US + DS \text{ alpha/beta delay without interleaving}) * (\text{Bidirectional Net data rate}) = \text{MAXDELAYOCTET} + (4 \text{ ms}) * \text{MBDC},$$

where MAXDELAYOCTET and MBDC are as specified in the VDSL2 profiles.

For the receiver, the minimum receiver storage requirements can be determined in a similar manner. More specifically, the RX PTM-TC must store a packet before passing it to the higher layer for a time equal to the round trip delay from when a retransmission message is transmitted to when the retransmitted packet is received. This is equal to storage requirements in octets (same as transmitter):

$$\text{Minimum RX memory(octets)} = \text{roundtripdelay} * \text{datarate},$$

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where the roundtripdelay is the time equal to the round trip from when a retransmission message is transmitted to when the retransmitted packet is received and the data rate is the data rate of the connection that is transferring the packets.

For ITU-T G.993.2 VDSL2 this can be computed using the VDSL2 profile parameters as:

$$\begin{aligned} \text{Minimum } RX \text{ memory (octets)} &= (DS + US \text{ Interleaving} \\ &\text{Delay in octets}) + (US + DS \text{ alpha/beta delay with-} \\ &\text{out interleaving}) * (\text{Bidirectional Net data rate}) = \\ &\text{MAXDLEYOCTET} + (4\text{ms}) * \text{MBDC}, \end{aligned}$$

where MAXDELAYOCTET and MBDC are as specified in the ITU-T G.993.2 VDSL2 profiles.

TABLE 1

Minimum TX or RX memory requirements for VDSL2				
VDSL2 PROFILE	8a, 8b, 8c, 8d	12a, 12b	17a	30a
TX or RX memory requirements (octets) = MAXDLEYOCTET + .002MBDC	90,536	99,536	123,304	231,072

The estimates in Table 1 assume that all the entire MAXDELAYOCTET and MBDC are used for the transfer of the packet stream, i.e., the reverse channel has a very low data rate and no interleaving.

Some xDSL standards specify minimum storage, i.e., memory, requirements for interleaving of RS codewords. Interleaving with RS coding is an effective way of correcting channel errors due to, for example, impulse noise. For example, VDSL2 requires support of an aggregate bidirectional interleaver and de-interleaver memory of 65 Kbytes for the 8a VDSL2 profile. This corresponds to storage requirement of approximately 32 Kbytes in a single transceiver.

Sharing of Memory Between the Retransmission Function and One or More of the Interleaving/Deinterleaving/RS Coding/RS Decoding Functions

From Table 1, it is apparent that the memory requirements to support the retransmission protocol may be more than double the storage requirements of a single transceiver. Additionally, the retransmission protocol provides a different method for correcting channel errors due to, for example, impulse noise.

Moreover, interleaving and RS coding methods and retransmission protocols provide different advantages with respect to error correction capabilities, latency, buffering requirements, and the like. For example, under certain configuration and noise conditions the interleaving/RS coding provides error correction/coding gain with less delay and overhead than the retransmission protocol (for packets that can be retransmitted). While under other conditions the retransmission protocol will provide better error correction with less delay and overhead than the interleaving/RS coding.

In some cases, a first portion of the memory can be used for one function and a second portion of the memory for some other function. For example, if the configuration and noise conditions are such that the interleaving/RS coding would not provide good error correction/coding gain, then all the available memory could be used for the retransmission function and none allocated to the interleaving/deinterleaving/RS coding/RS decoding functionality, e.g., the interleaving/deinterleaving could be disabled.

Likewise, if the configuration and noise conditions are such that the retransmission protocol would not provide good error correction/coding gain, then all the available memory could be used for the interleaving/deinterleaving/RS coding/

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RS decoding functionality and no memory would be used for the retransmission function, e.g., the retransmission function would be disabled.

Alternatively, or addition, both methods could be used because both have their advantages, with the system, e.g., the memory management module 370, being able to dynamically allocate a first portion of the memory 250/350 to the interleaving/deinterleaving/RS coding/RS decoding functionality and a second portion of the memory to the retransmission functionality. For example, 40% of the memory could be allocated to the interleaving/deinterleaving/RS coding/RS decoding functionality with the remaining 60% allocated to the retransmission of functionality. However, it should be appreciated, that in general, the memory can be divided, i.e., shared, in any manner.

The sharing of memory between the retransmission function and the interleaving/deinterleaving/RS coding/RS decoding functions is not restricted to retransmission protocols described in other embodiments that utilize QOS metrics to determine which packets should be retransmitted. In other words, the sharing of memory between the retransmission function and the interleaving/deinterleaving/RS coding/RS decoding functions can be utilized for retransmission systems where all errored packets are retransmitted, i.e., there is no QOS identifier in the retransmission protocol. For example, the FEC/interleaving could be used to meet the INPmin requirement specifically targeting the impulse noise that occurs frequently (e.g., on the order of minutes or seconds) but is short in duration and can therefore be corrected by the FEC/interleaving. For example, the retransmission protocol can be used to correct infrequent errors (on the order of hours) that are long in duration and would not be correctable by the FEC/interleaving. As another example, the FEC/interleaving function may be used in combination with the retransmission function because it is well known that FEC with minimal interleaving provides a 1 dB to 3 dB coding gain when used with a trellis code (as is often the case in xDSL systems). This means that even when the majority of the shared memory is allocated to a retransmission function to address channel noise (such as impulse noise), a smaller amount of memory may be allocated to the FEC/interleaving function for the coding gain advantage.

Associated with the ability to allocate or partition memory between one or more of the interleaving/deinterleaving/RS coding/RS decoding functionality and retransmission functionality, is the ability to exchange information between transceivers on how to establish this allocation. For example, the transmitting modem may send a message to the receiving modem indicating how much of the available memory is to be allocated to one or more of the interleaving/deinterleaving/RS coding/RS decoding functionality and how much memory is to be allocated to the retransmission functionality. For example, if the receiving modem contains 100 kBytes of available memory, the transmitting modem could send a message to the receiving modem indicating that 25 kBytes should be allocated to RS coding functionality and 75 kBytes should be allocated to the retransmission functionality. Since the receiving modem generally determines the interleaving/RS coding parameters that are used, the receiving modem could use this information to select parameters, e.g., interleaver depth and codeword size, that would result in an interleaving memory requirement that is no more than the amount indicated in the message.

Alternatively, or addition, the receiving modem can send a message to the transmitting modem indicating how much of the available memory is to be allocated to one or more of the

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interleaving/deinterleaving/RS coding/RS decoding functionality, and how much memory should be allocated to the retransmission functionality.

Sharing of Memory Between a Retransmission Function with Identification of Low-PER and/or Low-Latency Packets and One or More of Interleaving/Deinterleaving/RS Coding/RS Decoding Functions.

A way of reducing the total memory requirement of a transceiver that supports the retransmission functionality with the identification of the low-PER and/or the low-latency packets is to define a limit, such as a maximum value, for the data rate of the low-PER packet stream, i.e., the packets requiring retransmission to meet a specific PER requirement. For example, if the total data rate is 50 Mbps, and the roundtrip delay is 10 ms, the minimum TX or RX memory requirement is $50,000,000 \times 0.01/8 = 62500$ bytes if the retransmission function must support the case where all the transmitted packet (all 50 Mbps) are low-PER packets. If however, only a portion of the 50 Mbps data rate is allocated to the low-PER packet stream (e.g. 30 Mbps), whereas the remainder of the data rate is allocated to the low-latency packet stream (e.g. 20 Mbps), the minimum TX or RX memory requirement would be $30,000,000 \times 0.01/8 = 37500$ bytes (assuming a roundtrip delay of 10 ms). In this case, the transmitting modem (or receiving modem) may send a message to the receiving modem (or transmitting modem) that indicates the maximum data rate of the packet traffic that will be used in the retransmission function. Using the example above, the transmitting modem (or receiving modem) would send a message indicating that the low-PER traffic will not exceed 30 Mbps, in which case the receiving modem (or transmitting modem) will allocate memory to the retransmission functionality and the interleaving/RS coding (or deinterleaving/RS decoding) functionality accordingly.

One exemplary advantage of indicating the low-PER and low-latency packets as part of the retransmission protocol is that it provides a DDR-like functionality without the overhead of dynamically re-allocating latency paths. For example, when a video application is turned off (less low-PER packets on the connection), the data application data rate can be increased (more low-latency packets on the connection) without any changes in the transmission parameters.

The retransmission protocol can also be used with or without underlying FEC/interleaving (or deinterleaving). An exemplary approach is to use the FEC/interleaving to meet the INPmin requirement specifically targeting the impulse noise that occurs frequently, e.g., on the order of minutes or seconds. The retransmission protocol can be used to correct infrequent errors (on the order of hours) that will only typically be a problem for very-low PER applications, such as video.

When a retransmission protocol is combined with underlying FEC/interleaving (or deinterleaving), the retransmission protocol latency will grow in proportion to the additional FEC/interleaving delay. This is due to the fact that the required receiver buffering corresponds approximately to the round-trip delay time of packet transmission and message acknowledgment.

As an example of utilizing the retransmission protocol that identifies one or more of low-PER and low-latency packets with underlying FEC/Interleaving (or deinterleaving), the FEC/interleaving is used to achieve the INPmin requirements within the latency constraint and the retransmission function is used to provide another layer of error correction. The low-PER packets are passed through both the retransmission function and the FEC/interleaver and, as a result, a very low PER is achieved. The low-latency packets are passed through the

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FEC/Interleaver but not passed through the retransmission function. Since low-latency packets are passed through the FEC/interleaver, they will meet the INPmin and MaxDelay requirements without incurring the extra delay from the retransmission protocol.

Example Configuration Parameters:

DS Data rate=25 Mbps, INPmin=2, MaxDelayDS=8 ms

Example FEC/Interleaving Parameters:

NFEC=128, R=16 which results in an interleaver memory of approximately 14 Kbytes for INP=2 with 8 ms of delay.

Retransmission Protocol:

If we assume the US latency is 2 ms, the retransmission protocol will add a minimum of $8+2=10$ ms of latency. This means that the total DS latency (FEC/interleaving+Retransmission) will be approximately $8+10=18$ ms.

Memory Requirements:

The memory requirements for the retransmission protocol can be calculated as: $(10 \text{ ms}) \times (25 \text{ Mbps}) / 8 = 31$ Kbytes. Therefore the transmitter and receiver will both need a total memory of $(31+14)=45$ Kbytes for the retransmission protocol and FEC/Interleaving function.

Low-Per Packets:

Latency=18 ms. The PER is very low because INPmin=2 (from FEC/interleaving) is combined with the error correction of the retransmission function.

Low-Latency Packets:

Latency=8 ms. INP=2 from FEC/interleaving. No additional delay due to retransmission function.

Although this invention describes the retransmission being done as part of the PTM-TC, it could also be done inside other layer(s) of the xDSL transceiver, such as the PMD or the PMS-TC. Alternatively, it could be performed at a layer(s) above the PTM-TC, for example, in a new layer between the PTM-TC and the next higher layer, or in general any layer above the physical layer, e.g., layer 1, 2, 3, 4 or 5.

In this invention, the term "transmitter" generally refers to the transceiver that transmits the packets. Likewise the term "receiver" generally refers to the transceiver that receives the packets. Therefore the "transmitter" also receives the ACK/NAK messages and the "receiver" also transmits the ACK/NAK messages.

FIG. 2 outlines an exemplary method of operation of a transmitting modem utilizing the retransmission protocol. In particular, control begins in step S100 and continues to step S110. In step S110, a packet is received from a higher layer. Then, in step S120, a decision is made as to whether the received packet is a retransmitted type packet. If the packet is not a retransmitted type packet, such as a low-latency packet, control jumps to step S125 where the packet is optionally updated (as discussed above) with control continuing to step S130 where the packet is forwarded to the receiver. Control then continues to step S140 where the control sequence ends.

If the packet is a retransmitted type packet, such as a low-PER packet, control continues to step S150. In step S150, the packet can be updated with information such as a sequence identifier or other information that allows a receiver to be able to determine which packet (or packets) need to be retransmitted. Next, in step S160, the updated packet is stored in the retransmission buffer. Then, in step S170, the packet is forwarded to the receiver. Control then continues to step S180.

In step S180, a determination is made whether the packet needs to be retransmitted. If the packet needs to be retransmitted, control jumps back to step S170. Otherwise, control continues to step S190.

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In step S190, the packet is deleted from the retransmission buffer. Control then continues to step S140 where the control sequence ends.

FIG. 3 outlines an exemplary method of operation of a receiving modem utilizing the retransmission protocol. In particular, control begins in step S200 and continues to step S210. In step S210, a packet is received from the transmitter. Next, in step S220, a determination is made whether the packet has been identified as a retransmitted type packet. If the packet has not been identified as a retransmittable type packet, control jumps to step S230.

In step S230, the packet is forwarded to a higher layer. Control then continues to step S240 where the control sequence ends.

Alternatively, if the received packet is a retransmittable type packet, the packet is stored in the retransmission buffer in step S260. Next, in step S270, the integrity of the packet can be checked, for example utilizing a CRC. Then, in step S280, a determination is made whether the packet needs retransmission. If the packet needs retransmission, control continues to step S290 where the retransmitted packet is obtained, for example, based on the sending of a message(s), one or the other transceiver determining a packet is missing, or the like, as discussed above, with control continuing back to step S270 for an integrity check.

If the packet does not need retransmission, control continues to step S295 where the packet is forwarded to a higher layer and deleted from the retransmission buffer. Control then continues to step S240 where the control sequence ends.

FIG. 4 outlines an exemplary memory allocation method for sharing memory between the retransmission function and one or more of the interleaving/deinterleaving functionality and coding functionality. In particular, control begins in step S300 and continues to step S305. In step S305, a message is sent/received specifying the available memory. Typically, the receiver will send a message to the transmitter specifying the available memory, but the transmitter could also send a message to the receiver. Next, in step S310, a determination is made as to how the memory should be allocated. As discussed, this allocation can be based on one or more of error correction capability, latency, buffering requirements, SNR, impulse noise, or in general, any communication parameter. Next, in step S320, the memory allocation is communicated to another transceiver. Then, in step S330, a determination can be made as to whether the allocation is compatible. If the received allocation is not compatible, control continues to step S360 wherein another allocation can be requested, with control continuing back to step S320.

Alternatively, if the allocation is compatible, in step S340 the memory is allocated based on the received allocation. Control then continues to step S350 where the control sequence ends.

FIG. 5 illustrates an exemplary memory sharing methodology for use with a retransmission function and one or more of interleaving/deinterleaving functionality, RS coding/decoding functionality. In particular, control begins in step S400 and continues to step S410. In step S410, the memory allocation is received from, for example, a memory management module that may be located in the same transceiver, or at a remote transceiver. Next, in step S420, the memory sharing configuration is established and then, in step S430, the memory is shared between a retransmission function and one or more of the interleaving/deinterleaving functionality, RS coding/decoding functionality. Control then continues to step S440.

In step S440, a determination is made whether the memory sharing configuration should be changed. For example, the

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memory sharing configuration can be dynamically changed based on changes in the communication channel or data type(s) being sent on the communication channel. More specifically, for example, if the communications channel was not performing well, e.g., an increase in bit errors, it may be advantageous to increase the retransmission capability while decreasing the FEC/interleaving capability or vice-versa, which could have an impact on how the memory sharing should be configured.

If the memory sharing configuration should be changed, control continues to step S450 where another allocation can be requested, with control continuing back to step S410. Otherwise, control continues to step S460 where the control sequence ends.

While the above-described flowcharts have been discussed in relation to a particular sequence of events, it should be appreciated that changes to this sequence can occur without materially effecting the operation of the invention. Additionally, the exact sequence of events need not occur as set forth in the exemplary embodiments, but rather the steps can be performed by one or the other transceiver in the communication system provided both transceivers are aware of the technique being used for initialization. Additionally, the exemplary techniques illustrated herein are not limited to the specifically illustrated embodiments but can also be utilized with the other exemplary embodiments and each described feature is individually and separately claimable.

The above-described system can be implemented on wired and/or wireless telecommunications devices, such as a modem, a multicarrier modem, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a linecard, test equipment, a multicarrier transceiver, a wired and/or wireless wide/local area network system, a satellite communication system, network-based communication systems, such as an IP, Ethernet or ATM system, a modem equipped with diagnostic capabilities, or the like, or on a separate programmed general purpose computer having a communications device or in conjunction with any of the following communications protocols: CDSL, ADSL2, ADSL2+, VDSL1, VDSL2, HDSL, DSL Lite, IDSL, RADSL, SDSL, UDSL or the like.

Additionally, the systems, methods and protocols of this invention can be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element(s), an ASIC or other integrated circuit, a digital signal processor, a hard-wired electronic or logic circuit such as discrete element circuit, a programmable logic device such as PLD, PLA, FPGA, PAL, a modem, a transmitter/receiver, any comparable means, or the like. In general, any device capable of implementing a state machine that is in turn capable of implementing the methodology illustrated herein can be used to implement the various communication methods, protocols and techniques according to this invention.

Furthermore, the disclosed methods may be readily implemented in software using object or object-oriented software development environments that provide portable source code that can be used on a variety of computer or workstation platforms. Alternatively, the disclosed system may be implemented partially or fully in hardware using standard logic circuits or VLSI design. Whether software or hardware is used to implement the systems in accordance with this invention is dependent on the speed and/or efficiency requirements of the system, the particular function, and the particular software or hardware systems or microprocessor or microcomputer systems being utilized. The communication systems, methods and protocols illustrated herein can be readily implemented in hardware and/or software using any known or later

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developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

Moreover, the disclosed methods may be readily implemented in software that can be stored on a storage medium, executed on programmed general-purpose computer with the cooperation of a controller and memory, a special purpose computer, a microprocessor, or the like. In these instances, the systems and methods of this invention can be implemented as program embedded on personal computer such as an applet, JAVA® or CGI script, as a resource residing on a server or computer workstation, as a routine embedded in a dedicated communication system or system component, or the like. The system can also be implemented by physically incorporating the system and/or method into a software and/or hardware system, such as the hardware and software systems of a communications transceiver.

It is therefore apparent that there has been provided, in accordance with the present invention, systems and methods for packet retransmission and memory sharing. While this invention has been described in conjunction with a number of embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable arts. Accordingly, it is intended to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and scope of this invention.

The invention claimed is:

1. A method of packet retransmission comprising:

transmitting or receiving, using a transceiver, a plurality of packets;

identifying at least one packet of the plurality of packets as a packet that should be retransmitted;

allocating a memory between a retransmission function and an interleaving and/or deinterleaving function; and transmitting or receiving a message during initialization, wherein the message indicates how the memory is to be allocated between the retransmission function and the interleaving and/or deinterleaving function, and wherein at least a portion of the memory may be allocated to the retransmission function or the interleaving and/or deinterleaving function at any one particular time.

2. The method of claim 1, wherein the packets are used for video applications.

3. The method of claim 1, wherein the packets are used for internet access applications.

4. The method of claim 1, wherein the packets are used for voice applications.

5. The method of claim 1, wherein the transceiver contains at least one ASIC.

6. The method of claim 1, wherein the transceiver contains at least one DSP.

7. The transceiver of claim 1, wherein the transceiver is located on a linecard that is transporting video, internet access and voice data.

8. The transceiver of claim 1, wherein the transceiver is located in a customer premises equipment that is transporting video, internet access and voice data.

9. The transceiver of claim 1, wherein a sum of a maximum amount of the memory that can be allocated to the retransmission function and a maximum amount of the memory that can be allocated to the interleaving and/or deinterleaving function is more than a total amount of the memory.

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10. A transceiver capable of packet retransmission comprising:

a transmitter portion capable of: transmitting a plurality of packets, identifying at least one packet of the plurality of packets as a packet that should be retransmitted and allocating a memory between a retransmission function and an interleaving and/or deinterleaving function, wherein at least a portion of the memory may be allocated to the retransmission function or to the interleaving and/or deinterleaving function at any one particular time, and wherein a message transmitted during initialization indicates how the memory has been allocated between the retransmission function and the interleaving and/or deinterleaving function in the transceiver.

11. The transceiver of claim 10, wherein the packets are used for video applications.

12. The transceiver of claim 10, wherein the packets are used for internet access applications.

13. The transceiver of claim 10, wherein the packets are used for voice applications.

14. The transceiver of claim 10, wherein the transceiver contains at least one ASIC.

15. The transceiver of claim 10, wherein the transceiver contains at least one DSP.

16. The transceiver of claim 10, wherein the transceiver is located on a linecard that is capable of transporting video, internet access and voice data.

17. The transceiver of claim 10, wherein a sum of a maximum amount of the memory that can be allocated to the retransmission function and a maximum amount of the memory that can be allocated to the interleaving/deinterleaving function is more than a total amount of the memory.

18. A transceiver capable of packet retransmission comprising:

a receiver portion capable of: receiving a plurality of packets, identifying at least one packet of the plurality of packets as a packet that should be retransmitted and allocating a memory between a retransmission function and an interleaving and/or deinterleaving function

wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver and wherein at least a portion of the memory may be allocated between the retransmission function and the interleaving and/or deinterleaving function at any one particular time depending on the message.

19. The transceiver apparatus of claim 18, wherein the packets are used for video applications.

20. The transceiver of claim 18, wherein the packets are used for internet access applications.

21. The transceiver of claim 18, wherein the packets are used for voice applications.

22. The transceiver of claim 18, wherein the transceiver contains at least one ASIC.

23. The transceiver of claim 18, wherein the transceiver contains at least one DSP.

24. The transceiver of claim 18, wherein the transceiver is located in a customer premises equipment that is capable of transporting video, internet access and voice data.

25. The transceiver of claim 18, wherein a sum of a maximum amount of the memory that can be allocated to the retransmission function and a maximum amount of the memory that can be allocated to the interleaving and/or deinterleaving function is more than a total amount of the memory.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 8,468,411 B2
APPLICATION NO. : 12/783765
DATED : June 18, 2013
INVENTOR(S) : Marcos C. Tzannes

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In The Claims

Column 24, Claim 18, line 40, following "between" insert -- the retransmission function and --, therefore.

Column 24, Claim 18, line 41, delete "and" and insert -- and/or --, therefore.

Signed and Sealed this
Fifth Day of April, 2016



Michelle K. Lee
Director of the United States Patent and Trademark Office

EXHIBIT 8

US008937988B2

(12) **United States Patent**
Tzannes

(10) **Patent No.:** **US 8,937,988 B2**
(45) **Date of Patent:** **Jan. 20, 2015**

(54) **SYSTEMS AND METHODS FOR A
MULTICARRIER MODULATION SYSTEM
WITH A VARIABLE MARGIN**

H04L 5/0007; H04L 5/0046; H04L 5/006;
H04L 5/0044; H04L 5/14; H04L 27/2608;
H04W 72/04; H04M 11/062
USPC 375/222, 227, 259–260, 285, 295, 316,
375/350; 370/484–485
See application file for complete search history.

(71) Applicant: **TQ Delta, LLC**, Austin, TX (US)

(72) Inventor: **Marcos C. Tzannes**, Orinda, CA (US)

(73) Assignee: **TQ Delta, LLC**, Austin, TX (US)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/079,285**

(22) Filed: **Nov. 13, 2013**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(Continued)

(51) **Int. Cl.**
H04B 1/38 (2006.01)
H04L 27/28 (2006.01)
H04L 27/26 (2006.01)
H04L 5/00 (2006.01)

Primary Examiner — Khanh C Tran

(74) Attorney, Agent, or Firm — Jason H. Vick; Sheridan Ross, PC

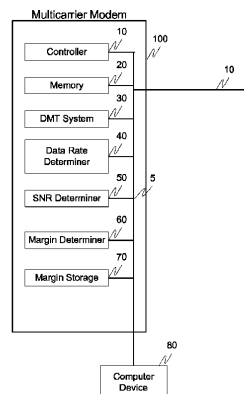
(52) **U.S. Cl.**
CPC **H04L 27/2601** (2013.01); **H04L 5/0007** (2013.01); **H04L 5/0044** (2013.01); **H04L 5/0046** (2013.01); **H04L 5/006** (2013.01); **H04L 27/2608** (2013.01); **H04B 1/38** (2013.01)
USPC **375/222**; **375/260**

(57) **ABSTRACT**

A multicarrier modem has a plurality of carriers over which data is transmitted. By assigning, for example, one or more different margins to the individual carriers the data rate and impairment immunity can be increased.

(58) **Field of Classification Search**
CPC H04L 1/0002; H04L 1/1671; H04L 1/243;

24 Claims, 2 Drawing Sheets



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Related U.S. Application Data

continuation of application No. 11/972,340, filed on Jan. 10, 2008, now abandoned, which is a continuation of application No. 11/242,024, filed on Oct. 4, 2005, now abandoned, which is a continuation of application No. 09/836,295, filed on Apr. 18, 2001, now abandoned.

- (60) Provisional application No. 60/197,727, filed on Apr. 18, 2000.

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Jan. 20, 2015

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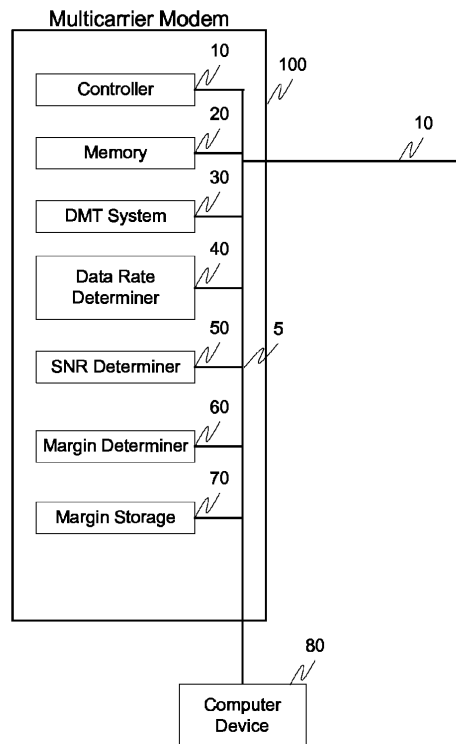


Fig. 1

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Jan. 20, 2015

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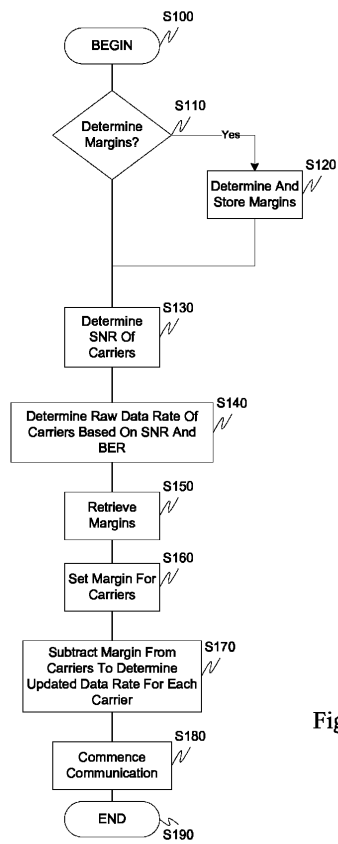


Fig. 2

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SYSTEMS AND METHODS FOR A MULTICARRIER MODULATION SYSTEM WITH A VARIABLE MARGIN

RELATED APPLICATION DATA

This application is a continuation of U.S. application Ser. No. 13/764,529, filed Feb. 11, 2013, now U.S. Pat. No. 8,625,660, which is a Continuation of U.S. application Ser. No. 12/694,143, filed Jan. 26, 2010, now U.S. Pat. No. 8,374,226, which is a continuation of U.S. application Ser. No. 11/972,340, filed Jan. 10, 2008, which is a continuation of U.S. application Ser. No. 11/242,024, filed Oct. 4, 2005, which is a continuation of U.S. application Ser. No. 09/836,295, filed Apr. 18, 2001, which claims the benefit of and priority under 35 U.S.C. §119(e) to U.S. Provisional Application No. 60/197,727, entitled "Multicarrier modulation system with variable margin to account for time varying impairments," filed Apr. 18, 2000, each of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to communications technologies. In particular, this invention relates to multicarrier modulation systems having multiple margins.

2. Description of Related Art

Multicarrier modulation, or Discrete Multitone Modulation (DMT), is a transmission method that is widely used for communication over difficult media. Multicarrier modulation divides the transmission frequency band into multiple subchannels, i.e., carriers or bins, with each carrier individually modulating a bit or a collection of bits. A transmitter modulates an input data stream containing information bits with one or more carriers, i.e., bins or subchannels, and transmits the modulated information. A receiver demodulates all the carriers in order to recover the transmitted information bits as an output data stream.

Multicarrier modulation has many advantages over single carrier modulation. These advantages include, for example, a higher immunity to impulse noise, a lower complexity equalization requirement in the presence of multipath, a higher immunity to narrow band interference, a higher data rate and bandwidth flexibility. Multicarrier modulation is being used in many applications to obtain these advantages, as well as for other reasons. These applications include Asymmetric Digital Subscriber Line (ADSL) systems, wireless LAN systems, power line communications systems, and other applications. ITU standards G.992.1 and G.992.2 and the ANSI T1.413 standard specify standard implementations for ADSL transceivers that use multicarrier modulation.

Discrete multitone modulation transceivers modulate a number of bits on each subchannel, the number of bits depending on the Signal to Noise Ratio (SNR) of that subchannel and the Bit Error Rate (BER) requirement of a link. For example, if the required BER is 1×10^{-7} , i.e., one bit in ten million is received in error on average, and the SNR of a particular subchannel is 21.5 dB, then that subchannel can modulate 4 bits, since 21.5 dB is the required SNR to transmit 4 QAM bits with a 1×10^{-7} BER. Other subchannels can have a different SNR and therefore may have a different number of bits allocated to them at the same BER. Additional information regarding bit loading can be found in copending U.S. application Ser. No. 09/510,773, incorporated herein by reference in its entirety.

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In many DMT systems, an additional parameter is used to determine the number of bits allocated to each subchannel. This parameter is called the SNR "margin," or simply the "margin." The margin specifies an extra SNR per subchannel, in addition to what is required to maintain the specified BER requirement. As an example, a DMT system with a 6 dB margin would require a $21.5 + 6 = 27.5$ dB SNR on a subchannel in order to transmit 4 bits on that subchannel with a 1×10^{-7} BER. This is 6 dB more than required by the example in the previous paragraph because now a 6 dB margin is added to the system. Another way of looking at this is that in the example of the previous paragraph, where 4 bits were allocated to a subchannel with 21.5 dB SNR, the margin was 0 dB.

DMT transceivers use a margin to increase the system's immunity to various types of time varying impairments. Examples of these impairments in DSL systems are: changes in the levels of crosstalk from other transmission systems, impulse noise, temperature changes in the telephone line, or the like. When a DMT system is operating with a positive SNR margin, the noise can change instantaneously by the level of the margin and the system will still maintain the required BER. For example, if the system is operating at a 6 dB margin, e.g., 4 bits are allocated to carriers with 27.5 dB SNR for $BER = 1 \times 10^{-7}$, the crosstalk levels can increase by 6 dB and the system will still be operating at the required 1×10^{-7} BER. Obviously the penalty for this increase in robustness is a decrease in the data rate, since with a 0 dB margin, a subchannel with 27.5 dB SNR can modulate 6 bits at 1×10^{-7} BER.

Therefore, there is a tradeoff between the robustness of the channel, such as a phone line, and the achievable data rate. The margin can be used to quantify this tradeoff. A higher margin results in a higher level of immunity to changing channel conditions at the expense of the achievable data rate. Likewise, a lower margin results in a higher data rate at the expense of a lower immunity to changing channel conditions.

Current DMT systems allocate a fixed margin to all subchannels. For example, ADSL systems typically use a 6 dB margin on all subchannels carrying data bits. This 6 dB margin is constant on all subchannels and is independent of the type of impairment that the margin is trying to protect against.

SUMMARY OF THE INVENTION

For simplicity of reference, the systems and methods of this invention will hereinafter refer to the transceivers, or multicarrier modems, generically as modems. One such modem is typically located at a customer premises such as a home or business and is "downstream" from a central office with which it communicates. The other modem is typically located at the central office and is "upstream" from the customer premises. Consistent with industry practice, the modems are often referred to as "ATU-R" ("ADSL transceiver unit, remote," i.e., located at the customer premises) and "ATU-C" ("ADSL transceiver unit, central office," i.e., located at the central office). Each modem includes a transmitter section for transmitting data and a receiver section for receiving data, and is of the discrete multitone type, i.e., the modem transmits data over a multiplicity of subchannels of limited bandwidth. Typically, the upstream or ATU-C modem transmits data to the downstream or ATU-R modem over a first set of subchannels, which are usually the higher-frequency subchannels, and receives data from the downstream or ATU-R modem over a second, usually smaller, set of subchannels, commonly the lower-frequency subchannels.

For example, in digital subscriber line (DSL) technology, communications over a local subscriber loop between a cen-

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tral office and a subscriber premises is accomplished by modulating the data to be transmitted onto a multiplicity of discrete frequency carriers which are summed together and then transmitted over a subscriber loop. Individually, the carriers form discrete, non-overlapping communication subchannels which are of a limited bandwidth. Collectively, the carriers form what is effectively a broadband communications channel. At the receiver end, the carriers are demodulated and the data recovered.

DSL systems experience disturbances from other data services on adjacent phone lines, such as, for example, ADSL, HDSL, ISDN, T1, or the like. Additionally, DSL systems may experience disturbances from impulse noise, crosstalk, temperature changes, or the like. These disturbances may commence after the subject DSL service is already initiated and, since DSL for Internet access is envisioned as a always-on service, the affects of these disturbances should be considered by the subject DSL transceiver. Additionally, the length of the phone line is a type of impairment that varies from one ADSL subscriber to another, i.e. from one ADSL installation to another, and therefore has an effect on the ADSL modem performance.

The systems and methods of this invention allow the margin in a discrete multitone modulation system to vary depending on a type of impairment. For example, this impairment can be changing over some duration or from one installation to another. Thus, different margins can be assigned to one or more of the carriers in a discrete multitone modulation communication system.

As noted above, there is a tradeoff between the robustness of the link and the achievable data rate. By setting a higher margin, a higher level of immunity to changing channel con-

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BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the invention will be described in detail, with reference to the following figures wherein:
FIG. 1 is a functional block diagram illustrating an exemplary modem according to this invention; and
FIG. 2 is a flowchart outlining an exemplary method for assigning margins according to this invention.

DETAILED DESCRIPTION OF THE INVENTION

In an exemplary embodiment of the invention, the margin is set to be different on at least two subchannels in a discrete multitone modulation system. In this exemplary embodiment, subchannels which are expected to incur greater variations in impairment levels are set to have a higher margin, whereas subchannels which are expected to incur lower variations in impairment levels are set to have lower margins. As an example of this embodiment, consider an ADSL transmission system transmitting data over telephone wires and consider the case where the impairment is changing channel conditions due to temperature fluctuations. Since telephone wire is typically made out of copper, the attenuation, i.e., the insertion loss, characteristics will depend on the temperature of the wire. As the temperature of the wire increases, the attenuation, i.e., the insertion loss, will increase. Furthermore, the insertion loss also varies with frequency as the temperature changes. Therefore, as the temperature increases, in addition to an overall increase in insertion loss, the insertion loss at the higher frequencies increases more than the insertion loss at the lower frequencies. Table 1 shows a correlation of frequency versus insertion loss of an exemplary 13,500 ft. 26 AWG line at various frequencies for 70° F. and 120° F.

TABLE 1

Insertion loss of 13500 ft 26 AWG line versus frequency at 70 F. and 120 F.											
	Frequency (kHz)										
	20	40	100	200	260	300	400	500	600	780	1100
Insertion loss (dB) at 70° F	29.8	36.7	45.2	52.8	57.3	60.2	67.7	74.8	81.7	93.0	110
Insertion loss (dB) at 120° F	31.9	39.6	49.4	57.4	61.8	64.8	72.3	79.3	86.1	97.9	116

ditions is achieved at the expense of the data rate. Similarly, while a lower margin may result in a higher data rate, the immunity to changing channel conditions is reduced.

However, setting the margin equally for all subchannels at least fails to account for impairments that change over time and how the impairments may have different effects on subchannels at different frequencies. For example, temperature changes and line length effect different frequencies with differing degrees of interference.

Aspects of the present invention relate to a communications system having a plurality of margins.

Aspects of the present invention also relates to a method of assigning a plurality of margins to a communications system.

Aspects of this present invention additionally relate to multicarrier modulation systems and methods for different margins to be assigned to different subchannels to account for varying impairments.

These and other features and advantages of this invention are described in, or are apparent from, the following detailed description of the embodiments.

From Table 1, it is apparent that the difference in insertion loss from 120° F. to 70° F. is 2.1 dB at 20 kHz, whereas the difference in insertion loss from 120° F. to 70° F. is 6 dB at 1100 kHz. For this exemplary embodiment, a higher margin could be allocated to carriers at higher frequencies and a lower margin allocated to carriers at lower frequencies. For example, the carrier at 20 kHz will only need a 2.1 dB margin, because even if the temperature changes from 70° F. to 120° F., the insertion loss will only change by 2.1 dB and, as a result, the system bit error rate requirement can still be met after the temperature change. Similarly, the carrier at 1100 kHz will need a 6 dB margin, since as the temperature changes from 70° F. to 120° F., the insertion loss will change by 6 dB and, as a result, the system bit error rate requirement will still be satisfied even after the temperature change.

However, it is to be appreciated that the margin is not allocated to each subchannel in a fixed manner, but rather varies based on the expected change in impairments over time or as impairments vary from one DSL installation to another. However, that does not preclude the possibility that different subchannels can have the same margin assigned to them. For example, a subchannel may have a certain margin assigned

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based on a particular impairment, while another subchannel may have the same margin assigned based on another impairment. These impairments can include, but are not limited to, changes in the levels of crosstalk from other transmission systems, impulse noise, temperature changes, line length, radio frequency interference and other ingress, or the like. As a result, for example, since certain subchannels are not overly burdened with a common margin, the overall data rate of the system can be increased without sacrificing the robustness of the system.

For example, and with reference to Table 1, by lowering the margin of the lower carriers from 6 dB to 2.1 dB, the channel data rate has increased. This increase can occur without a loss of the immunity to temperature variations on the line since the lower frequencies are less susceptible to temperature changes than the higher frequencies. In general, the systems and methods of this invention can be adapted to set a margin for any impairment that varies over time, or is installation based, and may, for example, effect different frequencies in different ways.

As another example, consider crosstalk from another transmission system. If the crosstalking transmission system is known to use only a portion of the frequency spectrum utilized by the discrete multitone modulation system, then the margins can be decreased on the carriers that are known to be outside the frequency spectrum of the crosstalking system. For example, ISDN systems are an example of a crosstalk source for ADSL systems. ISDN systems typically transmit only up to approximately 150 kHz. Thus, for example, employing the teachings of this invention, carriers above 150 kHz can operate at lower margins than carriers below 150 kHz where the ISDN crosstalk is present.

As another example, the margin in an ADSL system can be varied depending on the length of the telephone wire. Table 2 shows a relationship of insertion loss of an exemplary 9000 ft. 26 AWG line at frequencies for 70° F. and 120° F.

TABLE 2

Insertion loss of 9000 ft 26 AWG line versus frequency at 70 F. and 120 F.											
	Frequency (kHz)										
	20	40	100	200	260	300	400	500	600	780	1100
Insertion loss (dB) at 70° F	20.0	24.4	30.1	35.2	38.2	40.2	45.1	49.9	54.4	62.0	73.6
Insertion loss (dB) at 120° F	21.4	26.3	32.8	38.2	41.2	43.2	48.2	52.9	57.4	65.3	77.5

Comparing Table 1 and Table 2, it is apparent that an increase in insertion loss as temperature increases depends on the length of the telephone line as well. Thus, on the exemplary 9,000 ft. phone line, a 50° F. temperature change results in an average of only 2.8 dB increase in insertion loss. On the 13,500 ft. phone line, a 50° F. temperature change resulted in an average of 4.3 dB increase in insertion loss. For this illustrative example, the margin on the subchannels is varied depending on the length of the phone line. As an example, if the phone line is shorter, e.g., 9,000 ft., the average margin can be decreased on the subchannels by 4.3–2.8=1.5 dB as compared to a longer 13,500 ft. loop without sacrificing immunity to temperature changes on the phone line. This is possible because a shorter phone line will not experience as much of a change in insertion loss due to temperature changes as a longer phone line.

For this illustrative example, the margin allocated to different subchannels takes into account information about the

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length of the telephone line. As an example, the insertion loss difference from 70° F. to 120° F. at 20 kHz is 2.1 dB for the 13,500 ft. line. On the other hand, the insertion loss difference from 70° F. to 120° F. at 20 kHz is 1.4 dB for the 9,000 ft. line. Therefore, for this exemplary situation, a margin of 2.1 dB would be allocated to the carrier at 20 kHz on a 13,500 ft. line whereas a margin of 1.4 dB would be allocated to the carrier at 20 kHz on the 9,000 ft. line. The immunity to temperature variations on the line would be the same for both the systems operating at 9,000 ft. and 13,500 ft. As a result, the overall system data rate can be increased on shorter lines without sacrificing a loss in robustness.

FIG. 1 illustrates an exemplary embodiment of a multicarrier modem 100. In particular, the multicarrier modem 100 comprises a controller 10, a memory 20, a discrete multitone modulation system 30, a data rate determiner 40, a signal to noise ratio determiner 50, a margin determiner 60 and a margin storage 70, all interconnected by link 5. The multicarrier modem 100 is also connected to one or more computer or computer-type devices 80 and additional modems (not shown) via communications link 10. For ease of illustration, the multicarrier modem 100 has been illustrated in block diagram format with only the components needed for the exemplary embodiment of this invention. Additional information and further discussion of the operation and structure of an exemplary multicarrier modem can be found in copending U.S. patent application Ser. No. 09/485,614 entitled "Splitterless Multicarrier Modem."

While the exemplary embodiment illustrated in FIG. 1 shows the multicarrier modem 100 and various components collocated, it is to be appreciated that the various components of the multicarrier modem can be rearranged and located in whole or in part at an ATU-R and/or ATU-C. Furthermore, it is to be appreciated, that the components of the multicarrier modem 100 can be located at various locations within a distributed network, such as a POTS network, or other com-

parable telecommunications network. Thus, it should be appreciated, that the components of the multicarrier modem 100 can be combined into one device or distributed amongst a plurality of devices. As will be appreciated from the following description, and for reasons of computational efficiency, the components of the multicarrier modem can be arranged at any location within a telecommunications network and/or modem without affecting the operation of the system.

The links 5 and 10 can be a wired or a wireless link or any other known or later developed element(s) that is capable of supplying and communicating electronic data to and from the connected elements. Additionally, the computer device 80, can be, for example, a personal computer or other device. In general, the computer device 80 can be any device that uses a modem to transmit and/or receive data.

In operation, the multicarrier modem 100 is installed, for example, in a customer premises or in a central office. During this installation, certain fixed quantities such as line length are

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known and can be stored in the multicarrier modem 100. During an initial installation, or at any subsequent time for which a redetermination in margins is appropriate, for example, based on an increased bit error rate, changes in the signal to noise ratio, seasonal changes, or the like, the controller 10, in cooperation with the memory 20, the discrete multitone modulation system 30 and the margin determiner 60 can determine and store margins. For example, as illustrated above in exemplary Tables 1 and 2, margins can be determined for temperature fluctuations and the length of the wire line based on, for example, the actual installation and historical data. Furthermore, routines can be established by the margin determiner 60 to evaluate and compile statistical information relating to one or more carriers. For example, this statistical information can be compiled during modem idle times in response to impairments seen on the one or more carriers. This statistical information can then be used to determine appropriate margins for one or more carriers.

Alternatively, the modem may measure the noise on the line during idle times and determine that a particular type of crosstalk, e.g., another ADSL or HDSL modem, is present. Since the spectral content of these types of crosstalkers are known, this information can be used to determine the margin. For example, if the crosstalker is an ATU-R ADSL modem then it is known that ATU-R ADSL modems transmit approximately in the 20-130 kHz range. This information can be used to determine the margin for the carriers in the 20-130 kHz frequency range.

Alternatively, a predetermined set of margins, for example, for known impairments, can be downloaded from, for example, a central office modem or other location within a communications network. The determined and/or downloaded margins are then stored in the margin storage 70. Similarly, groups of margins can be stored based on, for example, geographic information, seasonal information, line length information, or the like.

During training of the multicarrier modem 100, the SNR determiner 50, in cooperation with the controller 10, the memory 20, and the DMT system 30, determines the signal to noise ratio of the carriers. Knowing the signal to noise ratio of the carriers, the data rate determiner 40 determines the raw data rate of the carriers based on the signal to noise ratio and the bit error rate. This raw data rate reflects the data rate of carriers with no margin.

Generally, the bit error rate is set in advance, for example, by the manufacturer. Additionally, the data rate is generally governed by a range that is, for example, guaranteed as a maximum, by a DSL provider. Therefore, based on the set bit error rate, the signal to noise ratio for a known quantity of bits can be determined.

Knowing the signal to noise ratio, the margins for the carriers can be set, for example, based on one or more, or a combination of, entered criteria or determined criteria. For example, an entered criteria can be based on the loop length. A determined criteria can be, for example, based on standard temperature variance information that can, for example, be downloaded from the service provider. Alternatively, for example, the margins can be set based on historical data that relates to, for example, impairments on the line. In general, the margins can be set such that a balance between the data rate and the impairment immunity is maximized.

Having retrieved the margins for one or more of the carriers, the margins are set in the DMT system 30. The margins can then be subtracted from the carrier to determine an updated data rate for each carrier. Having set the margins, and knowing the data rate, the DMT system can then commence communication over the communications link 10.

FIG. 2 illustrates an exemplary method of assigning margins to carriers according to an exemplary embodiment of this

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invention. In particular, control begins in step S100 and continues to step S110. In step S110, a determination is made whether margins are to be determined. If margins are to be determined, control continues to step S120. Otherwise, control jumps to step S130.

In step S120, the margins are determined and stored. Control then continues to step S130.

In step S130, the signal to noise ratio of the carriers are determined. Next, in step S140, the raw data rate of the carriers is determined based on the signal to noise ratio and the bit error rate. Next, in step S150, the margins for the carriers are retrieved. Control then continues to step S160.

In step S160, the margins for the carriers are set. Next, in step S170, the margins are subtracted from the carriers to determine an updated data rate for each carrier. Control then continues to step S180.

In step S180, communications commence. Control then continues to step S190 where the control sequence ends.

However, it is to be appreciated that the steps in FIG. 2 need not occur in the order illustrated. For example, at any point in time there could be an option to re-determine the margins. Similarly, based on, for example, the time of the day, day, location, error rate, service provider directive, a change in the quality of service requirement, or the like, the margins could be adjusted. Alternatively, at any time, updated margins could be downloaded and stored in the margin storage. Alternatively, if it known that margins will be incorporated in the determination of the data rate, step S140 could be bypassed since it is known that the raw data rate will not be used.

Furthermore, the systems and methods of this invention can also apply to any multicarrier modulation based communication system including wireless LANs, such as wireless LAN 802.11 and ETSI Hyperlan standards, wireless access systems, home and access power-line communication systems, or the like.

As illustrated in FIG. 1, the multicarrier modem and related components can be implemented either on a DSL modem, or a separate program general purpose computer having a communications device. However, the multicarrier modem can also be implemented in a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element, and ASIC or other integrated circuit, a digital signal processor, a hardwired or electronic or logic circuit such as a discrete element circuit, a programmable logic device such as a PLD, PLA, FPGA, PAL, or the like, and associated communications equipment. In general, any device capable of implementing a finite state machine that is in turn capable of implementing the flowchart illustrated in FIG. 2 can be used to implement the multicarrier modem 100 according to this invention.

Furthermore, a disclosed method may be readily implemented in software using object or object-oriented software development environment that provides portable source code that can be used on a variety of computers, workstations, or modem hardware platforms. Alternatively, the disclosed modem may be implemented partially or fully in hardware using standard logic circuits or a VLSI design. Other software or hardware can be used to implement the systems in accordance with this invention depending on the speed and/or efficiency requirements of the systems, the particular function, and the particular software or hardware systems or microprocessor or microcomputer systems being utilized. The multicarrier modem illustrated herein, however, can be readily implemented in hardware and/or software using any known or later developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

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Moreover, the disclosed methods can be readily implemented as software executed on a programmed general purpose computer, a special purpose computer, a microprocessor and associated communications equipment, or the like. In these instances, the methods and systems of this invention can be implemented as a program embedded on a modem, such as a DSL modem, or the like. The multicarrier modem can also be implemented by physically incorporating the system and method in a software and/or hardware system, such as a hardware and software system of a modem, such as an ADSL modem, or the like.

It is, therefore, apparent that there has been provided in accordance with the present invention, systems and methods for assigning margins to carriers. While this invention has been described in conjunction with a number of embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable art. Accordingly, Applicants intend to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and the scope of this invention.

What is claimed is:

1. A multicarrier communications method, comprising: modulating for transmission, in a transceiver, a first plurality of bits onto a first carrier using a first Signal to Noise Ratio (SNR) margin;

modulating for transmission, in the transceiver, a second plurality of bits onto a second carrier using a second Signal to Noise Ratio (SNR) margin; and
modulating for transmission, in said transceiver, a third plurality of bits onto said first carrier using a third SNR margin,

wherein the first SNR margin specifies a first value for an allowable increase in noise without an increase in the bit error rate (BER) associated with the first carrier,

wherein the second SNR margin specifies a second value for an allowable increase in noise without an increase in the bit error rate (BER) associated with the second carrier,

wherein the third SNR margin specifies a third value for an allowable increase in noise without an increase in the bit error rate (BER) associated with said first carrier,

wherein the first SNR margin is different than the second SNR margin,

wherein the first SNR margin is different than the third SNR margin, and

wherein the first plurality of bits, the second plurality of bits and the third plurality of bits are each different from one another.

2. The method of claim 1, wherein at least one of the first, second and third SNR margins are further based on one or more of a change in temperature, a crosstalk from another transmission system, a length of a telephone wire, a radio frequency interference and an impulse noise.

3. The method of claim 1, wherein at least one of the first, second and third SNR margins are further based on one or more of an expected change in temperature, an expected crosstalk from another transmission system, a change in length of a telephone wire, an expected radio frequency interference and an expected impulse noise.

4. A method of communications, comprising:

demodulating for reception, in a transceiver, a first plurality of bits from a first carrier using a first Signal to Noise Ratio (SNR) margin;

demodulating for reception, in the transceiver, a second plurality of bits from a second carrier using a second SNR margin; and

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demodulating for reception, in the transceiver, a third plurality of bits from the first carrier using a third SNR margin,

wherein the first SNR margin specifies a first value for an allowable increase in noise without an increase in the bit error rate (BER) associated with the first carrier,

wherein the second SNR margin specifies a second value for an allowable increase in noise without an increase in the bit error rate (BER) associated with the second carrier,

wherein the third SNR margin specifies a third value for an allowable increase in noise without an increase in the bit error rate (BER) associated with said first carrier,

wherein the first SNR margin is different than the second SNR margin,

wherein the first SNR margin is different than the third SNR margin, and

wherein the first plurality of bits, the second plurality of bits and the third plurality of bits are each different from one another.

5. The method of claim 4, wherein at least one of the first SNR margin, the second SNR margin and the third SNR margins are based on one or more of a change in temperature, a crosstalk from another transmission system, a radio frequency interferer, a length of a telephone wire and an impulse noise.

6. The method of claim 4, wherein at least one of the first, second and third SNR margins are further based on one or more of an expected change in temperature, an expected crosstalk from another transmission system, a change in length of a telephone wire, an expected radio frequency interference and an expected impulse noise.

7. An apparatus comprising:

a multicarrier communications transceiver operable to modulate for transmission a first plurality of bits onto a first carrier using a first Signal to Noise Ratio (SNR) margin and to modulate for transmission a second plurality of bits onto a second carrier using a second SNR margin, and to modulate for transmission a third plurality of bits onto the first carrier using a third SNR margin, wherein the first SNR margin specifies a first value for an allowable increase in noise without an increase in the bit error rate (BER) associated with the first carrier,

wherein the second SNR margin specifies a second value for an allowable increase in noise without an increase in the bit error rate (BER) associated with the second carrier,

wherein the third SNR margin specifies a third value for an allowable increase in noise without an increase in the bit error rate (BER) associated with said first carrier,

wherein the first SNR margin is different than the second SNR margin,

wherein the first SNR margin is different than the third SNR margin, and

wherein the first plurality of bits, the second plurality of bits and the third plurality of bits are each different from one another.

8. The apparatus of claim 7, wherein at least one of the first SNR margin, the second SNR margin and the third SNR margins are based at least on crosstalk or an expected crosstalk from another transmission system.

9. The apparatus of claim 7, wherein at least one of the first SNR margin, the second SNR margin and the third SNR margins are based at least on a change in temperature or an expected change in temperature.

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10. The apparatus of claim 7, wherein at least one of the first SNR margin, the second SNR margin and the third SNR margins are based at least on impulse noise or expected impulse noise.

11. The apparatus of claim 7, wherein at least one of the first SNR margin, the second SNR margin and the third SNR margin is based at least on a length of a telephone line or a change in a length of a telephone line.

12. The apparatus of claim 7, wherein the apparatus is a linecard that is capable of transporting internet data.

13. The apparatus of claim 7, wherein the apparatus is a customer premises equipment that is capable of transporting internet data.

14. The apparatus of claim 7, wherein the transceiver includes at least one digital signal processor.

15. The apparatus of claim 7, wherein the transceiver includes at least one ASIC (Application-Specific Integrated circuit).

16. An apparatus comprising:

a multicarrier communications transceiver operable to demodulate for reception a first plurality of bits from a first carrier using a first Signal to Noise Ratio (SNR) margin and to demodulate for reception a second plurality of bits from a second carrier using a second SNR margin, and to demodulate for reception a third plurality of bits from the first carrier using a third SNR margin, wherein the first SNR margin specifies a first value for an allowable increase in noise without an increase in the bit error rate (BER) associated with the first carrier,

wherein the second SNR margin specifies a second value for an allowable increase in noise without an increase in the bit error rate (BER) associated with the second carrier,

wherein the third SNR margin specifies a third value for an allowable increase in noise without an increase in the bit error rate (BER) associated with said first carrier,

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wherein the first SNR margin is different than the second SNR margin,

wherein the first SNR margin is different than the third SNR margin, and

wherein the first plurality of bits, the second plurality of bits and the third plurality of bits are each different from one another.

17. The apparatus of claim 16, wherein at least one of the first SNR margin, the second SNR margin and the third SNR margin is based at least on crosstalk or expected crosstalk from another transmission system.

18. The apparatus of claim 16, wherein at least one of the first SNR margin, the second SNR margin and the third SNR margin is based at least on a change in temperature or an expected change in temperature.

19. The apparatus of claim 16, wherein at least one of the first SNR margin, the second SNR margin and the third SNR margin is based at least on impulse noise or expected impulse noise.

20. The apparatus of claim 16, wherein at least one of the first SNR margin, the second SNR margin and the third SNR margin is based at least on a length of a telephone line or a change in the length of telephone wire.

21. The apparatus of claim 16, wherein the apparatus is a linecard that is capable of transporting internet data.

22. The apparatus of claim 16, wherein the apparatus is a customer premises equipment that is capable of transporting internet data.

23. The apparatus of claim 16, wherein the transceiver includes at least one digital signal processor.

24. The apparatus of claim 16, wherein the transceiver includes at least one ASIC (Application-Specific Integrated Circuit).

* * * * *

EXHIBIT 9

US009094348B2

(12) **United States Patent**
Tzannes

(10) **Patent No.:** **US 9,094,348 B2**
(45) **Date of Patent:** **Jul. 28, 2015**

(54) **PACKET RETRANSMISSION**

(71) Applicant: **TQ DELTA, LLC**, Austin, TX (US)

(72) Inventor: **Marcos C. Tzannes**, Orinda, CA (US)

(73) Assignee: **TQ DELTA, LLC**, Austin, TX (US)

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H04L 12/721 (2013.01)
H04L 12/701 (2013.01)
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See application file for complete search history.

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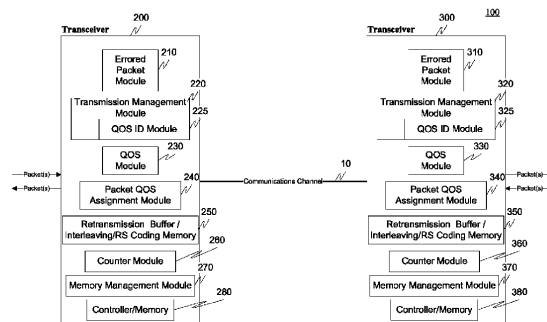
Primary Examiner — Charles Ehne

(74) *Attorney, Agent, or Firm* — Jason H. Vick; Sheridan Ross, PC

(57) **ABSTRACT**

Through the identification of different packet-types, packets can be handled based on an assigned packet handling identifier. This identifier can, for example, enable forwarding of latency-sensitive packets without delay and allow error-sensitive packets to be stored for possible retransmission. In another embodiment, and optionally in conjunction with retransmission protocols including a packet handling identifier, a memory used for retransmission of packets can be shared with other transceiver functionality such as, coding, decoding, interleaving, deinterleaving, error correction, and the like.

28 Claims, 4 Drawing Sheets



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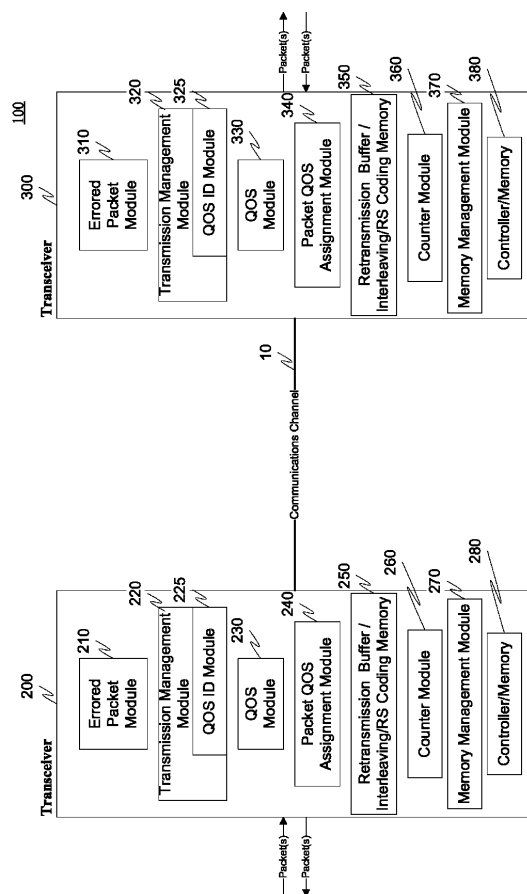


Fig. 1

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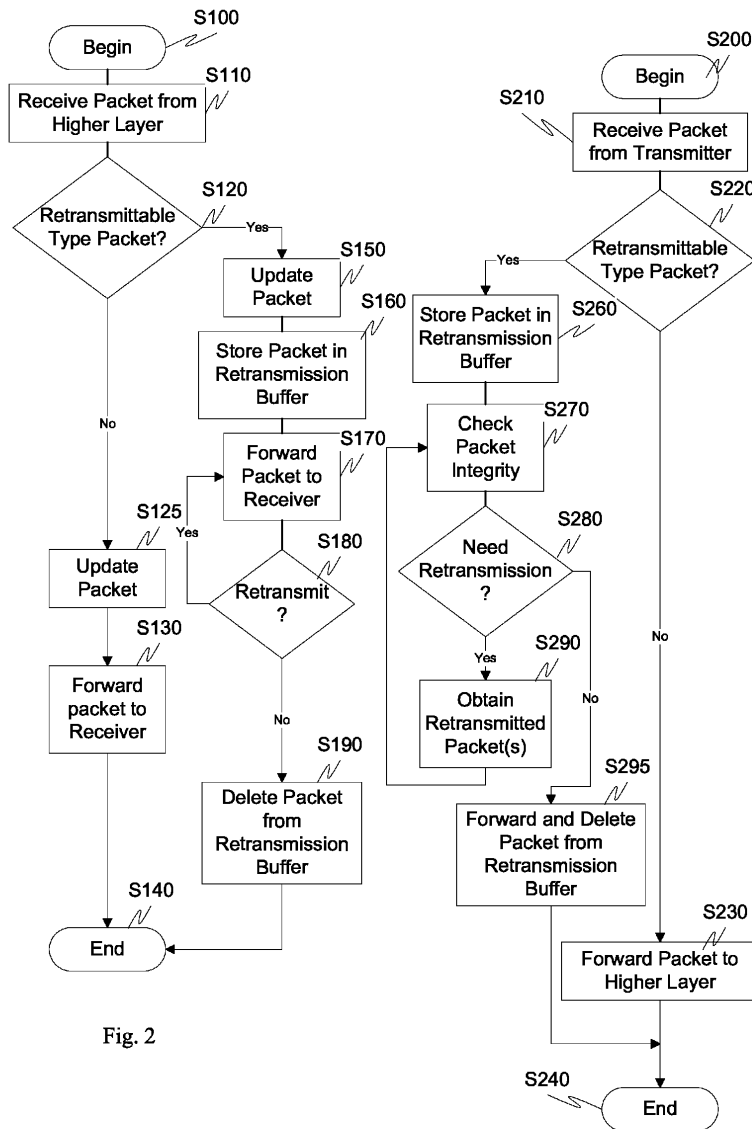


Fig. 2

Fig. 3

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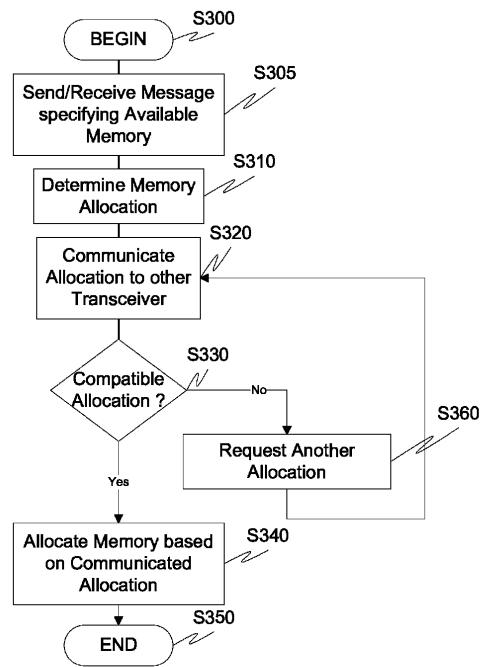


Fig. 4

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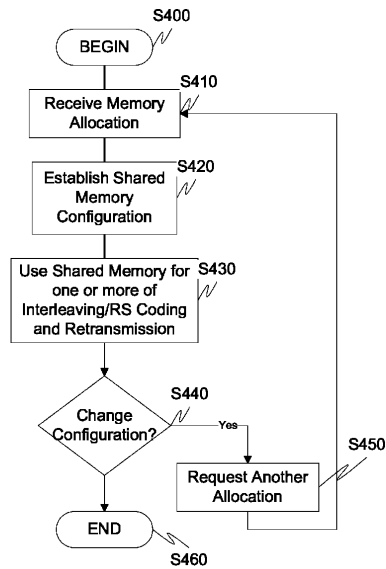


Fig. 5

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PACKET RETRANSMISSION

RELATED APPLICATION DATA

This application is a Continuation of U.S. patent application Ser. No. 12/760,728, filed Apr. 15, 2010, now U.S. Pat. No. 8,595,577, which is Divisional of U.S. patent application Ser. No. 12/295,828, filed Oct. 2, 2008, now U.S. Pat. No. 8,335,956, which is a national stage application under 35 U.S.C. 371 of PCT Application No. PCT/US2007/066522 having an international filing date of Apr. 12, 2007, which designated the United States, which PCT application claims the benefit of and priority under 35 U.S.C. §119(e) to U.S. Patent Application Nos. 60/792,236, filed Apr. 12, 2006, entitled "xDSL Packet Retransmission Mechanism," and 60/849,650, filed Oct. 5, 2006, entitled "xDSL Packet Retransmission Mechanism with Examples," each of which are incorporated herein by reference in their entirety.

BACKGROUND

Field of the Invention

This invention generally relates to communication systems. More specifically, an exemplary embodiment of this invention relates to retransmission of packets in a communication environment. An exemplary embodiment of this invention also relates to memory sharing between transmission functions and other transceiver functions.

SUMMARY

Exemplary aspects of the invention relate to handling of packets and the assignment of a packet handling identifier. Exemplary aspects relate to sharing of resources between retransmitted packets and other transceiver functions. In addition, exemplary aspects relate to sharing of resources between packets associated with the packet handling identifier and other transceiver functions.

More specifically, aspects of the invention relate to assigning a packet handling identifier to one or more packets. Based on the packet handling identifier, a packet can either be, for example, forwarded directly to another communication device (or layer) or, alternatively, held for possible retransmission protocols. For example, packets received from, for example, a higher-layer of a communication device, can be designated to have a specific packet handling identifier, such as a Quality of Service (QOS) level. The QOS level of a packet indicates the importance of certain service metrics (or characteristics) of one or more packets.

Two exemplary QOS metrics are delay (or latency) and Packet Error Rate (PER). While these two metrics are used for illustrative purposes herein, it should be appreciated that other metrics can also be used with this invention. For example, other QOS metrics could include one or more of a Bit Error Rate (BER), data rate, delay variation (or jitter), packet loss rate, time between error events (TBE), or the like.

As an example, in the case where the two QOS metrics are latency and PER, packets containing, for example, video information (such as IPTV) may have the requirement for a very low packet error rate but can often tolerate higher delay. In contrast, voice or data (e.g., gaming) traffic may have very low latency requirements but can tolerate a higher packet error rate. For this particular example, the video packets could be designated as "low-PER" QOS packets and the voice or data packets could be designated as "low-latency" QOS packets. For example, a specific QOS identifier could be assigned

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to the low-latency packets while a different QOS identifier could be assigned to the low-PER packets. The low-latency packets could be forwarded directly to another transceiver, or a higher layer, while the low-PER packets can be stored in a retransmission buffer, e.g., memory, that can be used to reduce packet error.

As mentioned above, exemplary aspects also relate to sharing of resources between a retransmission function and other transceiver functions.

The exemplary systems and methods of this invention can utilize memory, such as a retransmission buffer, for the storing of packets for retransmission functions. Since other transceiver functions may also require memory to perform certain functionality, an exemplary aspect of this invention also relates to sharing the memory for retransmission functions with the memory required for other transceiver functions. For example, memory can be dynamically allocated based on configuration settings or noise conditions and, for example, the memory divided between one or more of interleaving/deinterleaving, RS Coding/Decoding functionality and the functionality used retransmission.

Aspects of the invention thus relate to identification of one or more packets.

Additional aspects of the invention relate to identifying one or more packets that can be retransmitted.

Still further aspects of the invention relate to identifying one or more packets that should not be retransmitted.

Aspects of the invention also relate to retransmission of one or more of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-data frame, a PTM-TC codeword, and RS codeword and a DMT symbols.

Still further aspects of the invention relate to appending an identifier to a packet.

Still further aspects of the invention relate to appending a sequence identifier to at least one packet.

Aspects of the invention also relate to routing one or more packets based on a packet handling identifier.

Aspects of the invention also relate to retransmitting a packet.

Aspects of the invention further relate to retransmit a packet based on a retransmission request.

Still further aspects of the invention relate to sharing memory between a retransmission function and one or more of an interleaver, deinterleaver, coder, decoder and other transceiver functionalities.

Other more specific aspects of the invention relate to sharing memory between a retransmission buffer (or memory) and interleaving/deinterleaving and/or coding/decoding functionality.

Additional exemplary, non-limiting aspects of the invention are:

1. A method of packet retransmission comprising: transmitting or receiving a plurality of packets; identifying at least one packet of the plurality of packets as a packet that should not be retransmitted.

2. The method of aspect 1, wherein the packet is any grouping of bytes.

3. The method of aspect 1, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

4. The method of aspect 1, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

5. The method of aspect 4, wherein the identifying step comprises using a special value for a sequence identifier (SID).

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6. The method of aspect 4, wherein the appended bit field comprises a dedicated CRC.

7. The method of aspect 1, wherein the at least one packet is not stored for retransmission.

8. The method of aspect 1, wherein the at least one packet is passed immediately to a high layer.

9. A packet retransmission module capable of transmitting or receiving a plurality of packets and capable of identifying at least one packet of the plurality of packets as a packet that should not be retransmitted.

10. The module of aspect 9, wherein the packet is any grouping of bytes.

11. The module of aspect 9, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

12. The module of aspect 9, wherein the module is capable of appending a bit field comprising a sequence identifier (SID) to each packet.

13. The module of aspect 12, wherein the identifying comprises using a special value for the SID.

14. The module of aspect 12, wherein the appended bit field comprises a dedicated CRC.

15. The module of aspect 9, wherein the at least one packet is not stored by the module for retransmission.

16. The module of aspect 9, wherein the at least one packet is passed by the module immediately to a high layer.

17. The module of aspect 9, wherein the module is implemented in one or more of a wireless transceiver, a wireless LAN station, a wired transceiver, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a multicarrier transceiver, a general purpose computer, a special purpose computer, a programmed microprocessor, a microcontroller and peripheral integrated circuit element(s), an ASIC, a digital signal processor, a hard-wired electronic or logic circuit and a programmable logic device.

18. The module of aspect 9, wherein the module is implemented in one or more of a PTM-TC, ATM-TC, PMD and PMS-TC.

19. A method comprising sharing memory between an interleaving and/or deinterleaving memory and a packet retransmission memory.

20. A method comprising allocating a first portion of shared memory for retransmission and a second portion of the shared memory for interleaving and/or deinterleaving.

21. The method of aspect 20, further comprising transmitting or receiving a message indicating how to allocate the shared memory.

22. The method of aspect 19 or 20, further comprising transmitting or receiving a message indicating how to share the memory.

23. A memory capable of being shared between an interleaving and/or deinterleaving buffer and a packet retransmission buffer.

24. A module capable of allocating a first portion of shared memory for retransmission and a second portion of the shared memory for interleaving and/or deinterleaving.

25. The module of aspect 24, wherein the module is capable of transmitting or receiving a message indicating how to allocate the shared memory.

26. The module of aspect 24, wherein the module is capable of transmitting or receiving a message indicating how to share the memory.

27. The module of aspect 24, wherein the module is one or more of a wireless transceiver, a wireless LAN station, a wired transceiver, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a multicarrier transceiver, a general

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purpose computer, a special purpose computer, a programmed microprocessor, a microcontroller and peripheral integrated circuit element(s), an ASIC, a digital signal processor, a hard-wired electronic or logic circuit and a programmable logic device.

28. A method of packet retransmission comprising: transmitting or receiving a plurality of packets; identifying at least one packet of the plurality of packets as a packet that should be retransmitted and at least one packet of the plurality of packets as a packet that should not be retransmitted.

29. The method of aspect 28, wherein the packet is any grouping of bytes.

30. The method of aspect 28, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

31. The method of aspect 28, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

32. The method of aspect 31, wherein the identifying step comprises using a special value for a sequence identifier (SID).

33. The method of aspect 31, wherein the appended bit field comprises a dedicated CRC.

34. The method of aspect 28, wherein at least one packet is stored for retransmission.

35. The method of aspect 28, wherein at least one packet is passed immediately to a high layer.

36. A packet handling method comprising: receiving a stream of packets; identifying a first number of packets in the stream of packets as low-latency packets; identifying a second number of packets in the stream of packets as low-error packets; forwarding the low-latency and low-error packets to a transceiver or a higher layer; and storing the low-error packets for error correction.

37. The method of aspect 36, further comprising appending the low-error packets with an identifier.

38. A method of allocating memory in a transceiver comprising:

analyzing one or more communication parameters; identifying a memory allocation; and allocating memory based on the memory allocation to a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding.

39. A memory sharing method in a transceiver comprising: receiving a memory allocation; establishing a shared memory for one or more of interleaving, deinterleaving, RS coding, RS decoding and packet retransmission functions; and sharing the shared memory between a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functions.

40. The method of aspect 39, further comprising determining a compatibility of the memory allocation.

41. The method of aspect 39, wherein the compatibility of the memory allocation is based on channel performance metrics.

42. Means for performing the functionality of any of the aforementioned aspects.

43. An information storage media comprising information that when executed performs the functionality of any of the aforementioned aspects.

44. Any one or more of the features as substantially described herein.

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45. Means for packet retransmission comprising:
means for transmitting or receiving a plurality of packets;
means for identifying at least one packet of the plurality of
packets as a packet that should not be retransmitted.

46. The means of aspect 45, wherein the packet is any
grouping of bytes.

47. The means of aspect 45, wherein the packet is one of an
IP packet, an Ethernet packet, an ATM cell, a PTM packet, an
ADSL Mux-Data Frame, a PTM-TC codeword, an RS code-
word and a DMT symbol.

48. The means of aspect 45, wherein a bit field comprising
a sequence identifier (SID) is appended to each packet.

49. The means of aspect 48, wherein the means for identi-
fying comprises using a special value for a sequence identifier
(SID).

50. The means of aspect 48, wherein the appended bit field
comprises a dedicated CRC.

51. The means of aspect 45, wherein the at least one packet
is not stored for retransmission.

52. The means of aspect 45, wherein the at least one packet
is passed immediately to a high layer.

53. Means for sharing memory between an interleaving
and/or deinterleaving function and a packet retransmission
function.

54. Means for allocating a first portion of shared memory
for retransmission and a second portion of the shared memory
for interleaving and/or deinterleaving.

55. The means of aspect 54, further comprising means for
transmitting or receiving a message indicating how to allocate
the shared memory.

56. The means of aspect 54, further comprising means for
transmitting or receiving a message indicating how to share
the memory.

57. Means for sharing a memory between an interleaving
and/or deinterleaving function and a packet retransmission
function.

58. Means for packet retransmission comprising:
means for transmitting or receiving a plurality of packets;
means for identifying at least one packet of the plurality of
packets as a packet that should be retransmitted and at
least one packet of the plurality of packets as a packet
that should not be retransmitted.

59. The means of aspect 58, wherein the packet is any
grouping of bytes.

60. The means of aspect 58, wherein the packet is one of an
IP packet, an Ethernet packet, an ATM cell, a PTM packet, an
ADSL Mux-Data Frame, a PTM-TC codeword, an RS code-
word and a DMT symbol.

61. The means of aspect 58, wherein a bit field comprising
a sequence identifier (SID) is appended to each packet.

62. The means of aspect 61, wherein the means for identi-
fying comprises using a special value for the sequence iden-
tifier (SID).

63. The means of aspect 58, wherein the appended bit field
comprises a dedicated CRC.

64. The means of aspect 58, wherein at least one packet is
stored for retransmission.

65. The means of aspect 58, wherein at least one packet is
passed immediately to a high layer.

66. A packet handling means comprising:
means for receiving a stream of packets;
means for identifying a first number of packets in the
stream of packets as low-latency packets;
means for identifying a second number of packets in the
stream of packets as low-error packets;
means for forwarding the low-latency and low-error pack-
ets to a transceiver or higher layer; and

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means for storing the low-error packets for error correc-
tion.

67. The means of aspect 66, further comprising means for
appending the low-error packets with an identifier.

68. Means for allocating memory in a transceiver compris-
ing:

means for analyzing one or more communication param-
eters;

means for identifying a memory allocation; and

means for allocating memory based on the memory allo-
cation to a retransmission function and one or more of an
interleaving, deinterleaving, RS coding and RS decod-
ing function.

69. Means for memory sharing in a transceiver comprising:
means for receiving a memory allocation;

means for establishing a shared memory for one or more of
interleaving, deinterleaving, RS coding, RS decoding
and packet retransmission function; and

means for sharing the shared memory between a retran-
smission function and one or more of interleaving,
deinterleaving, RS coding and RS decoding functional-
ity.

70. The means of aspect 69, further comprising means for
determining a compatibility of the memory allocation.

71. The means of aspect 69, wherein the compatibility of
the memory allocation is based on channel performance met-
rics.

72. A transceiver capable of performing packet retransmis-
sion comprising:

a transmission management module configurable to trans-
mit or receive a plurality of packets; and

a QOS module configurable to identify at least one packet
of the plurality of packets as a packet that should not be
retransmitted.

73. The transceiver of aspect 72, wherein the packet is any
grouping of bytes.

74. The transceiver of aspect 72, wherein the packet is one
of an IP packet, an Ethernet packet, an ATM cell, a PTM
packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an
RS codeword and a DMT symbol.

75. The transceiver of aspect 72, wherein a bit field com-
prising a sequence identifier (SID) is appended to each
packet.

76. The transceiver of aspect 75, wherein the QOS module
uses a special value for a sequence identifier (SID).

77. The transceiver of aspect 75, wherein the appended bit
field comprises a dedicated CRC.

78. The transceiver of aspect 72, wherein the at least one
packet is not stored for retransmission.

79. The transceiver of aspect 72, wherein the at least one
packet is passed immediately to a high layer.

80. A memory capable of being shared between interleav-
ing and/or deinterleaving and packet retransmission.

81. A memory management module capable of allocating a
first portion of shared memory for retransmission and capable
of allocating a second portion of the shared memory to one or
more of interleaving and deinterleaving functionality.

82. The module of aspect 81, further comprising a module
for transmitting or receiving a message indicating how to
allocate the shared memory.

83. The module of aspect 81, further comprising a module
for transmitting or receiving a message indicating how to
share the memory.

84. A module capable of being shared between interleaving
and/or deinterleaving and packet retransmission.

85. A transceiver capable of performing packet retransmis-
sion comprising:

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a transmission management module configurable to transmit or receive a plurality of packets; and
a QOS module configurable to identify at least one packet of the plurality of packets as a packet that should be retransmitted and at least one packet of the plurality of

packets as a packet that should not be retransmitted.
86. The transceiver of aspect 85, wherein the packet is any grouping of bytes.

87. The transceiver of aspect 85, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

88. The transceiver of aspect 85, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

89. The transceiver of aspect 88, wherein the identifying step comprises using a special value for a sequence identifier (SID).

90. The transceiver of aspect 88, wherein the appended bit field comprises a dedicated CRC.

91. The transceiver of aspect 85, wherein at least one packet is stored for retransmission.

92. The transceiver of aspect 85, wherein at least one packet is passed immediately to a high layer.

93. A transceiver capable of handling a stream of packets comprising:

a QOS module capable of identifying a first number of packets in the stream of packets as low-latency packets and a second number of packets in the stream of packets as low-error packets;

a transmission management module capable of forwarding the low-latency and low-error packets to another transceiver; and

a buffer module capable of storing the low-error packets for error correction.

94. The transceiver of aspect 93, further comprising a packet QOS assignment module capable of appending the low-error packets with an identifier.

95. A transceiver capable of having an allocatable memory comprising:

a controller capable of analyzing one or more communication parameters; and

a memory management module capable of identifying a memory allocation and allocating a shared memory based on the memory allocation to a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functions.

96. A transceiver capable of sharing memory comprising: a controller capable of receiving a memory allocation; and a memory management module capable of establishing a shared memory for a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functions.

97. The transceiver aspect 96, wherein the memory management module further determines a compatibility of the memory allocation.

98. The transceiver of aspect 96, wherein the memory allocation is based on one or more communication channel performance metrics.

99. In a communication environment where packets are being transmitted, a method for allocating a first portion of shared memory for retransmission of packets and a second portion of the shared memory for interleaving and/or deinterleaving.

100. The method of aspect 99, wherein all errored packets are retransmitted.

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101. The method of aspects 19, 20 and 99, wherein a retransmission function identifies packets that should not be retransmitted.

102. The method of aspect 99, wherein all packets are being transmitted without an assigned a QOS level.

103. A packet communication method comprising:
in a first mode of operation:

transmitting or receiving a plurality of packets;

identifying at least one packet of the plurality of packets as a packet that should not be retransmitted;

in a second mode of operation:

transmitting or receiving a plurality of packets;

allocating a first portion of shared memory for retransmission of packets and a second portion of the shared memory for one or more of interleaving, deinterleaving, coding, decoding and error correction; and

in a third mode of operation:

transmitting or receiving a plurality of packets;

identifying at least one packet of the plurality of packets as a retransmittable-type packet;

identifying at least one packet of the plurality of packets as a non-retransmittable-type packet;

allocating a first portion of shared memory for retransmission of the retransmittable-type packets and a second portion of the shared memory for one or more of interleaving, deinterleaving, coding, decoding and error correction.

104. The method of aspect 103, wherein the retransmittable-type packet is a low-latency packet.

105. The method of aspect 103, wherein the retransmittable-type packet is a low-error packet.

These and other features and advantages of this invention are described in, or are apparent from, the following detailed description of the exemplary embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The exemplary embodiments of the invention will be described in detail, with reference to the following figures wherein:

FIG. 1 illustrates an exemplary communication system according to this invention.

FIG. 2 is a flowchart outlining an exemplary method for packet retransmission according to this invention.

FIG. 3 is a flowchart outlining an exemplary method for retransmitted packet reception according to this invention.

FIG. 4 is a flowchart outlining an exemplary method for memory allocation according to this invention.

FIG. 5 is a flowchart outlining an exemplary method for memory sharing according to this invention.

DETAILED DESCRIPTION

The exemplary embodiments of this invention will be described in relation to packet retransmission and/or memory sharing in an xDSL environment. However, it should be appreciated, that in general, the systems and methods of this invention will work equally well for any type of communication system in any environment.

The exemplary systems and methods of this invention will also be described in relation to multicarrier modems, such as xDSL modems and VDSL modems, and associated communication hardware, software and communication channels. However, to avoid unnecessarily obscuring the present invention, the following description omits well-known structures and devices that may be shown in block diagram form or otherwise summarized.

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For purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the present invention. It should be appreciated however that the present invention may be practiced in a variety of ways beyond the specific details set forth herein.

Furthermore, while the exemplary embodiments illustrated herein show the various components of the system collocated, it is to be appreciated that the various components of the system can be located at distant portions of a distributed network, such as a communications network and/or the Internet, or within a dedicated secure, unsecured and/or encrypted system. Thus, it should be appreciated that the components of the system can be combined into one or more devices, such as a modem, or collocated on a particular node of a distributed network, such as a telecommunications network. As will be appreciated from the following description, and for reasons of computational efficiency, the components of the system can be arranged at any location within a distributed network without affecting the operation of the system. For example, the various components can be located in a Central Office modem (CO, ATU-C, VTU-O), a Customer Premises modem (CPE, ATU-R, VTU-R), an xDSL management device, or some combination thereof. Similarly, one or more functional portions of the system could be distributed between a modem and an associated computing device.

Furthermore, it should be appreciated that the various links, including communications channel 10, connecting the elements (not shown) can be wired or wireless links, or any combination thereof, or any other known or later developed element(s) that is capable of supplying and/or communicating data to and from the connected elements. The term module as used herein can refer to any known or later developed hardware, software, firmware, or combination thereof that is capable of performing the functionality associated with that element. The terms determine, calculate and compute, and variations thereof, as used herein are used interchangeably and include any type of methodology, process, mathematical operation or technique. Transmitting modem and Transmitting transceiver as well as Receiving modem and Receiving transceiver are used interchangeably herein.

Moreover, while some of the exemplary embodiments described herein are directed toward a transmitter portion of a transceiver performing interleaving and/or coding on transmitted information, it should be appreciated that a corresponding deinterleaving and/or decoding is performed by a receiving portion of a transceiver. Thus, while perhaps not specifically illustrated in every example, this disclosure is intended to include this corresponding functionality in both the same transceiver and/or another transceiver.

Communication system 100 comprises a portion of a transceiver 200 and a portion of a transceiver 300. The transceiver 200, in addition to well known componentry, comprises an errored packet module 210, a transmission management module 220, a QOS ID module 225, a QOS module 230, a packet QOS assignment module 240, a retransmission buffer/interleaving/deinterleaving/RS coding/RS Decoding memory 250, a counter module 260, a memory management module 270 and a controller/memory 280.

Connected via communication channel 10 to transceiver 200 is transceiver 300. The transceiver 300, in addition to well known componentry, comprises an errored packet module 310, a transmission management module 320, a QOS ID module 325, a QOS module 330, a packet QOS assignment module 340, a retransmission buffer/interleaving/deinterleaving/RS coding/RS Decoding memory 350, a counter module 360, a memory management module 370 and a controller/memory 380.

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As discussed above, the systems, methods and protocols discussed herein will be described in relation to xDSL systems, such as those specified in ADSL2 ITU-T G.992.3, ADSL2+ITU G.992.5, and VDSL2 ITU G.993.2, which are incorporated herein by reference in their entirety.

In operation, a first aspect of the invention relates to retransmission of one or more packets, the retransmission identifier being implemented at any transmission layer where packet boundaries are defined. For example, it can be implemented in the Packet Transmission Mode TC (PTM-TC) of xDSL systems. For reference, "Annex A" which is of record in the identified provisional filing and incorporated by reference herein contains the PTM-TC of ADSL2 and VDSL2 systems as specified in the ITU-T G.992.3 ADSL2 standard.

As discussed herein, the invention will generally be described in relation to the retransmission mechanism being incorporated as part of the PTM-TC however, it should be appreciated that it can also be implemented inside other layer(s) of a communication device, such as an xDSL transceiver, such as within the PMD or PMS-TC.

The retransmission techniques disclosed herein can also be performed at a layer above the PTM-TC, for example, in a new layer between the PTM-TC and the next higher layer, or at any layer above the physical layer, e.g., layers 2, 3, 4, 5, etc.

Additionally, while "packet" is used herein, the term "packet" includes any basic data unit, i.e., a grouping of bytes. For example, a packet could be an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data frame, a PTM-TC codeword, an RS Codeword, a DMT symbol, or, in general, any grouping of data bytes or information. A packet could also be a combination of one or more of the above. For example, a packet could be constructed by concatenating any number of ATM cells to create a larger grouping of bits. For example, five 53-byte ATM cells could be combined into a 265 byte packet or four 65 PTM-TC codewords could be combined into a 260 byte packet. A packet could also be based on dividing any of the above groupings of bytes. For example, larger IP or Ethernet packets could be divided into smaller groups of bytes to be used as a "packet" with the retransmission functionality described herein. For example, a 1500 byte IP packet could be divided into three 500 byte packets and used by the retransmission protocol. If the retransmission function is implemented as part of the PTM-TC, packets are received from a higher-layer in the xDSL transmitter PTM-TC and sent via the xDSL transmitter PMS-TC and PMD over the communication channel to the xDSL receiver. The xDSL receiver PMD and PMS-TC process the received signal and pass the results to the PTM-TC, which processes the information and passes the received packet up to a higher layer(s).

Packets received from the higher layer at the xDSL transmitter PTM-TC can be designated to have a QOS level. The QOS level of a packet can indicate the importance of certain service metrics (or characteristics) of this (or more) packet(s). Two exemplary QOS metrics are delay (or latency) and PER. Although, as discussed above, these two characteristics are the focus of the invention, any number of different QOS metrics could also be used.

As an example, in the case where the 2 QOS metrics are latency and PER, a first set of packets carrying certain information may have a requirement for very low PER but may be able to tolerate higher delay. Other packets containing information such as voice or data traffic may have very low delay requirements but can tolerate a higher PER. According to an exemplary embodiment of this invention, the first set of packets would be designated as "low-PER" QOS packets whereas voice or data packets would be designated as "low-latency"

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QOS packets. The QOS level (or metric) of a packet could be designated in a number of ways. For example:

i) Certain bit fields in the header of data portions of each packet could contain certain values that specify the QOS requirements a packet. For example, the packet header could contain bit fields that indicate if the packet has a “low-PER” QOS requirement or a “low-latency” QOS requirement. These fields could be read by the transmitting modem and/or receiving modem to determine the QOS level of each packet.

ii) When sending packets from higher layer to the PTM-TC, the higher layer could indicate on a packet by packet basis the QOS requirements of each packet. For example, there could be a separate signal on the interface that indicates if a packet being transferred has a “low-PER” QOS requirement or a “low-latency” QOS requirement.

iii) When sending packets from higher layer to the PTM-TC, there could be a separate interface (or channel) for packets with different QOS requirements. For example, one channel could be used to transfer packets that have a “low-PER” QOS requirement and a second channel could be used to transfer packets that have a “low-latency” QOS requirement. This general concept could also be scaled to accommodate a plurality of different QOS requirements and a plurality of channels.

iv) As in the case of Pre-Emption in the PTM-TC (see Annex A), two logically separated γ -interfaces could be used for the transport of a low-PER and low-latency packet flow through a single bearer channel. This general idea could then be scaled to support any number of packet types.

Other mechanisms can also be used to designate the QOS level of a packet—provided the transmitter and/or receiver retransmission protocol is capable of knowing the QOS level for one or more packets.

Once the QOS level is known by the PTM-TCs, an efficient packet retransmission can be designed. The exemplary packet retransmission methods and protocols can be designed to include any one or more of the following system level characteristics:

All packets are received from the higher layer and passed to the higher layers in the correct order.

“Low-latency” QOS packets will not incur any extra delay due to retransmission.

Only packets with “low-PER” QOS should be retransmitted, and therefore only low-PER packets will incur the extra delay due to the retransmission mechanism.

Flow control can be minimized such that the transmitter can generally accept all packets from the higher layer at the required data rate without holding-off (or “blocking”) packets from the higher layer during the retransmission process.

Packet delay-variation/jitter can be minimal.

A “DRR-like” functionality in a single bearer without requiring latency/interleaver OLR.

The transceiver 200, in cooperation with the QOS module 230, receives packets from a higher-layer. In cooperation with the packet QOS assignment module 240, a packet Sequence ID (SID) is appended to the received packets. The packets, in cooperation with the transmission management module 220, can then be transmitted in the order in which they were received.

The QOS Module 230, if not already performed by a high layer, also identifies packets based on the QOS requirement of the packet(s). Then, in cooperation with the packet QOS assignment module 240, a QOS identifier is associated with the packet as discussed hereinafter.

If, for example, the packet is identified as a low-PER packet, and assigned such an identifier by the QOS module

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230, when the transmission management module 220 receives the packet, the packet is identified by the QOS ID module 225 as being a low-PER packet and the packet is forwarded for storage in the retransmission buffer 250. Alternatively, if the packet has been labeled as a low-latency packet, and identified as such by the by the QOS ID module 225, the packet can be transmitted to the receiving modem in cooperation with the transmission management module 220.

The low-PER packets can be stored for a sufficient amount of time to wait for a retransmission message from the receiver PTM-TC. During this time, the transmitting modem can continue to receive packets from one or more higher layers, label these packets, if needed, and store these packets, if they are identified as low-PER packets, in the same way. The resulting minimum storage requirements for the transmitter PTM-TC are estimated below.

For successful retransmission, the receiving modem should be able to inform the transmitting modem which packet, or packets, need to be retransmitted. One exemplary way of performing this is by transmitting packets with an appended bit field that contains a counter indicating the place of each packet in a stream of packets. This counter value is also known as a Sequence ID (SID). For example, a bit field containing a 16-bit counter could be appended to each packet and the counter module 260 would be incremented by one after each packet was transmitted. In cooperation with the packet assignment module 240, a packet counter field could be appended to the packet in a number of places, for example, at the beginning or end of the packet, or at the beginning or end of the packet header.

Packets received from a higher-layer may already have information in a header or data field of the packet that contains the packet count, or sequence, information. In addition, the packet counter field may be appended with an additional CRC field that contains a cyclic redundancy check that is computed on the packet counter field bits only. This CRC can be used by the receiver to determine if the packet counter field is received correctly, i.e., without bit errors. This CRC can be in addition to the standard CRC inserted by the standard PTM-TC (the standard packet PTM-TC CRC is a CRC that covers all bits in a packet). The standard packet CRC may also cover the new packet counter field in its CRC as well. This helps if the receiving modem uses the presence or absence of the packet counter field in a packet to detect if the packet has a low-PER or low-latency requirement (discussed below).

Alternatively, or in addition, the packet counter field (with or without a dedicated CRC) can be appended only to the packets with a specific QOS requirement, whereas all other packets can be transmitted without modification. For example, all video packets with low-PER QOS could contain the appended packet counter field whereas all the voice/data low-latency packets could be transmitted unchanged. One exemplary benefit of this is that the overhead (rate loss) due to adding the packet counter field is incurred only when transmitting low-PER packets.

Alternatively, or in addition, all low-PER and low-latency packets can be transmitted with the low packet counter field (with or without a dedicated CRC). In this case, the packet counter field of the low-latency packets may contain a special value indicating that a packet is not a low-PER packet. Also, the packet counter field of the low-latency packet may not even contain a count value, since the low-latency packets are not intended to be retransmitted. In this case, the packet counter field could contain a counter value only for low-PER packets and the counter value would only be incremented when a low-PER packet was transmitted. As an example, if the packet counter field is 16 bits, the special value of all zeros

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could be used to indicate that a packet is a low-latency packet. In this case, low-PER packets could contain counter values from one up to $2^{16}-1$, but not including all zeros, since this special zero value can be used to indicate a low-latency packet.

The receiving modem, e.g., receiver PTM-TC, which in this case is illustrated as the transceiver 300 and includes comparable functionality to that described in relation to transceiver 200, receives packets from the transmitting modem via the PMS-TC. If the received packet is identified as a low-latency packet by the QOS ID module 325, the packet is passed to a higher-layer. If a received packet is identified by the QOS ID module 325 as a low-PER packet, the packet is forwarded, with the cooperation of the transmission management module 320, to the retransmission buffer 350 for a minimum amount of time before passing to a higher-layer.

The storage time in the retransmission buffer 350 helps ensure that the retransmission protocol provides a constant delay, e.g., no delay variation seen by the upper layers. This way, if a packet needs to be retransmitted, the receiving modem can continue to provide packets to the higher-layers at a constant rate while waiting for the retransmitted packet(s) to arrive from the transmitting modem. The resulting minimum memory (or storage) requirements for the receiving PTM-TC are estimated below.

Alternatively, low-PER packets without errors may not be stored for a minimum amount of time before passing to a higher-layer. The error-free low-PER packets can be passed to the higher-layer immediately just like the low-latency packets. However, when a low-PER packet is in error, it is stored along with all of the following low-PER packets before passing to a higher-layer in order to wait for the retransmitted packet(s) to arrive. This will cause a delay variation on the low-PER packets whenever a retransmission occurs. However, this delay variation would not apply to the low-latency packets.

The QOS ID module 325 can detect that a packet is either low-PER or low-latency using several different methods. For example, if all low-PER and low-latency packets contain the appended packet counter field, then the receiving modem, in cooperation with the counter module 360, detects a low-latency packet when a packet counter field contains the designated special value, which was inserted by the transmitting modem, indicating the packet is a low-latency packet.

Alternatively, or in addition, the receiver could detect a low-PER packet when the packet counter field contains a valid packet counter value. Additionally, if a dedicated CRC is appended to the packet counter field, the CRC could be used to detect if the packet counter field bits are in error.

If the packet counter field, including the CRC, is only appended to low-PER packets, the absence or presence of this field in a packet can be used by the receiving modem, and in particular the QOS ID module, to detect a low-delay packet. For example, the receiving modem can examine the position in the packet where the packet counter field would be, if it was a low-PER packet, and if the packet counter field CRC fails while the standard whole packet CRC is correct, the receiving modem could determine that the packet is a low-delay packet, since it does not contain the packet counter field. Likewise, for example, the receiving modem can examine the position in the packet where the packet counter field would be, if it was a low-PER packet, and if the packet counter field CRC is correct, the receiving modem would determine that the packet is a low-PER packet, regardless of the status of the standard whole packet CRC.

The receiving modem, in cooperation with the retransmission buffer 350, and the errored packet module 310, can be

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used to detect missing or errored packets in a number of exemplary ways. For example, the errored packet module 310 can detect bit errors in the packet using the standard/whole packet PTM-TC CRC. Alternatively, or in addition, the errored packet module 310 can detect bit errors in the packet counter field if the transmitting modem appended a dedicated CRC to the packet counter field. This CRC is valuable because it can be used by the errored packet module in the receiving modem to determine if a packet has the correct packet number, even if the standard whole packet CRC happens to be in error.

Alternatively, or in addition, the errored packet module 310, can detect an errored or missing packet by receiving a packet with a correct CRC, either in the standard or packet counter field, which contains a packet counter number that is not the expected packet counter number. For example, if the errored packet module 310, in cooperation with the counter module 360, detects the receipt of a packet with a counter number equal to 5, wherein the errored packet module 310 is expecting to receive a packet with a counter equal to 3, the errored packet module 310 can determine that two packets, namely packets numbered 3 and 4, were lost due to errors.

Once a packet(s) is found to be in error, there are several exemplary ways in which a receiving modem can communicate information to the transmitting modem indicating that a retransmission of one or more packets is required. For example, the receiving modem, in cooperation with the errored packet module 310, can send an acknowledgment (ACK) message to the transmitting modem for every correctly received message or every predetermined number of packets. As long as the transmitting modem, and in particular the errored packet module 210, receives messages acknowledging receipt of packets in sequential order, there is no need for retransmission of information to the receiving modem. However, if the transmitting modem, and in particular the errored packet module 210, receives a message from the receiving modem, and in particular the errored packet module 310, indicating that a packet was correctly received with a counter value that is out of order, a retransmission by the transmitting modem is required. In the above example, where the receiving modem received a packet with a counter value equal to 5, without receiving packets numbered 3 and 4, the transmitting modem could receive an ACK for the packet with counter value of 2 and then an ACK for the packet with a counter value of 5. The transmitting modem would then determine that it was necessary to retransmit packets with counter values of 3 and 4 since they were not received.

Alternatively, or in addition, a timeout value could be specified for the transmitting modem. This timeout value could correspond to the amount of time that the transmitting modem should wait for an ACK for particular packet before retransmitting the packet. The timeout value could be set to be at least as long as the round-trip delay required for the transmitting modem to send a packet to the receiving modem and for the receiving modem to send an ACK back to the transmitting modem. If an ACK is not received by the timeout value, the transmitting modem could retransmit the packet.

Alternatively, or in addition, a negative acknowledgment (NAK) could be sent to the transmitting modem when a packet is detected as errored or missing. In the above example, when the receiving modem received the packet with a counter value of 5, while expecting a counter value of 3, the receiving modem could send a NAK message to the transmitting modem indicating that packets with counter values of 3 and 4 were not correctly received and needed to be retransmitted.

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Alternatively, or in addition, if a packet was received with a correct packet counter CRC and a valid packet counter value *a* and an incorrect standard whole packet CRC, the receiving modem could send a NAK message to the transmitting modem indicating that a packet with a value of *a* was incorrectly received and needed to be retransmitted.

Assuming that errored packets are infrequent, any methodology that sends an ACK for each correctly received packet can require a larger amount of data rate in the message channel that communicates this information back to the transmitting modem. In this case, sending only NAKs has the benefit that it requires sending a message only when an errored or missing packet is detected. Depending on the data rate capabilities of the message channel, and the PER, a retransmission system may use only ACKs, only NAKs, or both ACKs and NAKs at the same time.

The ACK and NAK messages sent back to the transmitting modem can be transmitted over the same physical channel i.e., phone line, in the opposite direction as the received packets. Since the channel has a limited data rate and is not necessarily error-free, it is important to make sure that these messages are as robust as possible and consume the least amount of data rate. Additionally, since the transmit and receive retransmission memory requirements depend on the round-trip latency of the connection, is important to minimize latency requirements for the message channel. There are several ways these requirements can be addressed.

The messages can be sent over a separate “low-latency” or “fast” path between the xDSL transceivers. This fast path could include little or even no delay due to interleaving and can be specified to have a latency that is less than 2 ms.

Alternatively, or in addition, the messages can be sent with increasing robustness by repeating transmission of each message a number of times. For example, the message could be repeated *x* times in order to make sure that even if *x*–1 messages were corrupted by the channel, at least one message would be received correctly.

Alternatively, or in addition, the messages can be sent such that each message is repeated a number of times and each repeated message is sent in a different DMT symbol. For example, the message can be repeated *x* times and each message sent in one of *x* DMT symbols. This way, even if *x*–1 DMT symbols were corrupted by the channel, at least one message would be received correctly.

Alternatively, or in addition, the messages can be sent such that each message is repeated a number of times and each repeated message is sent in different DMT symbols. For example, the message could be repeated *x* times and each message sent in one of *x* DMT symbols. This way, even if *x*–1 DMT symbols were corrupted by the channel, at least one message would be received correctly.

Alternatively, or in addition, the messages can be sent such that each message is repeated a number of times and each repeated message is sent a plurality of times in each DMT symbol. For example, the message could be repeated *x* times and each repeated message sent *y* times in one of *x* DMT symbols. This way, even if *x*–1 DMT symbols were corrupted by the channel and/or large portions of a DMT symbol were corrupted by a channel, the least one message would be received correctly.

Alternatively, or in addition, the messages can include multiple packet count values in order to reduce the data rate requirements. For example, if packets with counter values of 3–9 are correctly (or incorrectly) received an ACK (or NAK) message would be sent to indicate these packet values. For example, the message could contain the values 3 and 9 and the

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receiver of the message would automatically know that all intermediate values (4, 5, 6, 7, 8) are also been indicated in the message.

Alternatively, or in addition, the DMT sub-carriers that modulate these messages could operate with a much higher SNR margin e.g., 15 dB, as compared to the normal 6 dB margin of xDSL systems. This way, the messages would have a higher immunity to channel noise.

Alternatively, or in addition, a receiving modem may need to send an additional ACK or NAK message after already in the process of sending a repeated message. For example, a receiving modem may detect that packets with values 3 to 9 have been correctly received and send an ACK message back to the transmitting modem indicating this information. This message can be repeated *x* times with each repeated message being transmitted (at least once) on different DMT symbols. While sending the second repeated message on the second DMT symbol, the receiver could detect that packets with values 10 to 17 have now also been correctly received. In this case, the receiving modem could just append this information to the previous message or, alternatively, send a new separate message that is repeated as well *x* times with each repeated message being transmitted (at least once) on a different DMT symbol.

Alternatively, or in addition, when repeating a message *x* times on *x* DMT symbols, each repeated message can be modulated on a different set of DMT sub-carriers on each DMT symbol. This way, if one or more sub-carriers have a low SNR, the message will still be correctly received.

For low-PER packets, the delay due to this retransmission protocol is equal to the delay that results from storing these packets at the receiving modem (RX PTM-TC) to pass in the packets to a higher layer. Low-latency packets do not incur extra delay.

The transmitting modem must store a packet for retransmission for a time equal to the round trip delay from when the packet is sent to when the retransmission message is received. During this time the transmitting modem continues to receive packets from the higher layer and continues to store these packets in the same way. Therefore the storage requirements in octets can be computed as:

$$\text{Minimum TX memory (octets)} = \text{roundtripdelay} * \text{datarate},$$

where the roundtripdelay is the time equal to the round trip delay from when the packet is sent to when the retransmission message is received, and the datarate is the data rate of the connection that is transferring the packets.

For ITU-T G.993.2 VDSL2, which is incorporated herein by reference, this can be computed using the VDSL2 profile parameters as:

$$\text{Minimum TX memory (octets)} = (DS + US \text{ Interleaving Delay in octets}) + (US + DS \text{ alpha/beta delay without interleaving}) * (\text{Bidirectional Net data rate}) = \text{MAXDELAYOCTET} + (4 \text{ ms}) * \text{MBDC},$$

where MAXDELAYOCTET and MBDC are as specified in the VDSL2 profiles.

For the receiver, the minimum receiver storage requirements can be determined in a similar manner. More specifically, the RX PTM-TC must store a packet before passing it to the higher layer for a time equal to the round trip delay from when a retransmission message is transmitted to when the retransmitted packet is received. This is equal to storage requirements in octets (same as transmitter):

$$\text{Minimum RX memory (octets)} = \text{roundtripdelay} * \text{datarate},$$

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where the roundtripdelay is the time equal to the round trip from when a retransmission message is transmitted to when the retransmitted packet is received and the data rate is the data rate of the connection that is transferring the packets.

For ITU-T G.993.2 VDSL2 this can be computed using the VDSL2 profile parameters as:

$$\begin{aligned} \text{Minimum RX memory (octets)} &= (DS + US \text{ Interleaving} \\ &\text{Delay in octets}) + (US + DS \text{ alpha/beta delay with-} \\ &\text{out interleaving}) * (\text{Bidirectional Net data} \\ &\text{rate}) = \text{MAXDELAYOCTET} + (4 \text{ ms}) * \text{MBDC}, \end{aligned}$$

where MAXDELAYOCTET and MBDC are as specified in the ITU-T G.993.2 VDSL2 profiles.

TABLE 1

Minimum TX or RX memory requirements for VDSL2				
VDSL2 PROFILE	8a, 8b, 8c, 8d	12a, 12b	17a	30a
TX or RX memory requirements (octets) = MAXDELAYOCTET + .002MBDC	90,536	99,536	123,304	231,072

The estimates in Table 1 assume that all the entire MAXDELAYOCTET and MBDC are used for the transfer of the packet stream, i.e., the reverse channel has a very low data rate and no interleaving.

Some xDSL standards specify minimum storage, i.e., memory, requirements for interleaving of RS codewords. Interleaving with RS coding is an effective way of correcting channel errors due to, for example, impulse noise. For example, VDSL2 requires support of an aggregate bidirectional interleaver and de-interleaver memory of 65 Kbytes for the 8a VDSL2 profile. This corresponds to storage requirement of approximately 32 Kbytes in a single transceiver.

Sharing of Memory Between the Retransmission Function and One or More of the Interleaving/Deinterleaving/RS Coding/RS Decoding Functions

From Table 1, it is apparent that the memory requirements to support the retransmission protocol may be more than double the storage requirements of a single transceiver. Additionally, the retransmission protocol provides a different method for correcting channel errors due to, for example, impulse noise.

Moreover, interleaving and RS coding methods and retransmission protocols provide different advantages with respect to error correction capabilities, latency, buffering requirements, and the like. For example, under certain configuration and noise conditions the interleaving/RS coding provides error correction/coding gain with less delay and overhead than the retransmission protocol (for packets that can be retransmitted). While under other conditions the retransmission protocol will provide better error correction with less delay and overhead than the interleaving/RS coding.

In some cases, a first portion of the memory can be used for one function and a second portion of the memory for some other function. For example, if the configuration and noise conditions are such that the interleaving/RS coding would not provide good error correction/coding gain, then all the available memory could be used for the retransmission function and none allocated to the interleaving/deinterleaving/RS coding/RS decoding functionality, e.g., the interleaving/deinterleaving could be disabled.

Likewise, if the configuration and noise conditions are such that the retransmission protocol would not provide good error correction/coding gain, then all the available memory could be used for the interleaving/deinterleaving/RS coding/

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RS decoding functionality and no memory would be used for the retransmission function, e.g., the retransmission function would be disabled.

Alternatively, or addition, both methods could be used because both have their advantages, with the system, e.g., the memory management module 370, being able to dynamically allocate a first portion of the memory 250/350 to the interleaving/deinterleaving/RS coding/RS decoding functionality and a second portion of the memory to the retransmission functionality. For example, 40% of the memory could be allocated to the interleaving/deinterleaving/RS coding/RS decoding functionality with the remaining 60% allocated to the retransmission of functionality. However, it should be appreciated, that in general, the memory can be divided, i.e., shared, in any manner.

The sharing of memory between the retransmission function and the interleaving/deinterleaving/RS coding/RS decoding functions is not restricted to retransmission protocols described in other embodiments that utilize QOS metrics to determine which packets should be retransmitted. In other words, the sharing of memory between the retransmission function and the interleaving/deinterleaving/RS coding/RS decoding functions can be utilized for retransmission systems where all errored packets are retransmitted, i.e., there is no QOS identifier in the retransmission protocol. For example, the FEC/interleaving could be used to meet the INPmin requirement specifically targeting the impulse noise that occurs frequently (e.g., on the order of minutes or seconds) but is short in duration and can therefore be corrected by the FEC/interleaving. For example, the retransmission protocol can be used to correct infrequent errors (on the order of hours) that are long in duration and would not be correctable by the FEC/interleaving. As another example, the FEC/interleaving function may be used in combination with the retransmission function because it is well known that FEC with minimal interleaving provides a 1 dB to 3 dB coding gain when used with a trellis code (as is often the case in xDSL systems). This means that even when the majority of the shared memory is allocated to a retransmission function to address channel noise (such as impulse noise), a smaller amount of memory may be allocated to the FEC/interleaving function for the coding gain advantage.

Associated with the ability to allocate or partition memory between one or more of the interleaving/deinterleaving/RS coding/RS decoding functionality and retransmission functionality, is the ability to exchange information between transceivers on how to establish this allocation. For example, the transmitting modem may send a message to the receiving modem indicating how much of the available memory is to be allocated to one or more of the interleaving/deinterleaving/RS coding/RS decoding functionality and how much memory is to be allocated to the retransmission functionality. For example, if the receiving modem contains 100 kBytes of available memory, the transmitting modem could send a message to the receiving modem indicating that 25 kBytes should be allocated to RS coding functionality and 75 kBytes should be allocated to the retransmission functionality. Since the receiving modem generally determines the interleaving/RS coding parameters that are used, the receiving modem could use this information to select parameters, e.g., interleaver depth and codeword size, that would result in an interleaving memory requirement that is no more than the amount indicated in the message.

Alternatively, or addition, the receiving modem can send a message to the transmitting modem indicating how much of the available memory is to be allocated to one or more of the

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interleaving/deinterleaving/RS coding/RS decoding functionality, and how much memory should be allocated to the retransmission functionality.

Sharing of Memory Between a Retransmission Function with Identification of Low-PER and/or Low-Latency Packets and One or More of Interleaving/Deinterleaving/RS Coding/RS Decoding Functions.

A way of reducing the total memory requirement of a transceiver that supports the retransmission functionality with the identification of the low-PER and/or the low-latency packets is to define a limit, such as a maximum value, for the data rate of the low-PER packet stream, i.e., the packets requiring retransmission to meet a specific PER requirement. For example, if the total data rate is 50 Mbps, and the roundtrip delay is 10 ms, the minimum TX or RX memory requirement is $50,000,000 \times 0.01/8 = 62500$ bytes if the retransmission function must support the case where all the transmitted packet (all 50 Mbps) are low-PER packets. If however, only a portion of the 50 Mbps data rate is allocated to the low-PER packet stream (e.g. 30 Mbps), whereas the remainder of the data rate is allocated to the low-latency packet stream (e.g. 20 Mbps), the minimum TX or RX memory requirement would be $30,000,000 \times 0.01/8 = 37500$ bytes (assuming a roundtrip delay of 10 ms). In this case, the transmitting modem (or receiving modem) may send a message to the receiving modem (or transmitting modem) that indicates the maximum data rate of the packet traffic that will be used in the retransmission function. Using the example above, the transmitting modem (or receiving modem) would send a message indicating that the low-PER traffic will not exceed 30 Mbps, in which case the receiving modem (or transmitting modem) will allocate memory to the retransmission functionality and the interleaving/RS coding (or deinterleaving/RS decoding) functionality accordingly.

One exemplary advantage of indicating the low-PER and low-latency packets as part of the retransmission protocol is that it provides a DDR-like functionality without the overhead of dynamically re-allocating latency paths. For example, when a video application is turned off (less low-PER packets on the connection), the data application data rate can be increased (more low-latency packets on the connection) without any changes in the transmission parameters.

The retransmission protocol can also be used with or without underlying FEC/interleaving (or deinterleaving). An exemplary approach is to use the FEC/interleaving to meet the INPmin requirement specifically targeting the impulse noise that occurs frequently, e.g., on the order of minutes or seconds. The retransmission protocol can be used to correct infrequent errors (on the order of hours) that will only typically be a problem for very-low PER applications, such as video.

When a retransmission protocol is combined with underlying FEC/interleaving (or deinterleaving), the retransmission protocol latency will grow in proportion to the additional FEC/interleaving delay. This is due to the fact that the required receiver buffering corresponds approximately to the round-trip delay time of packet transmission and message acknowledgment.

As an example of utilizing the retransmission protocol that identifies one or more of low-PER and low-latency packets with underlying FEC/Interleaving (or deinterleaving), the FEC/interleaving is used to achieve the INPmin requirements within the latency constraint and the retransmission function is used to provide another layer of error correction. The low-PER packets are passed through both the retransmission function and the FEC/interleaver and, as a result, a very low PER is achieved. The low-latency packets are passed through the

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FEC/Interleaver but not passed through the retransmission function. Since low-latency packets are passed through the FEC/interleaver, they will meet the INPmin and MaxDelay requirements without incurring the extra delay from the retransmission protocol.

Example configuration parameters:

DS Data rate=25 Mbps, INPmin=2, MaxDelayDS=8 ms

Example FEC/Interleaving parameters:

NFEC=128, R=16 which results in an interleaver memory of approximately 14 Kbytes for INP=2 with 8 ms of delay.

Retransmission protocol:

If we assume the US latency is 2 ms, the retransmission protocol will add a minimum of $8+2=10$ ms of latency. This means that the total DS latency (FEC/interleaving+Retransmission) will be approximately $8+10=18$ ms.

Memory requirements:

The memory requirements for the retransmission protocol can be calculated as: $(10 \text{ ms}) \times (25 \text{ Mbps})/8 = 31$ Kbytes. Therefore the transmitter and receiver will both need a total memory of $(31+14)=45$ Kbytes for the retransmission protocol and FEC/Interleaving function.

Low-PER packets:

Latency=18 ms. The PER is very low because INPmin=2 (from FEC/interleaving) is combined with the error correction of the retransmission function.

Low-Latency packets:

Latency=8 ms. INP=2 from FEC/interleaving. No additional delay due to retransmission function.

Although this invention describes the retransmission being done as part of the PTM-TC, it could also be done inside other layer(s) of the xDSL transceiver, such as the PMD or the PMS-TC. Alternatively, it could be performed at a layer(s) above the PTM-TC, for example, in a new layer between the PTM-TC and the next higher layer, or in general any layer above the physical layer, e.g., layer 1, 2, 3, 4 or 5.

In this invention, the term "transmitter" generally refers to the transceiver that transmits the packets. Likewise the term "receiver" generally refers to the transceiver that receives the packets. Therefore the "transmitter" also receives the ACK/NAK messages and the "receiver" also transmits the ACK/NAK messages.

FIG. 2 outlines an exemplary method of operation of a transmitting modem utilizing the retransmission protocol. In particular, control begins in step S100 and continues to step S110. In step S110, a packet is received from a higher layer. Then, in step S120, a decision is made as to whether the received packet is a retransmitted type packet. If the packet is not a retransmitted type packet, such as a low-latency packet, control jumps to step S125 where the packet is optionally updated (as discussed above) with control continuing to step S130 where the packet is forwarded to the receiver. Control then continues to step S140 where the control sequence ends.

If the packet is a retransmitted type packet, such as a low-PER packet, control continues to step S150. In step S150, the packet can be updated with information such as a sequence identifier or other information that allows a receiver to be able to determine which packet (or packets) need to be retransmitted. Next, in step S160, the updated packet is stored in the retransmission buffer. Then, in step S170, the packet is forwarded to the receiver. Control then continues to step S180.

In step S180, a determination is made whether the packet needs to be retransmitted. If the packet needs to be retransmitted, control jumps back to step S170. Otherwise, control continues to step S190.

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In step S190, the packet is deleted from the retransmission buffer. Control then continues to step S140 where the control sequence ends.

FIG. 3 outlines an exemplary method of operation of a receiving modem utilizing the retransmission protocol. In particular, control begins in step S200 and continues to step S210. In step S210, a packet is received from the transmitter. Next, in step S220, a determination is made whether the packet has been identified as a retransmitted type packet. If the packet has not been identified as a retransmittable type packet, control jumps to step S230.

In step S230, the packet is forwarded to a higher layer. Control then continues to step S240 where the control sequence ends.

Alternatively, if the received packet is a retransmittable type packet, the packet is stored in the retransmission buffer in step S260. Next, in step S270, the integrity of the packet can be checked, for example utilizing a CRC. Then, in step S280, a determination is made whether the packet needs retransmission. If the packet needs retransmission, control continues to step S290 where the retransmitted packet is obtained, for example, based on the sending of a message(s), one or the other transceiver determining a packet is missing, or the like, as discussed above, with control continuing back to step S270 for an integrity check.

If the packet does not need retransmission, control continues to step S295 where the packet is forwarded to a higher layer and deleted from the retransmission buffer. Control then continues to step S240 where the control sequence ends.

FIG. 4 outlines an exemplary memory allocation method for sharing memory between the retransmission function and one or more of the interleaving/deinterleaving functionality and coding functionality. In particular, control begins in step S300 and continues to step S305. In step S305, a message is sent/received specifying the available memory. Typically, the receiver will send a message to the transmitter specifying the available memory, but the transmitter could also send a message to the receiver. Next, in step S310, a determination is made as to how the memory should be allocated. As discussed, this allocation can be based on one or more of error correction capability, latency, buffering requirements, SNR, impulse noise, or in general, any communication parameter. Next, in step S320, the memory allocation is communicated to another transceiver. Then, in step S330, a determination can be made as to whether the allocation is compatible. If the received allocation is not compatible, control continues to step S360 wherein another allocation can be requested, with control continuing back to step S320.

Alternatively, if the allocation is compatible, in step S340 the memory is allocated based on the received allocation. Control then continues to step S350 where the control sequence ends.

FIG. 5 illustrates an exemplary memory sharing methodology for use with a retransmission function and one or more of interleaving/deinterleaving functionality, RS coding/decoding functionality. In particular, control begins in step S400 and continues to step S410. In step S410, the memory allocation is received from, for example, a memory management module that may be located in the same transceiver, or at a remote transceiver. Next, in step S420, the memory sharing configuration is established and then, in step S430, the memory is shared between a retransmission function and one or more of the interleaving/deinterleaving functionality, RS coding/decoding functionality. Control then continues to step S440.

In step S440, a determination is made whether the memory sharing configuration should be changed. For example, the

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memory sharing configuration can be dynamically changed based on changes in the communication channel or data type(s) being sent on the communication channel. More specifically, for example, if the communications channel was not performing well, e.g., an increase in bit errors, it may be advantageous to increase the retransmission capability while decreasing the FEC/interleaving capability or vice-versa, which could have an impact on how the memory sharing should be configured.

If the memory sharing configuration should be changed, control continues to step S450 where another allocation can be requested, with control continuing back to step S410. Otherwise, control continues to step S460 where the control sequence ends.

While the above-described flowcharts have been discussed in relation to a particular sequence of events, it should be appreciated that changes to this sequence can occur without materially effecting the operation of the invention. Additionally, the exact sequence of events need not occur as set forth in the exemplary embodiments, but rather the steps can be performed by one or the other transceiver in the communication system provided both transceivers are aware of the technique being used for initialization. Additionally, the exemplary techniques illustrated herein are not limited to the specifically illustrated embodiments but can also be utilized with the other exemplary embodiments and each described feature is individually and separately claimable.

The above-described system can be implemented on wired and/or wireless telecommunications devices, such as a modem, a multicarrier modem, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a linecard, test equipment, a multicarrier transceiver, a wired and/or wireless wide/local area network system, a satellite communication system, network-based communication systems, such as an IP, Ethernet or ATM system, a modem equipped with diagnostic capabilities, or the like, or on a separate programmed general purpose computer having a communications device or in conjunction with any of the following communications protocols: CDSL, ADSL2, ADSL2+, VDSL1, VDSL2, HDSL, DSL Lite, IDSL, RADSL, SDSL, UDSL or the like.

Additionally, the systems, methods and protocols of this invention can be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element(s), an ASIC or other integrated circuit, a digital signal processor, a hard-wired electronic or logic circuit such as discrete element circuit, a programmable logic device such as PLD, PLA, FPGA, PAL, a modem, a transmitter/receiver, any comparable means, or the like. In general, any device capable of implementing a state machine that is in turn capable of implementing the methodology illustrated herein can be used to implement the various communication methods, protocols and techniques according to this invention.

Furthermore, the disclosed methods may be readily implemented in software using object or object-oriented software development environments that provide portable source code that can be used on a variety of computer or workstation platforms. Alternatively, the disclosed system may be implemented partially or fully in hardware using standard logic circuits or VLSI design. Whether software or hardware is used to implement the systems in accordance with this invention is dependent on the speed and/or efficiency requirements of the system, the particular function, and the particular software or hardware systems or microprocessor or microcomputer systems being utilized. The communication systems, methods and protocols illustrated herein can be readily implemented in hardware and/or software using any known or later

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developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

Moreover, the disclosed methods may be readily implemented in software that can be stored on a storage medium, executed on programmed general-purpose computer with the cooperation of a controller and memory, a special purpose computer, a microprocessor, or the like. In these instances, the systems and methods of this invention can be implemented as program embedded on personal computer such as an applet, JAVA® or CGI script, as a resource residing on a server or computer workstation, as a routine embedded in a dedicated communication system or system component, or the like. The system can also be implemented by physically incorporating the system and/or method into a software and/or hardware system, such as the hardware and software systems of a communications transceiver.

It is therefore apparent that there has been provided, in accordance with the present invention, systems and methods for packet retransmission and memory sharing. While this invention has been described in conjunction with a number of embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable arts. Accordingly, it is intended to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and scope of this invention.

The invention claimed is:

1. An apparatus comprising:

a multicarrier transceiver including a processor and memory operable to:

transmit a packet using a forward error correction encoder and an interleaver, wherein the packet comprises a header field and a plurality of PTM-TC codewords, a plurality of ATM cells or a plurality of Reed-Solomon codewords, and wherein the header field comprises a sequence identifier (SID); and

receive a plurality of messages using a forward error correction decoder and without using a deinterleaver, wherein each message of the plurality of messages is received in a different DMT symbol and wherein at least one message of the plurality of messages includes an acknowledgement (ACK) or a negative acknowledgement (NACK) of the transmitted packet.

2. The apparatus of claim 1, wherein the received messages have a higher immunity to noise than the transmitted packet.

3. The apparatus of claim 1, wherein the transceiver is operable to retransmit the packet using the forward error correction encoder and the interleaver.

4. The apparatus of claim 1, wherein the message indicates at least one count value associated with the packet.

5. The apparatus of claim 1, wherein the apparatus is a linecard that is capable of transporting video, voice and data.

6. The apparatus of claim 1, wherein the apparatus is a customer premises equipment that is capable of transporting video, voice and data.

7. The apparatus of claim 1, wherein the transceiver includes at least one digital signal processor.

8. The apparatus of claim 1, wherein the transceiver includes at least one ASIC.

9. An apparatus comprising:

a multicarrier transceiver including a processor and memory operable to:

receive a packet using a forward error correction decoder and a deinterleaver, wherein the packet comprises a header field and a plurality of PTM-TC codewords, a

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plurality of ATM cells or a plurality of Reed-Solomon codewords, and wherein the header field comprises a sequence identifier (SID); and

transmit a plurality of messages using a forward error correction encoder and without using an interleaver, wherein each message of the plurality of messages is transmitted in a different DMT symbol and wherein at least one message of the plurality of messages includes an acknowledgement (ACK) or a negative acknowledgement (NACK) of the received packet.

10. The apparatus of claim 9, wherein the transmitted messages have a higher immunity to noise than the received packet.

11. The apparatus of claim 9, wherein the transceiver is operable to receive a retransmitted packet using the forward error correction decoder and the deinterleaver.

12. The apparatus of claim 9, wherein the message indicates at least one count value associated with the packet.

13. The apparatus of claim 9, wherein the apparatus is a linecard that is capable of transporting video, voice and data.

14. The apparatus of claim 9, wherein the apparatus is a customer premises equipment that is capable of transporting video, voice and data.

15. The apparatus of claim 9, wherein the transceiver includes at least one digital signal processor.

16. The apparatus of claim 9, wherein the transceiver includes at least one ASIC.

17. A method, in a multicarrier transceiver, comprising:

transmitting a packet using a forward error correction encoder and an interleaver, wherein the packet comprises a header field and a plurality of PTM-TC codewords, a plurality of ATM cells or a plurality of Reed-Solomon codewords, and wherein the header field comprises a sequence identifier (SID); and

receiving a plurality of messages using a forward error correction decoder and without using a deinterleaver, wherein each message of the plurality of messages is received in a different DMT symbol and wherein at least one message of the plurality of messages includes an acknowledgement (ACK) or a negative acknowledgement (NACK) of the transmitted packet.

18. The method of claim 17, wherein the received messages have a higher immunity to noise than the transmitted packet.

19. The method of claim 17, further comprising retransmitting the packet using the forward error correction encoder and the interleaver.

20. The method of claim 17, wherein the message indicates at least one count value associated with the packet.

21. The method of claim 17, wherein the method is performed in a linecard that is transporting video, voice and data.

22. The method of claim 17, wherein the method is performed in a customer premises equipment that is transporting video, voice and data.

23. A method, in a multicarrier transceiver, comprising:

receiving a packet using a forward error correction decoder and a deinterleaver, wherein the packet comprises a header field and a plurality of PTM-TC codewords, a plurality of ATM cells or a plurality of Reed-Solomon codewords, and wherein the header field comprises a sequence identifier (SID); and

transmitting a plurality of messages using a forward error correction encoder and without using an interleaver, wherein each message of the plurality of messages is transmitted in a different DMT symbol and wherein at least one message of the plurality of messages includes

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an acknowledgement (ACK) or a negative acknowledgement (HACK) of the received packet.

24. The method of claim 23, wherein the transmitted messages have a higher immunity to noise than the received packet.

25. The method of claim 23, further comprising receiving a retransmitted packet using the forward error correction decoder and the deinterleaver.

26. The method of claim 23, wherein the message indicates at least one count value associated with the packet.

27. The method of claim 23, wherein the method is performed in a linecard that is transporting video, voice and data.

28. The method of claim 23, wherein the method is performed in a customer premises equipment that is transporting video, voice and data.

* * * * *

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 9,094,348 B2
APPLICATION NO. : 14/075194
DATED : July 28, 2015
INVENTOR(S) : Marcos C. Tzannes

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It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Claims

At Column 25, line 2, Claim 23, delete "(HACK)" and insert -- (NACK) --, therefore.

Signed and Sealed this
Twenty-second Day of December, 2015



Michelle K. Lee
Director of the United States Patent and Trademark Office

EXHIBIT 10



US009154354B2

(12) **United States Patent**
Tzannes

(10) **Patent No.:** **US 9,154,354 B2**
(45) **Date of Patent:** **Oct. 6, 2015**

(54) **SYSTEMS AND METHODS FOR A
MULTICARRIER MODULATION SYSTEM
WITH A VARIABLE MARGIN**

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H04L 5/0044; H04L 5/14; H04L 27/2608;
H04W 72/04; H04M 11/062
USPC 375/222, 227, 259-260, 285, 295, 316,
375/350; 370/484-485

(71) Applicant: **TQ DELTA, LLC**, Austin, TX (US)

(72) Inventor: **Marcos C. Tzannes**, Alamo, CA (US)

(73) Assignee: **TQ DELTA, LLC**, Austin, TX (US)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(Continued)

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(52) **U.S. Cl.**
CPC **H04L 27/2601** (2013.01); **H04B 1/38** (2013.01); **H04L 5/006** (2013.01); **H04L 5/0007** (2013.01); **H04L 5/0044** (2013.01); **H04L 5/0046** (2013.01); **H04L 27/2608** (2013.01)

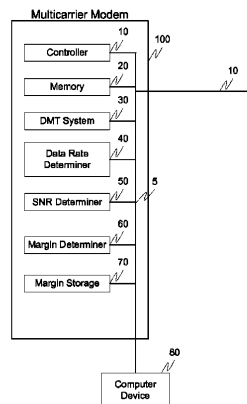
(58) **Field of Classification Search**
CPC H04L 1/0002; H04L 1/1671; H04L 1/243;

Primary Examiner — Khanh C Tran
(74) *Attorney, Agent, or Firm* — Jason H. Vick; Sheridan Ross, PC

(57) **ABSTRACT**

A multicarrier modem has a plurality of carriers over which data is transmitted. By assigning, for example, one or more different margins to the individual carriers the data rate and impairment immunity can be increased.

12 Claims, 2 Drawing Sheets



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Related U.S. Application Data

continuation of application No. 12/694,143, filed on Jan. 26, 2010, now Pat. No. 8,374,226, which is a continuation of application No. 11/972,340, filed on Jan. 10, 2008, now abandoned, which is a continuation of application No. 11/242,024, filed on Oct. 4, 2005, now abandoned, which is a continuation of application No. 09/836,295, filed on Apr. 18, 2001, now abandoned.

- (60) Provisional application No. 60/197,727, filed on Apr. 18, 2000.

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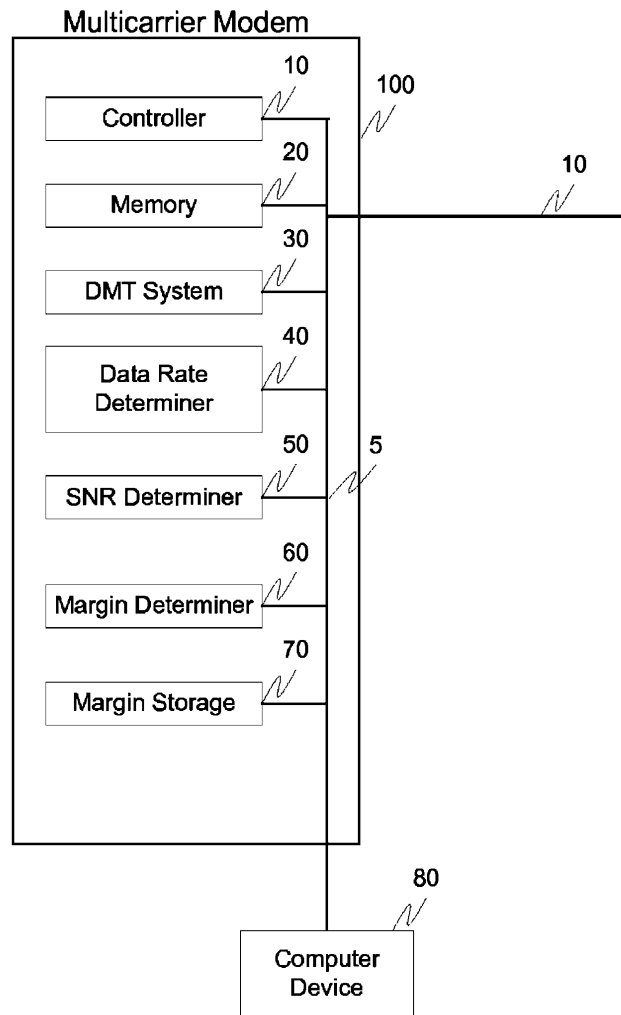


Fig. 1

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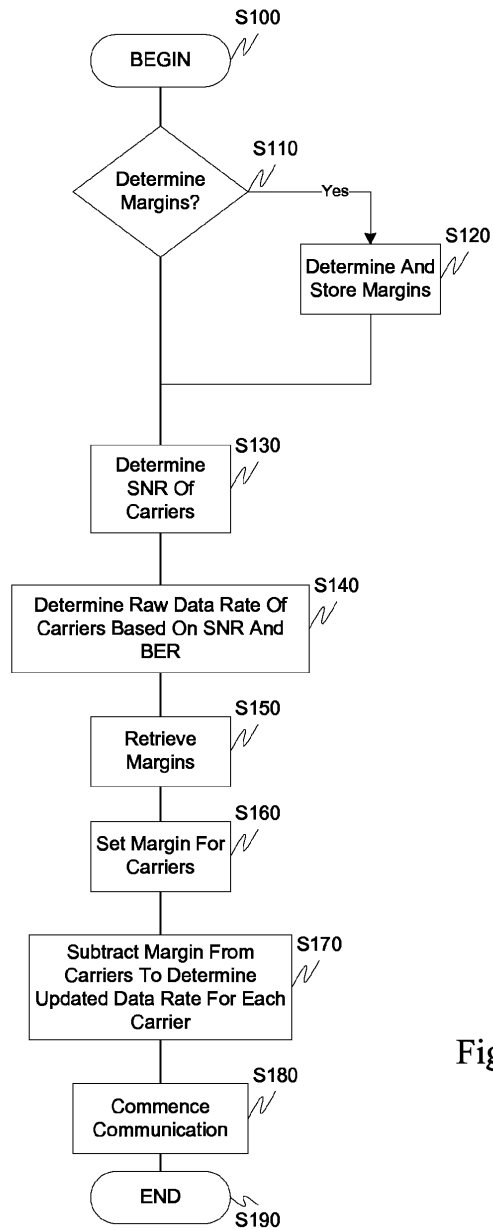


Fig. 2

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SYSTEMS AND METHODS FOR A MULTICARRIER MODULATION SYSTEM WITH A VARIABLE MARGIN

RELATED APPLICATION DATA

This application is a continuation of U.S. application Ser. No. 14/079,285, filed Nov. 13, 2013, now U.S. Pat. No. 8,937,988, which is a continuation of U.S. application Ser. No. 13/764,529, filed Feb. 11, 2013, now U.S. Pat. No. 8,625,660, which is a Continuation of U.S. application Ser. No. 12/694,143, filed Jan. 26, 2010, now U.S. Pat. No. 8,374,226, which is a continuation of U.S. application Ser. No. 11/972,340, filed Jan. 10, 2008, which is a continuation of U.S. application Ser. No. 11/242,024, filed Oct. 4, 2005, which is a continuation of U.S. application Ser. No. 09/836,295, filed Apr. 18, 2001, which claims the benefit of and priority under 35 U.S.C. §119(e) to U.S. Provisional Application No. 60/197,727, entitled "Multicarrier modulation system with variable margin to account for time varying impairments," filed Apr. 18, 2000, each of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to communications technologies. In particular, this invention relates to multicarrier modulation systems having multiple margins.

2. Description of Related Art

Multicarrier modulation, or Discrete Multitone Modulation (DMT), is a transmission method that is widely used for communication over difficult media. Multicarrier modulation divides the transmission frequency band into multiple subchannels, i.e., carriers or bins, with each carrier individually modulating a bit or a collection of bits. A transmitter modulates an input data stream containing information bits with one or more carriers, i.e., bins or subchannels, and transmits the modulated information. A receiver demodulates all the carriers in order to recover the transmitted information bits as an output data stream.

Multicarrier modulation has many advantages over single carrier modulation. These advantages include, for example, a higher immunity to impulse noise, a lower complexity equalization requirement in the presence of multipath, a higher immunity to narrow band interference, a higher data rate and bandwidth flexibility. Multicarrier modulation is being used in many applications to obtain these advantages, as well as for other reasons. These applications include Asymmetric Digital Subscriber Line (ADSL) systems, wireless LAN systems, power line communications systems, and other applications. ITU standards G.992.1 and G.992.2 and the ANSI T1.413 standard specify standard implementations for ADSL transceivers that use multicarrier modulation.

Discrete multitone modulation transceivers modulate a number of bits on each subchannel, the number of bits depending on the Signal to Noise Ratio (SNR) of that subchannel and the Bit Error Rate (BER) requirement of a link. For example, if the required BER is 1×10^{-7} , i.e., one bit in ten million is received in error on average, and the SNR of a particular subchannel is 21.5 dB, then that subchannel can modulate 4 bits, since 21.5 dB is the required SNR to transmit 4 QAM bits with a 1×10^{-7} BER. Other subchannels can have a different SNR and therefore may have a different number of bits allocated to them at the same BER. Additional informa-

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tion regarding bit loading can be found in copending U.S. application Ser. No. 09/510,773, incorporated herein by reference in its entirety.

In many DMT systems, an additional parameter is used to determine the number of bits allocated to each subchannel. This parameter is called the SNR "margin," or simply the "margin." The margin specifies an extra SNR per subchannel, in addition to what is required to maintain the specified BER requirement. As an example, a DMT system with a 6 dB margin would require a $21.5 + 6 = 27.5$ dB SNR on a subchannel in order to transmit 4 bits on that subchannel with a 1×10^{-7} BER. This is 6 dB more than required by the example in the previous paragraph because now a 6 dB margin is added to the system. Another way of looking at this is that in the example of the previous paragraph, where 4 bits were allocated to a subchannel with 21.5 dB SNR, the margin was 0 dB.

DMT transceivers use a margin to increase the system's immunity to various types of time varying impairments. Examples of these impairments in DSL systems are: changes in the levels of crosstalk from other transmission systems, impulse noise, temperature changes in the telephone line, or the like. When a DMT system is operating with a positive SNR margin, the noise can change instantaneously by the level of the margin and the system will still maintain the required BER. For example, if the system is operating at a 6 dB margin, e.g., 4 bits are allocated to carriers with 27.5 dB SNR for $BER = 1 \times 10^{-7}$, the crosstalk levels can increase by 6 dB and the system will still be operating at the required 1×10^{-7} BER. Obviously the penalty for this increase in robustness is a decrease in the data rate, since with a 0 dB margin, a subchannel with 27.5 dB SNR can modulate 6 bits at 1×10^{-7} BER.

Therefore, there is a tradeoff between the robustness of the channel, such as a phone line, and the achievable data rate. The margin can be used to quantify this tradeoff. A higher margin results in a higher level of immunity to changing channel conditions at the expense of the achievable data rate. Likewise, a lower margin results in a higher data rate at the expense of a lower immunity to changing channel conditions.

Current DMT systems allocate a fixed margin to all subchannels. For example, ADSL systems typically use a 6 dB margin on all subchannels carrying data bits. This 6 dB margin is constant on all subchannels and is independent of the type of impairment that the margin is trying to protect against.

SUMMARY OF THE INVENTION

For simplicity of reference, the systems and methods of this invention will hereinafter refer to the transceivers, or multicarrier modems, generically as modems. One such modem is typically located at a customer premises such as a home or business and is "downstream" from a central office with which it communicates. The other modem is typically located at the central office and is "upstream" from the customer premises. Consistent with industry practice, the modems are often referred to as "ATU-R" ("ADSL transceiver unit, remote," i.e., located at the customer premises) and "ATU-C" ("ADSL transceiver unit, central office," i.e., located at the central office). Each modem includes a transmitter section for transmitting data and a receiver section for receiving data, and is of the discrete multitone type, i.e., the modem transmits data over a multiplicity of subchannels of limited bandwidth. Typically, the upstream or ATU-C modem transmits data to the downstream or ATU-R modem over a first set of subchannels, which are usually the higher-frequency subchannels, and receives data from the downstream

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or ATU-R modem over a second, usually smaller, set of subchannels, commonly the lower-frequency subchannels.

For example, in digital subscriber line (DSL) technology, communications over a local subscriber loop between a central office and a subscriber premises is accomplished by modulating the data to be transmitted onto a multiplicity of discrete frequency carriers which are summed together and then transmitted over a subscriber loop. Individually, the carriers form discrete, non-overlapping communication subchannels which are of a limited bandwidth. Collectively, the carriers form what is effectively a broadband communications channel. At the receiver end, the carriers are demodulated and the data recovered.

DSL systems experience disturbances from other data services on adjacent phone lines, such as, for example, ADSL, HDSL, ISDN, T1, or the like. Additionally, DSL systems may experience disturbances from impulse noise, crosstalk, temperature changes, or the like. These disturbances may commence after the subject DSL service is already initiated and, since DSL for Internet access is envisioned as a always-on service, the affects of these disturbances should be considered by the subject DSL transceiver. Additionally, the length of the phone line is a type of impairment that varies from one ADSL subscriber to another, i.e. from one ADSL installation to another, and therefore has an effect on the ADSL modem performance.

The systems and methods of this invention allow the margin in a discrete multitone modulation system to vary depending on a type of impairment. For example, this impairment can be changing over some duration or from one installation to another. Thus, different margins can be assigned to one or more of the carriers in a discrete multitone modulation communication system.

As noted above, there is a tradeoff between the robustness of the link and the achievable data rate. By setting a higher

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These and other features and advantages of this invention are described in, or are apparent from, the following detailed description of the embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the invention will be described in detail, with reference to the following figures wherein:

FIG. 1 is a functional block diagram illustrating an exemplary modem according to this invention; and

FIG. 2 is a flowchart outlining an exemplary method for assigning margins according to this invention.

DETAILED DESCRIPTION OF THE INVENTION

In an exemplary embodiment of the invention, the margin is set to be different on at least two subchannels in a discrete multitone modulation system. In this exemplary embodiment, subchannels which are expected to incur greater variations in impairment levels are set to have a higher margin, whereas subchannels which are expected to incur lower variations in impairment levels are set to have lower margins. As an example of this embodiment, consider an ADSL transmission system transmitting data over telephone wires and consider the case where the impairment is changing channel conditions due to temperature fluctuations. Since telephone wire is typically made out of copper, the attenuation, i.e., the insertion loss, characteristics will depend on the temperature of the wire. As the temperature of the wire increases, the attenuation, i.e., the insertion loss, will increase. Furthermore, the insertion loss also varies with frequency as the temperature changes. Therefore, as the temperature increases, in addition to an overall increase in insertion loss, the insertion loss at the higher frequencies increases more than the insertion loss at the lower frequencies. Table 1 shows a correlation of frequency versus insertion loss of an exemplary 13,500 ft. 26 AWG line at various frequencies for 70° F. and 120° F.

TABLE 1

	Insertion loss of 13500 ft 26 AWG line versus frequency at 70° F. and 120° F.										
	Frequency (kHz)										
	20	40	100	200	260	300	400	500	600	780	1100
Insertion loss (dB) at 70° F.	29.8	36.7	45.2	52.8	57.3	60.2	67.7	74.8	81.7	93.0	110
Insertion loss (dB) at 120° F.	31.9	39.6	49.4	57.4	61.8	64.8	72.3	79.3	86.1	97.9	116

margin, a higher level of immunity to changing channel conditions is achieved at the expense of the data rate. Similarly, while a lower margin may result in a higher data rate, the immunity to changing channel conditions is reduced.

However, setting the margin equally for all subchannels at least fails to account for impairments that change over time and how the impairments may have different effects on subchannels at different frequencies. For example, temperature changes and line length effect different frequencies with differing degrees of interference.

Aspects of the present invention relate to a communications system having a plurality of margins.

Aspects of the present invention also relates to a method of assigning a plurality of margins to a communications system.

Aspects of this present invention additionally relate to multicarrier modulation systems and methods for different margins to be assigned to different subchannels to account for varying impairments.

From Table 1, it is apparent that the difference in insertion loss from 120° F. to 70° F. is 2.1 dB at 20 kHz, whereas the difference in insertion loss from 120° F. to 70° F. is 6 dB at 1100 kHz. For this exemplary embodiment, a higher margin could be allocated to carriers at higher frequencies and a lower margin allocated to carriers at lower frequencies. For example, the carrier at 20 kHz will only need a 2.1 dB margin, because even if the temperature changes from 70° F. to 120° F., the insertion loss will only change by 2.1 dB and, as a result, the system bit error rate requirement can still be met after the temperature change. Similarly, the carrier at 1100 kHz will need a 6 dB margin, since as the temperature changes from 70° F. to 120° F., the insertion loss will change by 6 dB and, as a result, the system bit error rate requirement will still be satisfied even after the temperature change.

However, it is to be appreciated that the margin is not allocated to each subchannel in a fixed manner, but rather varies based on the expected change in impairments over time

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or as impairments vary from one DSL installation to another. However, that does not preclude the possibility that different subchannels can have the same margin assigned to them. For example, a subchannel may have a certain margin assigned based on a particular impairment, while another subchannel may have the same margin assigned based on another impairment. These impairments can include, but are not limited to, changes in the levels of crosstalk from other transmission systems, impulse noise, temperature changes, line length, radio frequency interference and other ingress, or the like. As a result, for example, since certain subchannels are not overly burdened with a common margin, the overall data rate of the system can be increased without sacrificing the robustness of the system.

For example, and with reference to Table 1, by lowering the margin of the lower carriers from 6 dB to 2.1 dB, the channel data rate has increased. This increase can occur without a loss of the immunity to temperature variations on the line since the lower frequencies are less susceptible to temperature changes than the higher frequencies. In general, the systems and methods of this invention can be adapted to set a margin for any impairment that varies over time, or is installation based, and may, for example, effect different frequencies in different ways.

As another example, consider crosstalk from another transmission system. If the crosstalking transmission system is known to use only a portion of the frequency spectrum utilized by the discrete multitone modulation system, then the margins can be decreased on the carriers that are known to be outside the frequency spectrum of the crosstalking system. For example, ISDN systems are an example of a crosstalk source for ADSL systems. ISDN systems typically transmit only up to approximately 150 kHz. Thus, for example, employing the teachings of this invention, carriers above 150 kHz can operate at lower margins than carriers below 150 kHz where the ISDN crosstalk is present.

As another example, the margin in an ADSL system can be varied depending on the length of the telephone wire. Table 2 shows a relationship of insertion loss of an exemplary 9000 ft. 26 AWG line at frequencies for 70° F. and 120° F.

TABLE 2

Insertion loss of 9000 ft 26 AWG line versus frequency at 70 F. and 120 F.											
	Frequency (kHz)										
	20	40	100	200	260	300	400	500	600	780	1100
Insertion loss (dB) at 70° F.	20.0	24.4	30.1	35.2	38.2	40.2	45.1	49.9	54.4	62.0	73.6
Insertion loss (dB) at 120° F.	21.4	26.3	32.8	38.2	41.2	43.2	48.2	52.9	57.4	65.3	77.5

Comparing Table 1 and Table 2, it is apparent that an increase in insertion loss as temperature increases depends on the length of the telephone line as well. Thus, on the exemplary 9,000 ft. phone line, a 50° F. temperature change results in an average of only 2.8 dB increase in insertion loss. On the 13,500 ft. phone line, a 50° F. temperature change resulted in an average of 4.3 dB increase in insertion loss. For this illustrative example, the margin on the subchannels is varied depending on the length of the phone line. As an example, if the phone line is shorter, e.g., 9,000 ft., the average margin can be decreased on the subchannels by 4.3–2.8=1.5 dB as compared to a longer 13,500 ft. loop without sacrificing immunity to temperature changes on the phone line. This is

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possible because a shorter phone line will not experience as much of a change in insertion loss due to temperature changes as a longer phone line.

For this illustrative example, the margin allocated to different subchannels takes into account information about the length of the telephone line. As an example, the insertion loss difference from 70° F. to 120° F. at 20 kHz is 2.1 dB for the 13,500 ft. line. On the other hand, the insertion loss difference from 70° F. to 120° F. at 20 kHz is 1.4 dB for the 9,000 ft. line. Therefore, for this exemplary situation, a margin of 2.1 dB would be allocated to the carrier at 20 kHz on a 13,500 ft. line whereas a margin of 1.4 dB would be allocated to the carrier at 20 kHz on the 9,000 ft. line. The immunity to temperature variations on the line would be the same for both the systems operating at 9,000 ft. and 13,500 ft. As a result, the overall system data rate can be increased on shorter lines without sacrificing a loss in robustness.

FIG. 1 illustrates an exemplary embodiment of a multicarrier modem 100. In particular, the multicarrier modem 100 comprises a controller 10, a memory 20, a discrete multitone modulation system 30, a data rate determiner 40, a signal to noise ratio determiner 50, a margin determiner 60 and a margin storage 70, all interconnected by link 5. The multicarrier modem 100 is also connected to one or more computer or computer-type devices 80 and additional modems (not shown) via communications link 10. For ease of illustration, the multicarrier modem 100 has been illustrated in block diagram format with only the components needed for the exemplary embodiment of this invention. Additional information and further discussion of the operation and structure of an exemplary multicarrier modem can be found in copending U.S. patent application Ser. No. 09/485,614 entitled "Splitterless Multicarrier Modem."

While the exemplary embodiment illustrated in FIG. 1 shows the multicarrier modem 100 and various components collocated, it is to be appreciated that the various components of the multicarrier modem can be rearranged and located in whole or in part at an ATU-R and/or ATU-C. Furthermore, it is to be appreciated, that the components of the multicarrier modem 100 can be located at various locations within a

distributed network, such as a POTS network, or other comparable telecommunications network. Thus, it should be appreciated, that the components of the multicarrier modem 100 can be combined into one device or distributed amongst a plurality of devices. As will be appreciated from the following description, and for reasons of computational efficiency, the components of the multicarrier modem can be arranged at any location within a telecommunications network and/or modem without affecting the operation of the system.

The links 5 and 10 can be a wired or a wireless link or any other known or later developed element(s) that is capable of supplying and communicating electronic data to and from the connected elements. Additionally, the computer device 80,

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can be, for example, a personal computer or other device. In general, the computer device **80** can be any device that uses a modem to transmit and/or receive data.

In operation, the multicarrier modem **100** is installed, for example, in a customer premises or in a central office. During this installation, certain fixed quantities such as line length are known and can be stored in the multicarrier modem **100**. During an initial installation, or at any subsequent time for which a redetermination in margins is appropriate, for example, based on an increased bit error rate, changes in the signal to noise ratio, seasonal changes, or the like, the controller **10**, in cooperation with the memory **20**, the discrete multitone modulation system **30** and the margin determiner **60** can determine and store margins. For example, as illustrated above in exemplary Tables 1 and 2, margins can be determined for temperature fluctuations and the length of the wire line based on, for example, the actual installation and historical data. Furthermore, routines can be established by the margin determiner **60** to evaluate and compile statistical information relating to one or more carriers. For example, this statistical information can be compiled during modem idle times in response to impairments seen on the one or more carriers. This statistical information can then be used to determine appropriate margins for one or more carriers.

Alternatively, the modem may measure the noise on the line during idle times and determine that a particular type of crosstalk, e.g., another ADSL or HDSL modem, is present. Since the spectral content of these types of crosstalkers are known, this information can be used to determine the margin. For example, if the crosstalker is an ATU-R ADSL modem then it is known that ATU-R ADSL modems transmit approximately in the 20-130 kHz range. This information can be used to determine the margin for the carriers in the 20-130 kHz frequency range.

Alternatively, a predetermined set of margins, for example, for known impairments, can be downloaded from, for example, a central office modem or other location within a communications network. The determined and/or downloaded margins are then stored in the margin storage **70**. Similarly, groups of margins can be stored based on, for example, geographic information, seasonal information, line length information, or the like.

During training of the multicarrier modem **100**, the SNR determiner **50**, in cooperation with the controller **10**, the memory **20**, and the DMT system **30**, determines the signal to noise ratio of the carriers. Knowing the signal to noise ratio of the carriers, the data rate determiner **40** determines the raw data rate of the carriers based on the signal to noise ratio and the bit error rate. This raw data rate reflects the data rate of carriers with no margin.

Generally, the bit error rate is set in advance, for example, by the manufacturer. Additionally, the data rate is generally governed by a range that is, for example, guaranteed as a maximum, by a DSL provider. Therefore, based on the set bit error rate, the signal to noise ratio for a known quantity of bits can be determined.

Knowing the signal to noise ratio, the margins for the carriers can be set, for example, based on one or more, or a combination of, entered criteria or determined criteria. For example, an entered criteria can be based on the loop length. A determined criteria can be, for example, based on standard temperature variance information that can, for example, be downloaded from the service provider. Alternatively, for example, the margins can be set based on historical data that relates to, for example, impairments on the line. In general, the margins can be set such that a balance between the data rate and the impairment immunity is maximized.

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Having retrieved the margins for one or more of the carriers, the margins are set in the DMT system **30**. The margins can then be subtracted from the carrier to determine an updated data rate for each carrier. Having set the margins, and knowing the data rate, the DMT system can then commence communication over the communications link **10**.

FIG. 2 illustrates an exemplary method of assigning margins to carriers according to an exemplary embodiment of this invention. In particular, control begins in step **S100** and continues to step **S110**. In step **S110**, a determination is made whether margins are to be determined. If margins are to be determined, control continues to step **S120**. Otherwise, control jumps to step **S130**.

In step **S120**, the margins are determined and stored. Control then continues to step **S130**.

In step **S130** the signal to noise ratio of the carriers are determined. Next, in step **S140**, the raw data rate of the carriers is determined based on the signal to noise ratio and the bit error rate. Next, in step **S150**, the margins for the carriers are retrieved. Control then continues to step **S160**.

In step **S160**, the margins for the carriers are set. Next, in step **S170**, the margins are subtracted from the carriers to determine an updated data rate for each carrier. Control then continues to step **S180**.

In step **S180**, communications commence. Control then continues to step **S190** where the control sequence ends.

However, it is to be appreciated that the steps in FIG. 2 need not occur in the order illustrated. For example, at any point in time there could be an option to re-determine the margins. Similarly, based on, for example, the time of the day, day, location, error rate, service provider directive, a change in the quality of service requirement, or the like, the margins could be adjusted. Alternatively, at any time, updated margins could be downloaded and stored in the margin storage. Alternatively, if it is known that margins will be incorporated in the determination of the data rate, step **S140** could be bypassed since it is known that the raw data rate will not be used.

Furthermore, the systems and methods of this invention can also apply to any multicarrier modulation based communication system including wireless LANs, such as wireless LAN 802.11 and ETSI Hyperlan standards, wireless access systems, home and access power-line communication systems, or the like.

As illustrated in FIG. 1, the multicarrier modem and related components can be implemented either on a DSL modem, or a separate program general purpose computer having a communications device. However, the multicarrier modem can also be implemented in a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element, and ASIC or other integrated circuit, a digital signal processor, a hardwired or electronic or logic circuit such as a discrete element circuit, a programmable logic device such as a PLD, PLA, FPGA, PAL, or the like, and associated communications equipment. In general, any device capable of implementing a finite state machine that is in turn capable of implementing the flowchart illustrated in FIG. 2 can be used to implement the multicarrier modem **100** according to this invention.

Furthermore, a disclosed method may be readily implemented in software using object or object-oriented software development environment that provides portable source code that can be used on a variety of computers, workstations, or modem hardware platforms. Alternatively, the disclosed modem may be implemented partially or fully in hardware using standard logic circuits or a VLSI design. Other software or hardware can be used to implement the systems in accordance with this invention depending on the speed and/or

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efficiency requirements of the systems, the particular function, and the particular software or hardware systems or microprocessor or microcomputer systems being utilized. The multicarrier modem illustrated herein, however, can be readily implemented in hardware and/or software using any known or later developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

Moreover, the disclosed methods can be readily implemented as software executed on a programmed general purpose computer, a special purpose computer, a microprocessor and associated communications equipment, or the like. In these instances, the methods and systems of this invention can be implemented as a program embedded on a modem, such as a DSL modem, or the like. The multicarrier modem can also be implemented by physically incorporating the system and method in a software and/or hardware system, such as a hardware and software system of a modem, such as an ADSL modem, or the like.

It is, therefore, apparent that there has been provided in accordance with the present invention, systems and methods for assigning margins to carriers. While this invention has been described in conjunction with a number of embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable art. Accordingly, Applicants intend to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and the scope of this invention.

What is claimed is:

1. A method in a multicarrier communications transceiver comprising:

transmitting a multicarrier symbol comprising a first plurality of carriers and a second plurality of carriers;
transmitting a first plurality of bits on the first plurality of carriers using a first SNR margin;

transmitting a second plurality of bits on the second plurality of carriers using a second SNR margin;
wherein the first plurality of carriers is different than the second plurality of carriers,

wherein the first SNR margin is different than the second SNR margin, and

wherein the first SNR margin provides more robust transmission than the second SNR margin.

2. The method of claim 1, wherein the first SNR margin specifies a first value for an increase in noise associated with the first plurality of carriers.

3. The method of claim 1, wherein the second SNR margin specifies a second value for an increase in noise associated with the second plurality of carriers.

4. A method in a multicarrier communications transceiver comprising:

receiving a multicarrier symbol comprising a first plurality of carriers and a second plurality of carriers;

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receiving a first plurality of bits on the first plurality of carriers using a first SNR margin;

receiving a second plurality of bits on the second plurality of carriers using a second SNR margin;

wherein the first plurality of carriers is different than the second plurality of carriers,

wherein the first SNR margin is different than the second SNR margin, and

wherein the first SNR margin provides more robust reception than the second SNR margin.

5. The method of claim 4, wherein the first SNR margin specifies a first value for an increase in noise associated with the first plurality of carriers.

6. The method of claim 4, wherein the second SNR margin specifies a second value for an increase in noise associated with the second plurality of carriers.

7. A multicarrier communications transceiver operable to: transmit a multicarrier symbol comprising a first plurality of carriers and a second plurality of carriers;

transmit a first plurality of bits on the first plurality of carriers using a first SNR margin;

transmit a second plurality of bits on the second plurality of carriers using a second SNR margin;

wherein the first plurality of carriers is different than the second plurality of carriers,

wherein the first SNR margin is different than the second SNR margin, and

wherein the first SNR margin provides more robust transmission than the second SNR margin.

8. The transceiver of claim 7, wherein the first SNR margin specifies a first value for an increase in noise associated with the first plurality of carriers.

9. The transceiver of claim 7, wherein the second SNR margin specifies a second value for an increase in noise associated with the second plurality of carriers.

10. A multicarrier communications transceiver operable to: receive a multicarrier symbol comprising a first plurality of carriers and a second plurality of carriers;

receive a first plurality of bits on the first plurality of carriers using a first SNR margin;

receive a second plurality of bits on the second plurality of carriers using a second SNR margin;

wherein the first plurality of carriers is different than the second plurality of carriers,

wherein the first SNR margin is different than the second SNR margin, and

wherein the first SNR margin provides more robust.

11. The transceiver of claim 10, wherein the first SNR margin specifies a first value for an increase in noise associated with the first plurality of carriers.

12. The transceiver of claim 10, wherein the second SNR margin specifies a second value for an increase in noise associated with the second plurality of carriers.

* * * * *

EXHIBIT 11



US009485055B2

(12) **United States Patent**
Tzannes

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(54) **PACKET RETRANSMISSION AND MEMORY SHARING**

USPC 714/748, 749, 776
See application file for complete search history.

(71) Applicant: **TQ DELTA, LLC**, Austin, TX (US)

(72) Inventor: **Marcos C. Tzannes**, Alamo, CA (US)

(73) Assignee: **TQ DELTA, LLC**, Austin, TX (US)

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Primary Examiner — Albert Decady

Assistant Examiner — Osman M Alshack

(74) *Attorney, Agent, or Firm* — Jason H. Vick; Sheridan Ross, PC

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ABSTRACT

Through the identification of different packet-types, packets can be handled based on an assigned packet handling identifier. This identifier can, for example, enable forwarding of latency-sensitive packets without delay and allow error-sensitive packets to be stored for possible retransmission. In another embodiment, and optionally in conjunction with retransmission protocols including a packet handling identifier, a memory used for retransmission of packets can be shared with other transceiver functionality such as, coding, decoding, interleaving, deinterleaving, error correction, and the like.

20 Claims, 4 Drawing Sheets

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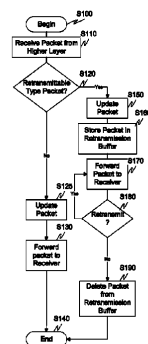
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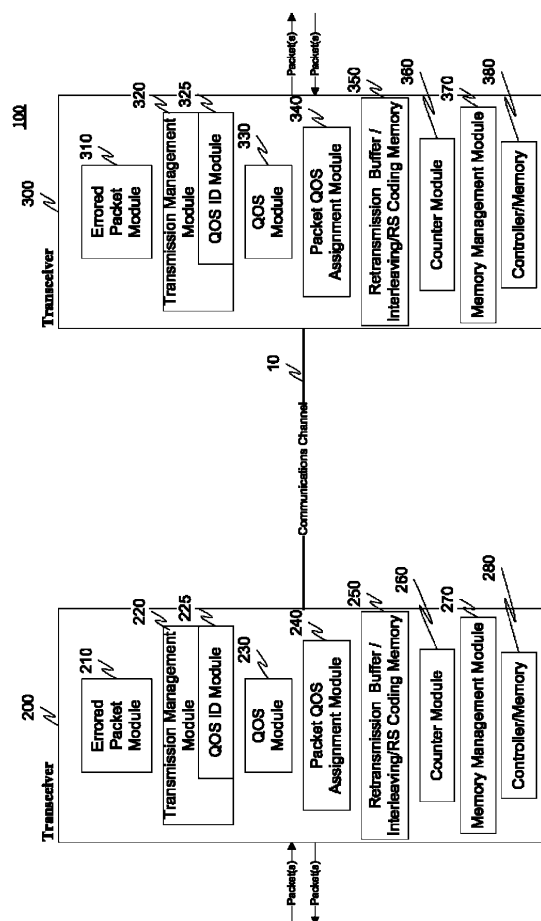


Fig. 1

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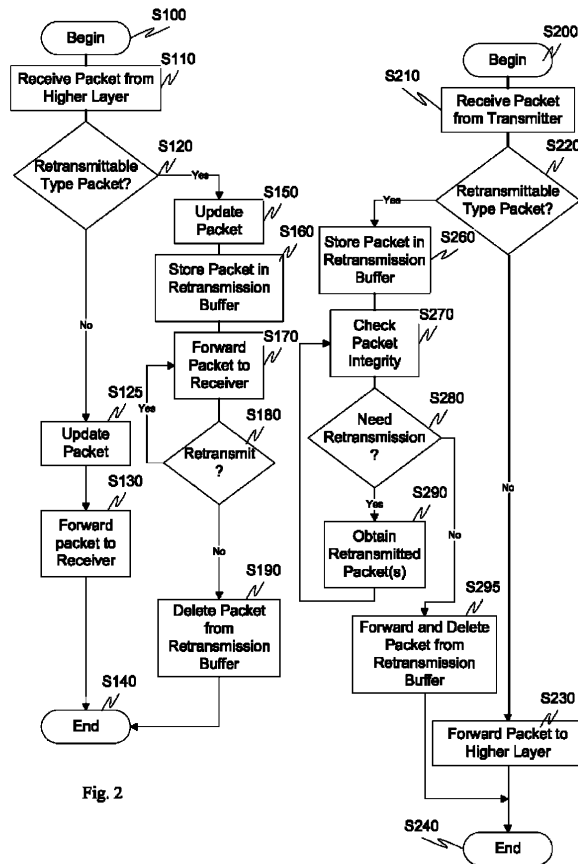


Fig. 2

Fig. 3

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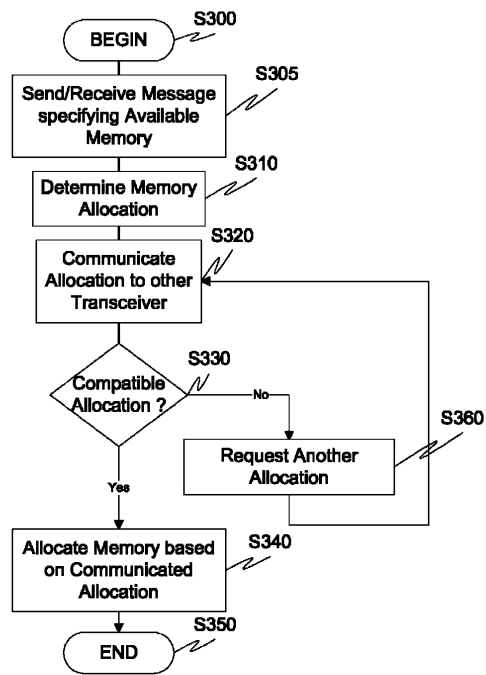


Fig. 4

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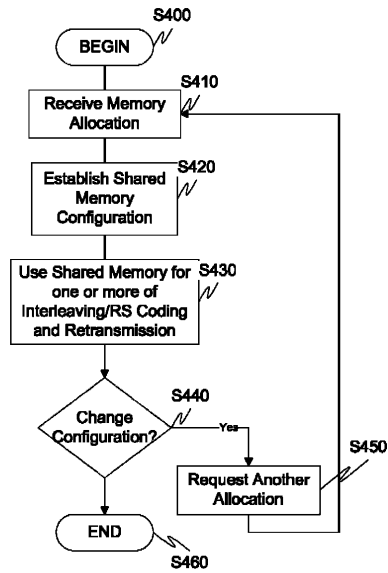


Fig. 5

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PACKET RETRANSMISSION AND MEMORY SHARING

RELATED APPLICATION DATA

This application is a Continuation of U.S. patent application Ser. No. 13/766,059, filed Feb. 13, 2013, now U.S. Pat. No. 8,645,784, which is a Continuation of U.S. patent application Ser. No. 12/783,758, filed May 20, 2010, now U.S. Pat. No. 8,407,546, which is a Continuation of U.S. patent application Ser. No. 12/295,828, filed Oct. 2, 2008, now U.S. Pat. No. 8,335,956, which is a national stage application under 35 U.S.C. 371 of PCT Application No. PCT/US2007/066522 having an international filing date of Apr. 12, 2007, which designated the United States, which PCT application claims the benefit of and priority under 35 U.S.C. §119(e) to U.S. Patent Application Nos. 60/792,236, filed Apr. 12, 2006, entitled "xDSL Packet Retransmission Mechanism," and 60/849,650, filed Oct. 5, 2006, entitled "xDSL Packet Retransmission Mechanism with Examples," each of which are incorporated herein by reference in their entirety.

BACKGROUND

Field of the Invention

This invention generally relates to communication systems. More specifically, an exemplary embodiment of this invention relates to retransmission of packets in a communication environment. An exemplary embodiment of this invention also relates to memory sharing between transmission functions and other transceiver functions.

SUMMARY

Exemplary aspects of the invention relate to handling of packets and the assignment of a packet handling identifier. Exemplary aspects relate to sharing of resources between retransmitted packets and other transceiver functions. In addition, exemplary aspects relate to sharing of resources between packets associated with the packet handling identifier and other transceiver functions.

More specifically, aspects of the invention relate to assigning a packet handling identifier to one or more packets. Based on the packet handling identifier, a packet can either be, for example, forwarded directly to another communication device (or layer) or, alternatively, held for possible retransmission protocols. For example, packets received from, for example, a higher-layer of a communication device, can be designated to have a specific packet handling identifier, such as a Quality of Service (QOS) level. The QOS level of a packet indicates the importance of certain service metrics (or characteristics) of one or more packets.

Two exemplary QOS metrics are delay (or latency) and Packet Error Rate (PER). While these two metrics are used for illustrative purposes herein, it should be appreciated that other metrics can also be used with this invention. For example, other QOS metrics could include one or more of a Bit Error Rate (BER), data rate, delay variation (or jitter), packet loss rate, time between error events (TBE), or the like.

As an example, in the case where the two QOS metrics are latency and PER, packets containing, for example, video information (such as IPTV) may have the requirement for a very low packet error rate but can often tolerate higher delay.

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In contrast, voice or data (e.g., gaming) traffic may have very low latency requirements but can tolerate a higher packet error rate. For this particular example, the video packets could be designated as "low-PER" QOS packets and the voice or data packets could be designated as "low-latency" QOS packets. For example, a specific QOS identifier could be assigned to the low-latency packets while a different QOS identifier could be assigned to the low-PER packets. The low-latency packets could be forwarded directly to another transceiver, or a higher layer, while the low-PER packets can be stored in a retransmission buffer, e.g., memory, that can be used to reduce packet error.

As mentioned above, exemplary aspects also relate to sharing of resources between a retransmission function and other transceiver functions.

The exemplary systems and methods of this invention can utilize memory, such as a retransmission buffer, for the storing of packets for retransmission functions. Since other transceiver functions may also require memory to perform certain functionality, an exemplary aspect of this invention also relates to sharing the memory for retransmission functions with the memory required for other transceiver functions. For example, memory can be dynamically allocated based on configuration settings or noise conditions and, for example, the memory divided between one or more of interleaving/deinterleaving, RS Coding/Decoding functionality and the functionality used retransmission.

Aspects of the invention thus relate to identification of one or more packets.

Additional aspects of the invention relate to identifying one or more packets that can be retransmitted.

Still further aspects of the invention relate to identifying one or more packets that should not be retransmitted.

Aspects of the invention also relate to retransmission of one or more of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-data frame, a PTM-TC codeword, and RS codeword and a DMT symbols.

Still further aspects of the invention relate to appending an identifier to a packet.

Still further aspects of the invention relate to appending a sequence identifier to at least one packet.

Aspects of the invention also relate to routing one or more packets based on a packet handling identifier.

Aspects of the invention also relate to retransmitting a packet.

Aspects of the invention further relate to retransmit a packet based on a retransmission request.

Still further aspects of the invention relate to sharing memory between a retransmission function and one or more of an interleaver, deinterleaver, coder, decoder and other transceiver functionalities.

Other more specific aspects of the invention relate to sharing memory between a retransmission buffer (or memory) and interleaving/deinterleaving and/or coding/decoding functionality.

Additional exemplary, non-limiting aspects of the invention are:

1. A method of packet retransmission comprising: transmitting or receiving a plurality of packets; identifying at least one packet of the plurality of packets as a packet that should not be retransmitted.

2. The method of aspect 1, wherein the packet is any grouping of bytes.

3. The method of aspect 1, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

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4. The method of aspect 1, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

5. The method of aspect 4, wherein the identifying step comprises using a special value for a sequence identifier (SID).

6. The method of aspect 4, wherein the appended bit field comprises a dedicated CRC.

7. The method of aspect 1, wherein the at least one packet is not stored for retransmission.

8. The method of aspect 1, wherein the at least one packet is passed immediately to a high layer.

9. A packet retransmission module capable of transmitting or receiving a plurality of packets and capable of identifying at least one packet of the plurality of packets as a packet that should not be retransmitted.

10. The module of aspect 9, wherein the packet is any grouping of bytes.

11. The module of aspect 9, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

12. The module of aspect 9, wherein the module is capable of appending a bit field comprising a sequence identifier (SID) to each packet.

13. The module of aspect 12, wherein the identifying comprises using a special value for the SID.

14. The module of aspect 12, wherein the appended bit field comprises a dedicated CRC.

15. The module of aspect 9, wherein the at least one packet is not stored by the module for retransmission.

16. The module of aspect 9, wherein the at least one packet is passed by the module immediately to a high layer.

17. The module of aspect 9, wherein the module is implemented in one or more of a wireless transceiver, a wireless LAN station, a wired transceiver, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a multicarrier transceiver, a general purpose computer, a special purpose computer, a programmed microprocessor, a microcontroller and peripheral integrated circuit element(s), an ASIC, a digital signal processor, a hard-wired electronic or logic circuit and a programmable logic device.

18. The module of aspect 9, wherein the module is implemented in one or more of a PTM-TC, ATM-TC, PMD and PMS-TC.

19. A method comprising sharing memory between an interleaving and/or deinterleaving memory and a packet retransmission memory.

20. A method comprising allocating a first portion of shared memory for retransmission and a second portion of the shared memory for interleaving and/or deinterleaving.

21. The method of aspect 20, further comprising transmitting or receiving a message indicating how to allocate the shared memory.

22. The method of aspect 19 or 20, further comprising transmitting or receiving a message indicating how to share the memory.

23. A memory capable of being shared between an interleaving and/or deinterleaving buffer and a packet retransmission buffer.

24. A module capable of allocating a first portion of shared memory for retransmission and a second portion of the shared memory for interleaving and/or deinterleaving.

25. The module of aspect 24, wherein the module is capable of transmitting or receiving a message indicating how to allocate the shared memory.

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26. The module of aspect 24, wherein the module is capable of transmitting or receiving a message indicating how to share the memory.

27. The module of aspect 24, wherein the module is one or more of a wireless transceiver, a wireless LAN station, a wired transceiver, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a multicarrier transceiver, a general purpose computer, a special purpose computer, a programmed microprocessor, a microcontroller and peripheral integrated circuit element(s), an ASIC, a digital signal processor, a hard-wired electronic or logic circuit and a programmable logic device.

28. A method of packet retransmission comprising: transmitting or receiving a plurality of packets; identifying at least one packet of the plurality of packets as a packet that should be retransmitted and at least one packet of the plurality of packets as a packet that should not be retransmitted.

29. The method of aspect 28, wherein the packet is any grouping of bytes.

30. The method of aspect 28, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

31. The method of aspect 28, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

32. The method of aspect 31, wherein the identifying step comprises using a special value for a sequence identifier (SID).

33. The method of aspect 31, wherein the appended bit field comprises a dedicated CRC.

34. The method of aspect 28, wherein at least one packet is stored for retransmission.

35. The method of aspect 28, wherein at least one packet is passed immediately to a high layer.

36. A packet handling method comprising: receiving a stream of packets; identifying a first number of packets in the stream of packets as low-latency packets; identifying a second number of packets in the stream of packets as low-error packets; forwarding the low-latency and low-error packets to a transceiver or a higher layer; and storing the low-error packets for error correction.

37. The method of aspect 36, further comprising appending the low-error packets with an identifier.

38. A method of allocating memory in a transceiver comprising:

analyzing one or more communication parameters; identifying a memory allocation; and allocating memory based on the memory allocation to a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding.

39. A memory sharing method in a transceiver comprising:

receiving a memory allocation; establishing a shared memory for one or more of interleaving, deinterleaving, RS coding, RS decoding and packet retransmission functions; and sharing the shared memory between a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functions.

40. The method of aspect 39, further comprising determining a compatibility of the memory allocation.

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41. The method of aspect 39, wherein the compatibility of the memory allocation is based on channel performance metrics.

42. Means for performing the functionality of any of the aforementioned aspects.

43. An information storage media comprising information that when executed performs the functionality of any of the aforementioned aspects.

44. Any one or more of the features as substantially described herein.

45. Means for packet retransmission comprising:
means for transmitting or receiving a plurality of packets;
means for identifying at least one packet of the plurality of packets as a packet that should not be retransmitted.

46. The means of aspect 45, wherein the packet is any grouping of bytes.

47. The means of aspect 45, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

48. The means of aspect 45, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

49. The means of aspect 48, wherein the means for identifying comprises using a special value for a sequence identifier (SID).

50. The means of aspect 48, wherein the appended bit field comprises a dedicated CRC.

51. The means of aspect 45, wherein the at least one packet is not stored for retransmission.

52. The means of aspect 45, wherein the at least one packet is passed immediately to a high layer.

53. Means for sharing memory between an interleaving and/or deinterleaving function and a packet retransmission function.

54. Means for allocating a first portion of shared memory for retransmission and a second portion of the shared memory for interleaving and/or deinterleaving.

55. The means of aspect 54, further comprising means for transmitting or receiving a message indicating how to allocate the shared memory.

56. The means of aspect 54, further comprising means for transmitting or receiving a message indicating how to share the memory.

57. Means for sharing a memory between an interleaving and/or deinterleaving function and a packet retransmission function.

58. Means for packet retransmission comprising:
means for transmitting or receiving a plurality of packets;
means for identifying at least one packet of the plurality of packets as a packet that should be retransmitted and at least one packet of the plurality of packets as a packet that should not be retransmitted.

59. The means of aspect 58, wherein the packet is any grouping of bytes.

60. The means of aspect 58, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

61. The means of aspect 58, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

62. The means of aspect 61, wherein the means for identifying comprises using a special value for the sequence identifier (SID).

63. The means of aspect 58, wherein the appended bit field comprises a dedicated CRC.

64. The means of aspect 58, wherein at least one packet is stored for retransmission.

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65. The means of aspect 58, wherein at least one packet is passed immediately to a high layer.

66. A packet handling means comprising:

means for receiving a stream of packets;

means for identifying a first number of packets in the stream of packets as low-latency packets;

means for identifying a second number of packets in the stream of packets as low-error packets;

means for forwarding the low-latency and low-error packets to a transceiver or higher layer; and

means for storing the low-error packets for error correction.

67. The means of aspect 66, further comprising means for appending the low-error packets with an identifier.

68. Means for allocating memory in a transceiver comprising:

means for analyzing one or more communication parameters;

means for identifying a memory allocation; and

means for allocating memory based on the memory allocation to a retransmission function and one or more of an interleaving, deinterleaving, RS coding and RS decoding function.

69. Means for memory sharing in a transceiver comprising:

means for receiving a memory allocation;

means for establishing a shared memory for one or more of interleaving, deinterleaving, RS coding, RS decoding and packet retransmission function; and

means for sharing the shared memory between a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functionality.

70. The means of aspect 69, further comprising means for determining a compatibility of the memory allocation.

71. The means of aspect 69, wherein the compatibility of the memory allocation is based on channel performance metrics.

72. A transceiver capable of performing packet retransmission comprising:

a transmission management module configurable to transmit or receive a plurality of packets; and

a QOS module configurable to identify at least one packet of the plurality of packets as a packet that should not be retransmitted.

73. The transceiver of aspect 72, wherein the packet is any grouping of bytes.

74. The transceiver of aspect 72, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

75. The transceiver of aspect 72, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

76. The transceiver of aspect 75, wherein the QOS module uses a special value for a sequence identifier (SID).

77. The transceiver of aspect 75, wherein the appended bit field comprises a dedicated CRC.

78. The transceiver of aspect 72, wherein the at least one packet is not stored for retransmission.

79. The transceiver of aspect 72, wherein the at least one packet is passed immediately to a high layer.

80. A memory capable of being shared between interleaving and/or deinterleaving and packet retransmission.

81. A memory management module capable of allocating a first portion of shared memory for retransmission and

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capable of allocating a second portion of the shared memory to one or more of interleaving and deinterleaving functionality.

82. The module of aspect 81, further comprising a module for transmitting or receiving a message indicating how to allocate the shared memory.

83. The module of aspect 81, further comprising a module for transmitting or receiving a message indicating how to share the memory.

84. A module capable of being shared between interleaving and/or deinterleaving and packet retransmission.

85. A transceiver capable of performing packet retransmission comprising:

a transmission management module configurable to transmit or receive a plurality of packets; and

a QOS module configurable to identify at least one packet of the plurality of packets as a packet that should be retransmitted and at least one packet of the plurality of packets as a packet that should not be retransmitted.

86. The transceiver of aspect 85, wherein the packet is any grouping of bytes.

87. The transceiver of aspect 85, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

88. The transceiver of aspect 85, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

89. The transceiver of aspect 88, wherein the identifying step comprises using a special value for a sequence identifier (SID).

90. The transceiver of aspect 88, wherein the appended bit field comprises a dedicated CRC.

91. The transceiver of aspect 85, wherein at least one packet is stored for retransmission.

92. The transceiver of aspect 85, wherein at least one packet is passed immediately to a high layer.

93. A transceiver capable of handling a stream of packets comprising:

a QOS module capable of identifying a first number of packets in the stream of packets as low-latency packets and a second number of packets in the stream of packets as low-error packets;

a transmission management module capable of forwarding the low-latency and low-error packets to another transceiver; and

a buffer module capable of storing the low-error packets for error correction.

94. The transceiver of aspect 93, further comprising a packet QOS assignment module capable of appending the low-error packets with an identifier.

95. A transceiver capable of having an allocatable memory comprising:

a controller capable of analyzing one or more communication parameters; and

a memory management module capable of identifying a memory allocation and allocating a shared memory based on the memory allocation to a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functions.

96. A transceiver capable of sharing memory comprising: a controller capable of receiving a memory allocation; and a memory management module capable of establishing a shared memory for a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functions.

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97. The transceiver aspect 96, wherein the memory management module further determines a compatibility of the memory allocation.

98. The transceiver of aspect 96, wherein the memory allocation is based on one or more communication channel performance metrics.

99. In a communication environment where packets are being transmitted, a method for allocating a first portion of shared memory for retransmission of packets and a second portion of the shared memory for interleaving and/or deinterleaving.

100. The method of aspect 99, wherein all errored packets are retransmitted.

101. The method of aspects 19, 20 and 99, wherein a retransmission function identifies packets that should not be retransmitted.

102. The method of aspect 99, wherein all packets are being transmitted without an assigned a QOS level.

103. A packet communication method comprising:

in a first mode of operation:

transmitting or receiving a plurality of packets;

identifying at least one packet of the plurality of packets as a packet that should not be retransmitted;

in a second mode of operation:

transmitting or receiving a plurality of packets;

allocating a first portion of shared memory for retransmission of packets and a second portion of the shared memory for one or more of interleaving, deinterleaving, coding, decoding and error correction; and

in a third mode of operation:

transmitting or receiving a plurality of packets;

identifying at least one packet of the plurality of packets as a retransmittable-type packet;

identifying at least one packet of the plurality of packets as a non-retransmittable-type packet;

allocating a first portion of shared memory for retransmission of the retransmittable-type packets and a second portion of the shared memory for one or more of interleaving, deinterleaving, coding, decoding and error correction.

104. The method of aspect 103, wherein the retransmittable-type packet is a low-latency packet.

105. The method of aspect 103, wherein the retransmittable-type packet is a low-error packet.

These and other features and advantages of this invention are described in, or are apparent from, the following detailed description of the exemplary embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The exemplary embodiments of the invention will be described in detail, with reference to the following figures wherein:

FIG. 1 illustrates an exemplary communication system according to this invention.

FIG. 2 is a flowchart outlining an exemplary method for packet retransmission according to this invention.

FIG. 3 is a flowchart outlining an exemplary method for retransmitted packet reception according to this invention.

FIG. 4 is a flowchart outlining an exemplary method for memory allocation according to this invention.

FIG. 5 is a flowchart outlining an exemplary method for memory sharing according to this invention.

DETAILED DESCRIPTION

The exemplary embodiments of this invention will be described in relation to packet retransmission and/or

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memory sharing in an xDSL environment. However, it should be appreciated, that in general, the systems and methods of this invention will work equally well for any type of communication system in any environment.

The exemplary systems and methods of this invention will also be described in relation to multicarrier modems, such as xDSL modems and VDSL modems, and associated communication hardware, software and communication channels. However, to avoid unnecessarily obscuring the present invention, the following description omits well-known structures and devices that may be shown in block diagram form or otherwise summarized.

For purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the present invention. It should be appreciated however that the present invention may be practiced in a variety of ways beyond the specific details set forth herein.

Furthermore, while the exemplary embodiments illustrated herein show the various components of the system collocated, it is to be appreciated that the various components of the system can be located at distant portions of a distributed network, such as a communications network and/or the Internet, or within a dedicated secure, unsecured and/or encrypted system. Thus, it should be appreciated that the components of the system can be combined into one or more devices, such as a modem, or collocated on a particular node of a distributed network, such as a telecommunications network. As will be appreciated from the following description, and for reasons of computational efficiency, the components of the system can be arranged at any location within a distributed network without affecting the operation of the system. For example, the various components can be located in a Central Office modem (CO, ATU-C, VTU-O), a Customer Premises modem (CPE, ATU-R, VTU-R), an xDSL management device, or some combination thereof. Similarly, one or more functional portions of the system could be distributed between a modem and an associated computing device.

Furthermore, it should be appreciated that the various links, including communications channel 10, connecting the elements (not shown) can be wired or wireless links, or any combination thereof, or any other known or later developed element(s) that is capable of supplying and/or communicating data to and from the connected elements. The term module as used herein can refer to any known or later developed hardware, software, firmware, or combination thereof that is capable of performing the functionality associated with that element. The terms determine, calculate and compute, and variations thereof, as used herein are used interchangeably and include any type of methodology, process, mathematical operation or technique. Transmitting modem and Transmitting transceiver as well as Receiving modem and Receiving transceiver are used interchangeably herein.

Moreover, while some of the exemplary embodiments described herein are directed toward a transmitter portion of a transceiver performing interleaving and/or coding on transmitted information, it should be appreciated that a corresponding deinterleaving and/or decoding is performed by a receiving portion of a transceiver. Thus, while perhaps not specifically illustrated in every example, this disclosure is intended to include this corresponding functionality in both the same transceiver and/or another transceiver.

Communication system 100 comprises a portion of a transceiver 200 and a portion of a transceiver 300. The transceiver 200, in addition to well known componentry, comprises an errored packet module 210, a transmission

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management module 220, a QOS ID module 225, a QOS module 230, a packet QOS assignment module 240, a retransmission buffer/interleaving/deinterleaving/RS coding/RS Decoding memory 250, a counter module 260, a memory management module 270 and a controller/memory 280.

Connected via communication channel 10 to transceiver 200 is transceiver 300. The transceiver 300, in addition to well known componentry, comprises an errored packet module 310, a transmission management module 320, a QOS ID module 325, a QOS module 330, a packet QOS assignment module 340, a retransmission buffer/interleaving/deinterleaving/RS coding/RS Decoding memory 350, a counter module 360, a memory management module 370 and a controller/memory 380.

As discussed above, the systems, methods and protocols discussed herein will be described in relation to xDSL systems, such as those specified in ADSL2 ITU-T G.992.3, ADSL2+ ITU G.992.5, and VDSL2 ITU G.993.2, which are incorporated herein by reference in their entirety.

In operation, a first aspect of the invention relates to retransmission of one or more packets, the retransmission identifier being implemented at any transmission layer where packet boundaries are defined. For example, it can be implemented in the Packet Transmission Mode TC (PTM-TC) of xDSL systems. For reference, "Annex A" which is of record in the identified provisional filing and incorporated by reference herein contains the PTM-TC of ADSL2 and VDSL2 systems as specified in the ITU-T G.992.3 ADSL2 standard.

As discussed herein, the invention will generally be described in relation to the retransmission mechanism being incorporated as part of the PTM-TC however, it should be appreciated that it can also be implemented inside other layer(s) of a communication device, such as an xDSL transceiver, such as within the PMD or PMS-TC.

The retransmission techniques disclosed herein can also be performed at a layer above the PTM-TC, for example, in a new layer between the PTM-TC and the next higher layer, or at any layer above the physical layer, e.g., layers 2, 3, 4, 5, etc.

Additionally, while "packet" is used herein, the term "packet" includes any basic data unit, i.e., a grouping of bytes. For example, a packet could be an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data frame, a PTM-TC codeword, an RS Codeword, a DMT symbol, or, in general, any grouping of data bytes or information. A packet could also be a combination of one or more of the above. For example, a packet could be constructed by concatenating any number of ATM cells to create a larger grouping of bits. For example, five 53-byte ATM cells could be combined into a 265 byte packet or four 65 PTM-TC codewords could be combined into a 260 byte packet. A packet could also be based on dividing any of the above groupings of bytes. For example, larger IP or Ethernet packets could be divided into smaller groups of bytes to be used as a "packet" with the retransmission functionality described herein. For example, a 1500 byte IP packet could be divided into three 500 byte packets and used by the retransmission protocol. If the retransmission function is implemented as part of the PTM-TC, packets are received from a higher-layer in the xDSL transmitter PTM-TC and sent via the xDSL transmitter PMS-TC and PMD over the communication channel to the xDSL receiver. The xDSL receiver PMD and PMS-TC process the received signal and

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pass the results to the PTM-TC, which processes the information and passes the received packet up to a higher layer(s).

Packets received from the higher layer at the xDSL transmitter PTM-TC can be designated to have a QOS level. The QOS level of a packet can indicate the importance of certain service metrics (or characteristics) of this (or more) packet(s). Two exemplary QOS metrics are delay (or latency) and PER. Although, as discussed above, these two characteristics are the focus of the invention, any number of different QOS metrics could also be used.

As an example, in the case where the 2 QOS metrics are latency and PER, a first set of packets carrying certain information may have a requirement for very low PER but may be able to tolerate higher delay. Other packets containing information such as voice or data traffic may have very low delay requirements but can tolerate a higher PER. According to an exemplary embodiment of this invention, the first set of packets would be designated as "low-PER" QOS packets whereas voice or data packets would be designated at "low-latency" QOS packets. The QOS level (or metric) of a packet could be designated in a number of ways. For example:

i) Certain bit fields in the header of data portions of each packet could contain certain values that specify the QOS requirements a packet. For example, the packet header could contain bit fields that indicate if the packet has a "low-PER" QOS requirement or a "low-latency" QOS requirement. These fields could be read by the transmitting modem and/or receiving modem to determine the QOS level of each packet.

ii) When sending packets from higher layer to the PTM-TC, the higher layer could indicate on a packet by packet basis the QOS requirements of each packet. For example, there could be a separate signal on the interface that indicates if a packet being transferred has a "low-PER" QOS requirement or a "low-latency" QOS requirement.

iii) When sending packets from higher layer to the PTM-TC, there could be a separate interface (or channel) for packets with different QOS requirements. For example, one channel could be used to transfer packets that have a "low-PER" QOS requirement and a second channel could be used to transfer packets that have a "low-latency" QOS requirement. This general concept could also be scaled to accommodate a plurality of different QOS requirements and a plurality of channels.

iv) As in the case of Pre-Emption in the PTM-TC (see Annex A), two logically separated y-interfaces could be used for the transport of a low-PER and low-latency packet flow through a single bearer channel. This general idea could then be scaled to support any number of packet types.

Other mechanisms can also be used to designate the QOS level of a packet—provided the transmitter and/or receiver retransmission protocol is capable of knowing the QOS level for one or more packets.

Once the QOS level is known by the PTM-TCs, an efficient packet retransmission can be designed. The exemplary packet retransmission methods and protocols can be designed to include any one or more of the following system level characteristics:

All packets are received from the higher layer and passed to the higher layers in the correct order.

"Low-latency" QOS packets will not incur any extra delay due to retransmission.

Only packets with "low-PER" QOS should be retransmitted, and therefore only low-PER packets will incur the extra delay due to the retransmission mechanism.

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Flow control can be minimized such that the transmitter can generally accept all packets from the higher layer at the required data rate without holding-off (or "blocking") packets from the higher layer during the retransmission process.

Packet delay-variation/jitter can be minimal.

A "DRR-like" functionality in a single bearer without requiring latency/interleaver OLR.

The transceiver 200, in cooperation with the QOS module 230, receives packets from a higher-layer. In cooperation with the packet QOS assignment module 240, a packet Sequence ID (SID) is appended to the received packets. The packets, in cooperation with the transmission management module 220, can then be transmitted in the order in which they were received.

The QOS Module 230, if not already performed by a high layer, also identifies packets based on the QOS requirement of the packet(s). Then, in cooperation with the packet QOS assignment module 240, a QOS identifier is associated with the packet as discussed hereinafter.

If, for example, the packet is identified as a low-PER packet, and assigned such an identifier by the QOS module 230, when the transmission management module 220 receives the packet, the packet is identified by the QOS ID module 225 as being a low-PER packet and the packet is forwarded for storage in the retransmission buffer 250. Alternatively, if the packet has been labeled as a low-latency packet, and identified as such by the by the QOS ID module 225, the packet can be transmitted to the receiving modem in cooperation with the transmission management module 220.

The low-PER packets can be stored for a sufficient amount of time to wait for a retransmission message from the receiver PTM-TC. During this time, the transmitting modem can continue to receive packets from one or more higher layers, label these packets, if needed, and store these packets, if they are identified as low-PER packets, in the same way. The resulting minimum storage requirements for the transmitter PTM-TC are estimated below.

For successful retransmission, the receiving modem should be able to inform the transmitting modem which packet, or packets, need to be retransmitted. One exemplary way of performing this is by transmitting packets with an appended bit field that contains a counter indicating the place of each packet in a stream of packets. This counter value is also known as a Sequence ID (SID). For example, a bit field containing a 16-bit counter could be appended to each packet and the counter module 260 would be incremented by one after each packet was transmitted. In cooperation with the packet assignment module 240, a packet counter field could be appended to the packet in a number of places, for example, at the beginning or end of the packet, or at the beginning or end of the packet header.

Packets received from a higher-layer may already have information in a header or data field of the packet that contains the packet count, or sequence, information. In addition, the packet counter field may be appended with an additional CRC field that contains a cyclic redundancy check that is computed on the packet counter bits only. This CRC can be used by the receiver to determine if the packet counter field is received correctly, i.e., without bit errors. This CRC can be in addition to the standard CRC inserted by the standard PTM-TC (the standard packet PTM-TC CRC is a CRC that covers all bits in a packet). The standard packet CRC may also cover the new packet counter field in its CRC as well. This helps if the receiving modem uses the presence or absence of the packet counter field in a

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packet to detect if the packet has a low-PER or low-latency requirement (discussed below).

Alternatively, or in addition, the packet counter field (with or without a dedicated CRC) can be appended only to the packets with a specific QOS requirement, whereas all other packets can be transmitted without modification. For example, all video packets with low-PER QOS could contain the appended packet counter field whereas all the voice/data low-latency packets could be transmitted unchanged. One exemplary benefit of this is that the overhead (rate loss) due to adding the packet counter field is incurred only when transmitting low-PER packets.

Alternatively, or in addition, all low-PER and low-latency packets can be transmitted with the low packet counter field (with or without a dedicated CRC). In this case, the packet counter field of the low-latency packets may contain a special value indicating that a packet is not a low-PER packet. Also, the packet counter field of the low-latency packet may not even contain a count value, since the low-latency packets are not intended to be retransmitted. In this case, the packet counter field could contain a counter value only for low-PER packets and the counter value would only be incremented when a low-PER packet was transmitted. As an example, if the packet counter field is 16 bits, the special value of all zeros could be used to indicate that a packet is a low-latency packet. In this case, low-PER packets could contain counter values from one up to $2^{16}-1$, but not including all zeros, since this special zero value can be used to indicate a low-latency packet.

The receiving modem, e.g., receiver PTM-TC, which in this case is illustrated as the transceiver 300 and includes comparable functionality to that described in relation to transceiver 200, receives packets from the transmitting modem via the PMS-TC. If the received packet is identified as a low-latency packet by the QOS ID module 325, the packet is passed to a higher-layer. If a received packet is identified by the QOS ID module 325 as a low-PER packet, the packet is forwarded, with the cooperation of the transmission management module 320, to the retransmission buffer 350 for a minimum amount of time before passing to a higher-layer.

The storage time in the retransmission buffer 350 helps ensure that the retransmission protocol provides a constant delay, e.g., no delay variation seen by the upper layers. This way, if a packet needs to be retransmitted, the receiving modem can continue to provide packets to the higher-layers at a constant rate while waiting for the retransmitted packet(s) to arrive from the transmitting modem. The resulting minimum memory (or storage) requirements for the receiving PTM-TC are estimated below.

Alternatively, low-PER packets without errors may not be stored for a minimum amount of time before passing to a higher-layer. The error-free low-PER packets can be passed to the higher-layer immediately just like the low-latency packets. However, when a low-PER packet is in error, it is stored along with all of the following low-PER packets before passing to a higher-layer in order to wait for the retransmitted packet(s) to arrive. This will cause a delay variation on the low-PER packets whenever a retransmission occurs. However, this delay variation would not apply to the low-latency packets.

The QOS ID module 325 can detect that a packet is either low-PER or low-latency using several different methods. For example, if all low-PER and low-latency packets contain the appended packet counter field, then the receiving modem, in cooperation with the counter module 360, detects a low-latency packet when a packet counter field contains

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the designated special value, which was inserted by the transmitting modem, indicating the packet is a low-latency packet.

Alternatively, or in addition, the receiver could detect a low-PER packet when the packet counter field contains a valid packet counter value. Additionally, if a dedicated CRC is appended to the packet counter field, the CRC could be used to detect if the packet counter field bits are in error.

If the packet counter field, including the CRC, is only appended to low-PER packets, the absence or presence of this field in a packet can be used by the receiving modem, and in particular the QOS ID module, to detect a low-delay packet. For example, the receiving modem can examine the position in the packet where the packet counter field would be, if it was a low-PER packet, and if the packet counter field CRC fails while the standard whole packet CRC is correct, the receiving modem could determine that the packet is a low-delay packet, since it does not contain the packet counter field. Likewise, for example, the receiving modem can examine the position in the packet where the packet counter field would be, if it was a low-PER packet, and if the packet counter field CRC is correct, the receiving modem would determine that the packet is a low-PER packet, regardless of the status of the standard whole packet CRC.

The receiving modem, in cooperation with the retransmission buffer 350, and the errored packet module 310, can be used to detect missing or errored packets in a number of exemplary ways. For example, the errored packet module 310 can detect bit errors in the packet using the standard/whole packet PTM-TC CRC. Alternatively, or in addition, the errored packet module 310 can detect bit errors in the packet counter field if the transmitting modem appended a dedicated CRC to the packet counter field. This CRC is valuable because it can be used by the errored packet module in the receiving modem to determine if a packet has the correct packet number, even if the standard whole packet CRC happens to be in error.

Alternatively, or in addition, the errored packet module 310, can detect an errored or missing packet by receiving a packet with a correct CRC, either in the standard or packet counter field, which contains a packet counter number that is not the expected packet counter number. For example, if the errored packet module 310, in cooperation with the counter module 360, detects the receipt of a packet with a counter number equal to 5, wherein the errored packet module 310 is expecting to receive a packet with a counter equal to 3, the errored packet module 310 can determine that two packets, namely packets numbered 3 and 4, were lost due to errors.

Once a packet(s) is found to be in error, there are several exemplary ways in which a receiving modem can communicate information to the transmitting modem indicating that a retransmission of one or more packets is required. For example, the receiving modem, in cooperation with the errored packet module 310, can send an acknowledgment (ACK) message to the transmitting modem for every correctly received message or every predetermined number of packets. As long as the transmitting modem, and in particular the errored packet module 210, receives messages acknowledging receipt of packets in sequential order, there is no need for retransmission of information to the receiving modem. However, if the transmitting modem, and in particular the errored packet module 210, receives a message from the receiving modem, and in particular the errored packet module 310, indicating that a packet was correctly received with a counter value that is out of order, a retransmission by the transmitting modem is required. In the above

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example, where the receiving modem received a packet with a counter value equal to 5, without receiving packets numbered 3 and 4, the transmitting modem could receive an ACK for the packet with counter value of 5. The transmitting modem would then determine that it was necessary to retransmit packets with counter values of 3 and 4 since they were not received.

Alternatively, or in addition, a timeout value could be specified for the transmitting modem. This timeout value could correspond to the amount of time that the transmitting modem should wait for an ACK for particular packet before retransmitting the packet. The timeout value could be set to be at least as long as the round-trip delay required for the transmitting modem to send a packet to the receiving modem and for the receiving modem to send an ACK back to the transmitting modem. If an ACK is not received by the timeout value, the transmitting modem could retransmit the packet.

Alternatively, or in addition, a negative acknowledgment (NAK) could be sent to the transmitting modem when a packet is detected as errored or missing. In the above example, when the receiving modem received the packet with a counter value of 5, while expecting a counter value of 3, the receiving modem could send a NAK message to the transmitting modem indicating that packets with counter values of 3 and 4 were not correctly received and needed to be retransmitted.

Alternatively, or in addition, if a packet was received with a correct packet counter CRC and a valid packet counter value and an incorrect standard whole packet CRC, the receiving modem could send a NAK message to the transmitting modem indicating that a packet with a value of x was incorrectly received and needed to be retransmitted.

Assuming that errored packets are infrequent, any methodology that sends an ACK for each correctly received packet can require a larger amount of data rate in the message channel that communicates this information back to the transmitting modem. In this case, sending only NAKs has the benefit that it requires sending a message only when an errored or missing packet is detected. Depending on the data rate capabilities of the message channel, and the PER, a retransmission system may use only ACKs, only NAKs, or both ACKs and NAKs at the same time.

The ACK and NAK messages sent back to the transmitting modem can be transmitted over the same physical channel i.e., phone line, in the opposite direction as the received packets. Since the channel has a limited data rate and is not necessarily error-free, it is important to make sure that these messages are as robust as possible and consume the least amount of data rate. Additionally, since the transmit and receive retransmission memory requirements depend on the round-trip latency of the connection, is important to minimize latency requirements for the message channel. There are several ways these requirements can be addressed.

The messages can be sent over a separate "low-latency" or "fast" path between the xDSL transceivers. This fast path could include little or even no delay due to interleaving and can be specified to have a latency that is less than 2 ms.

Alternatively, or in addition, the messages can be sent with increasing robustness by repeating transmission of each message a number of times. For example, the message could be repeated x times in order to make sure that even if $x-1$ messages were corrupted by the channel, at least one message would be received correctly.

Alternatively, or in addition, the messages can be sent such that each message is repeated a number of times and

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each repeated message is sent in a different DMT symbol. For example, the message can be repeated x times and each message sent in one of x DMT symbols. This way, even if $x-1$ DMT symbols were corrupted by the channel, at least one message would be received correctly.

Alternatively, or in addition, the messages can be sent such that each message is repeated a number of times and each repeated message is sent in different DMT symbols. For example, the message could be repeated x times and each message sent in one of x DMT symbols. This way, even if $x-1$ DMT symbols were corrupted by the channel, at least one message would be received correctly.

Alternatively, or in addition, the messages can be sent such that each message is repeated a number of times and each repeated message is sent a plurality of times in each DMT symbol. For example, the message could be repeated x times and each repeated message sent y times in one of x DMT symbols. This way, even if $x-1$ DMT symbols were corrupted by the channel and/or large portions of a DMT symbol were corrupted by a channel, the least one message would be received correctly.

Alternatively, or in addition, the messages can include multiple packet count values in order to reduce the data rate requirements. For example, if packets with counter values of 3-9 are correctly (or incorrectly) received an ACK (or NAK) message would be sent to indicate these packet values. For example, the message could contain the values 3 and 9 and the receiver of the message would automatically know that all intermediate values (4, 5, 6, 7, 8) are also been indicated in the message.

Alternatively, or in addition, the DMT sub-carriers that modulate these messages could operate with a much higher SNR margin e.g., 15 dB, as compared to the normal 6 dB margin of xDSL systems. This way, the messages would have a higher immunity to channel noise.

Alternatively, or in addition, a receiving modem may need to send an additional ACK or NAK message after already in the process of sending a repeated message. For example, a receiving modem may detect that packets with values 3 to 9 have been correctly received and send an ACK message back to the transmitting modem indicating this information. This message can be repeated x times with each repeated message being transmitted (at least once) on different DMT symbols. While sending the second repeated message on the second DMT symbol, the receiver could detect that packets with values 10 to 17 have now also been correctly received. In this case, the receiving modem could just append this information to the previous message or, alternatively, send a new separate message that is repeated as well x times with each repeated message being transmitted (at least once) on a different DMT symbol.

Alternatively, or in addition, when repeating a message x times on x DMT symbols, each repeated message can be modulated on a different set of DMT sub-carriers on each DMT symbol. This way, if one or more sub-carriers have a low SNR, the message will still be correctly received.

For low-PER packets, the delay due to this retransmission protocol is equal to the delay that results from storing these packets at the receiving modem (RX PTM-TC) to pass in the packets to a higher layer. Low-latency packets do not incur extra delay.

The transmitting modem must store a packet for retransmission for a time equal to the round trip delay from when the packet is sent to when the retransmission message is received. During this time the transmitting modem continues to receive packets from the higher layer and continues to

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store these packets in the same way. Therefore the storage requirements in octets can be computed as:

$$\text{Minimum TX memory (octets)} \\ = \text{roundtripdelay} * \text{datarate},$$

where the roundtripdelay is the time equal to the round trip delay from when the packet is sent to when the retransmission message is received, and the datarate is the data rate of the connection that is transferring the packets.

For ITU-T G.993.2 VDSL2, which is incorporated herein by reference, this can be computed using the VDSL2 profile parameters as:

$$\text{Minimum TX memory (octets)} = (DS + US \text{ Interleaving} \\ \text{Delay in octets}) + (US + DS \text{ alpha/beta delay without} \\ \text{interleaving}) * (\text{Bidirectional Net data rate}) \\ = \text{MAXDELAYOCTET} + (4 \text{ ms}) * \text{MBDC},$$

where MAXDELAYOCTET and MBDC are as specified in the VDSL2 profiles.

For the receiver, the minimum receiver storage requirements can be determined in a similar manner. More specifically, the RX PTM-TC must store a packet before passing it to the higher layer for a time equal to the round trip delay from when a retransmission message is transmitted to when the retransmitted packet is received. This is equal to storage requirements in octets (same as transmitter):

$$\text{Minimum RX memory (octets)} \\ = \text{roundtripdelay} * \text{datarate},$$

where the roundtripdelay is the time equal to the round trip from when a retransmission message is transmitted to when the retransmitted packet is received and the datarate is the data rate of the connection that is transferring the packets.

For ITU-T G.993.2 VDSL2 this can be computed using the VDSL2 profile parameters as:

$$\text{Minimum RX memory (octets)} = (DS + US \text{ Interleaving} \\ \text{Delay in octets}) + (US + DS \text{ alpha/beta delay without} \\ \text{interleaving}) * (\text{Bidirectional Net data rate}) \\ = \text{MAXDELAYOCTET} + (4 \text{ ms}) * \text{MBDC},$$

where MAXDELAYOCTET and MBDC are as specified in the ITU-T G.993.2 VDSL2 profiles.

TABLE 1

Minimum TX or RX memory requirements for VDSL2				
VDSL2 PROFILE	8a, 8b, 8c, 8d	12a, 12b	17a	30a
TX or RX memory requirements (octets) =	90,536	99,536	123,304	231,072
MAXDELAYOCTET + .002MBDC				

The estimates in Table 1 assume that all the entire MAXDELAYOCTET and MBDC are used for the transfer of the packet stream, i.e., the reverse channel has a very low data rate and no interleaving.

Some xDSL standards specify minimum storage, i.e., memory, requirements for interleaving of RS codewords. Interleaving with RS coding is an effective way of correcting channel errors due to, for example, impulse noise. For example, VDSL2 requires support of an aggregate bidirectional interleaver and de-interleaver memory of 65 Kbytes for the 8a VDSL2 profile. This corresponds to storage requirement of approximately 32 Kbytes in a single transceiver.

Sharing of Memory Between the Retransmission Function and One or More of the Interleaving/Deinterleaving/RS Coding/RS Decoding Functions

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From Table 1, it is apparent that the memory requirements to support the retransmission protocol may be more than double the storage requirements of a single transceiver. Additionally, the retransmission protocol provides a different method for correcting channel errors due to, for example, impulse noise.

Moreover, interleaving and RS coding methods and retransmission protocols provide different advantages with respect to error correction capabilities, latency, buffering requirements, and the like. For example, under certain configuration and noise conditions the interleaving/RS coding provides error correction/coding gain with less delay and overhead than the retransmission protocol (for packets that can be retransmitted). While under other conditions the retransmission protocol will provide better error correction with less delay and overhead than the interleaving/RS coding.

In some cases, a first portion of the memory can be used for one function and a second portion of the memory for some other function. For example, if the configuration and noise conditions are such that the interleaving/RS coding would not provide good error correction/coding gain, then all the available memory could be used for the retransmission function and none allocated to the interleaving/deinterleaving/RS coding/RS decoding functionality, e.g., the interleaving/deinterleaving could be disabled.

Likewise, if the configuration and noise conditions are such that the retransmission protocol would not provide good error correction/coding gain, then all the available memory could be used for the interleaving/deinterleaving/RS coding/RS decoding functionality and no memory would be used for the retransmission function, e.g., the retransmission function would be disabled.

Alternatively, or addition, both methods could be used because both have their advantages, with the system, e.g., the memory management module 370, being able to dynamically allocate a first portion of the memory 250/350 to the interleaving/deinterleaving/RS coding/RS decoding functionality and a second portion of the memory to the retransmission functionality. For example, 40% of the memory could be allocated to the interleaving/deinterleaving/RS coding/RS decoding functionality with the remaining 60% allocated to the retransmission of functionality. However, it should be appreciated, that in general, the memory can be divided, i.e., shared, in any manner.

The sharing of memory between the retransmission function and the interleaving/deinterleaving/RS coding/RS decoding functions is not restricted to retransmission protocols described in other embodiments that utilize QOS metrics to determine which packets should be retransmitted. In other words, the sharing of memory between the retransmission function and the interleaving/deinterleaving/RS coding/RS decoding functions can be utilized for retransmission systems where all errored packets are retransmitted, i.e., there is no QOS identifier in the retransmission protocol. For example, the FEC/interleaving could be used to meet the INPmin requirement specifically targeting the impulse noise that occurs frequently (e.g., on the order of minutes or seconds) but is short in duration and can therefore be corrected by the FEC/interleaving. For example, the retransmission protocol can be used to correct infrequent errors (on the order of hours) that are long in duration and would not be correctable by the FEC/interleaving. As another example, the FEC/interleaving function may be used in combination with the retransmission function because it is well known that FEC with minimal interleaving provides a 1 dB to 3 dB coding gain when used with a trellis code (as is often the

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case in xDSL systems). This means that even when the majority of the shared memory is allocated to a retransmission function to address channel noise (such as impulse noise), a smaller amount of memory may be allocated to the FEC/interleaving function for the coding gain advantage.

Associated with the ability to allocate or partition memory between one or more of the interleaving/deinterleaving/RS coding/RS decoding functionality and retransmission functionality, is the ability to exchange information between transceivers on how to establish this allocation. For example, the transmitting modem may send a message to the receiving modem indicating how much of the available memory is to be allocated to one or more of the interleaving/deinterleaving/RS coding/RS decoding functionality and how much memory is to be allocated to the retransmission functionality. For example, if the receiving modem contains 100 kBytes of available memory, the transmitting modem could send a message to the receiving modem indicating that 25 kBytes should be allocated to RS coding functionality and 75 kBytes should be allocated to the retransmission functionality. Since the receiving modem generally determines the interleaving/RS coding parameters that are used, the receiving modem could use this information to select parameters, e.g., interleaver depth and codeword size, that would result in an interleaving memory requirement that is no more than the amount indicated in the message.

Alternatively, or addition, the receiving modem can send a message to the transmitting modem indicating how much of the available memory is to be allocated to one or more of the interleaving/deinterleaving/RS coding/RS decoding functionality, and how much memory should be allocated to the retransmission functionality.

Sharing of Memory Between a Retransmission Function with Identification of Low-PER and/or Low-Latency Packets and One or More of Interleaving/Deinterleaving/RS Coding/RS Decoding Functions.

A way of reducing the total memory requirement of a transceiver that supports the retransmission functionality with the identification of the low-PER and/or the low-latency packets is to define a limit, such as a maximum value, for the data rate of the low-PER packet stream, i.e., the packets requiring retransmission to meet a specific PER requirement. For example, if the total data rate is 50 Mbps, and the roundtrip delay is 10 ms, the minimum TX or RX memory requirement is $50,000,000 \times 0.01/8 = 62500$ bytes if the retransmission function must support the case where all the transmitted packet (all 50 Mbps) are low-PER packets. If however, only a portion of the 50 Mbps data rate is allocated to the low-PER packet stream (e.g. 30 Mbps), whereas the remainder of the data rate is allocated to the low-latency packet stream (e.g. 20 Mbps), the minimum TX or RX memory requirement would be $30,000,000 \times 0.01/8 = 37500$ bytes (assuming a roundtrip delay of 10 ms). In this case, the transmitting modem (or receiving modem) may send a message to the receiving modem (or transmitting modem) that indicates the maximum data rate of the packet traffic that will be used in the retransmission function. Using the example above, the transmitting modem (or receiving modem) would send a message indicating that the low-PER traffic will not exceed 30 Mbps, in which case the receiving modem (or transmitting modem) will allocate memory to the retransmission functionality and the interleaving/RS coding (or deinterleaving/RS decoding) functionality accordingly.

One exemplary advantage of indicating the low-PER and low-latency packets as part of the retransmission protocol is that it provides a DDR-like functionality without the overhead of dynamically re-allocating latency paths. For

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example, when a video application is turned off (less low-PER packets on the connection), the data application data rate can be increased (more low-latency packets on the connection) without any changes in the transmission parameters.

The retransmission protocol can also be used with or without underlying FEC/interleaving (or deinterleaving). An exemplary approach is to use the FEC/interleaving to meet the INPmin requirement specifically targeting the impulse noise that occurs frequently, e.g., on the order of minutes or seconds. The retransmission protocol can be used to correct infrequent errors (on the order of hours) that will only typically be a problem for very-low PER applications, such as video.

When a retransmission protocol is combined with underlying FEC/interleaving (or deinterleaving), the retransmission protocol latency will grow in proportion to the additional FEC/interleaving delay. This is due to the fact that the required receiver buffering corresponds approximately to the round-trip delay time of packet transmission and message acknowledgment.

As an example of utilizing the retransmission protocol that identifies one or more of low-PER and low-latency packets with underlying FEC/Interleaving (or deinterleaving), the FEC/interleaving is used to achieve the INPmin requirements within the latency constraint and the retransmission function is used to provide another layer of error correction. The low-PER packets are passed through both the retransmission function and the FEC/interleaver and, as a result, a very low PER is achieved. The low-latency packets are passed through the FEC/Interleaver but not passed through the retransmission function. Since low-latency packets are passed through the FEC/interleaver, they will meet the INPmin and MaxDelay requirements without incurring the extra delay from the retransmission protocol.

Example Configuration Parameters:

DS Data rate=25 Mbps, INPmin=2, MaxDelayDS=8 ms

Example FEC/Interleaving Parameters:

NFEC=128, R=16 which results in an interleaver memory of approximately 14 Kbytes for INP=2 with 8 ms of delay.

Retransmission Protocol:

If we assume the US latency is 2 ms, the retransmission protocol will add a minimum of $8+2=10$ ms of latency. This means that the total DS latency (FEC/interleaving+Retransmission) will be approximately $8+10=18$ ms.

Memory Requirements:

The memory requirements for the retransmission protocol can be calculated as: $(10 \text{ ms}) \times (25 \text{ Mbps})/8 = 31$ Kbytes. Therefore the transmitter and receiver will both need a total memory of $(31+14)=45$ Kbytes for the retransmission protocol and FEC/Interleaving function.

Low-PER Packets:

Latency=18 ms. The PER is very low because INPmin=2 (from FEC/interleaving) is combined with the error correction of the retransmission function.

Low-Latency Packets:

Latency=8 ms. INP=2 from FEC/interleaving. No additional delay due to retransmission function.

Although this invention describes the retransmission being done as part of the PTM-TC, it could also be done inside other layer(s) of the xDSL transceiver, such as the PMD or the PMS-TC. Alternatively, it could be performed at a layer(s) above the PTM-TC, for example, in a new layer between the PTM-TC and the next higher layer, or in general any layer above the physical layer, e.g., layer 1, 2, 3, 4 or 5.

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In this invention, the term “transmitter” generally refers to the transceiver that transmits the packets. Likewise the term “receiver” generally refers to the transceiver that receives the packets. Therefore the “transmitter” also receives the ACK/NAK messages and the “receiver” also transmits the ACK/NAK messages.

FIG. 2 outlines an exemplary method of operation of a transmitting modem utilizing the retransmission protocol. In particular, control begins in step S100 and continues to step S110. In step S110, a packet is received from a higher layer. Then, in step S120, a decision is made as to whether the received packet is a retransmitted type packet. If the packet is not a retransmitted type packet, such as a low-latency packet, control jumps to step S125 where the packet is optionally updated (as discussed above) with control continuing to step S130 where the packet is forwarded to the receiver. Control then continues to step S140 where the control sequence ends.

If the packet is a retransmitted type packet, such as a low-PER packet, control continues to step S150. In step S150, the packet can be updated with information such as a sequence identifier or other information that allows a receiver to be able to determine which packet (or packets) need to be retransmitted. Next, in step S160, the updated packet is stored in the retransmission buffer. Then, in step S170, the packet is forwarded to the receiver. Control then continues to step S180.

In step S180, a determination is made whether the packet needs to be retransmitted. If the packet needs to be retransmitted, control jumps back to step S170. Otherwise, control continues to step S190.

In step S190, the packet is deleted from the retransmission buffer. Control then continues to step S140 where the control sequence ends.

FIG. 3 outlines an exemplary method of operation of a receiving modem utilizing the retransmission protocol. In particular, control begins in step S200 and continues to step S210. In step S210, a packet is received from the transmitter. Next, in step S220, a determination is made whether the packet has been identified as a retransmitted type packet. If the packet has not been identified as a retransmittable type packet, control jumps to step S230.

In step S230, the packet is forwarded to a higher layer. Control then continues to step S240 where the control sequence ends.

Alternatively, if the received packet is a retransmittable type packet, the packet is stored in the retransmission buffer in step S260. Next, in step S270, the integrity of the packet can be checked, for example utilizing a CRC. Then, in step S280, a determination is made whether the packet needs retransmission. If the packet needs retransmission, control continues to step S290 where the retransmitted packet is obtained, for example, based on the sending of a message(s), one or the other transceiver determining a packet is missing, or the like, as discussed above, with control continuing back to step S270 for an integrity check.

If the packet does not need retransmission, control continues to step S295 where the packet is forwarded to a higher layer and deleted from the retransmission buffer. Control then continues to step S240 where the control sequence ends.

FIG. 4 outlines an exemplary memory allocation method for sharing memory between the retransmission function and one or more of the interleaving/deinterleaving functionality and coding functionality. In particular, control begins in step S300 and continues to step S305. In step S305, a message is sent/received specifying the available memory. Typically,

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the receiver will send a message to the transmitter specifying the available memory, but the transmitter could also send a message to the receiver. Next, in step S310, a determination is made as to how the memory should be allocated. As discussed, this allocation can be based on one or more of error correction capability, latency, buffering requirements, SNR, impulse noise, or in general, any communication parameter. Next, in step S320, the memory allocation is communicated to another transceiver. Then, in step S330, a determination can be made as to whether the allocation is compatible. If the received allocation is not compatible, control continues to step S360 wherein another allocation can be requested, with control continuing back to step S320.

Alternatively, if the allocation is compatible, in step S340 the memory is allocated based on the received allocation. Control then continues to step S350 where the control sequence ends.

FIG. 5 illustrates an exemplary memory sharing methodology for use with a retransmission function and one or more of interleaving/deinterleaving functionality, RS coding/decoding functionality. In particular, control begins in step S400 and continues to step S410. In step S410, the memory allocation is received from, for example, a memory management module that may be located in the same transceiver, or at a remote transceiver. Next, in step S420, the memory sharing configuration is established and then, in step S430, the memory is shared between a retransmission function and one or more of the interleaving/deinterleaving functionality, RS coding/decoding functionality. Control then continues to step S440.

In step S440, a determination is made whether the memory sharing configuration should be changed. For example, the memory sharing configuration can be dynamically changed based on changes in the communication channel or data type(s) being sent on the communication channel. More specifically, for example, if the communications channel was not performing well, e.g., an increase in bit errors, it may be advantageous to increase the retransmission capability while decreasing the FEC/interleaving capability or vice-versa, which could have an impact on how the memory sharing should be configured.

If the memory sharing configuration should be changed, control continues to step S450 where another allocation can be requested, with control continuing back to step S410. Otherwise, control continues to step S460 where the control sequence ends.

While the above-described flowcharts have been discussed in relation to a particular sequence of events, it should be appreciated that changes to this sequence can occur without materially effecting the operation of the invention. Additionally, the exact sequence of events need not occur as set forth in the exemplary embodiments, but rather the steps can be performed by one or the other transceiver in the communication system provided both transceivers are aware of the technique being used for initialization. Additionally, the exemplary techniques illustrated herein are not limited to the specifically illustrated embodiments but can also be utilized with the other exemplary embodiments and each described feature is individually and separately claimable.

The above-described system can be implemented on wired and/or wireless telecommunications devices, such as a modem, a multicarrier modem, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a linecard, test equipment, a multicarrier transceiver, a wired and/or wireless wide/local area network system, a satellite communication system, network-based communication systems, such

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as an IP, Ethernet or ATM system, a modem equipped with diagnostic capabilities, or the like, or on a separate programmed general purpose computer having a communications device or in conjunction with any of the following communications protocols: CDSL, ADSL2, ADSL2+, VDSL1, VDSL2, HDSL, DSL Lite, IDSL, RADSL, SDSL, UDSL or the like.

Additionally, the systems, methods and protocols of this invention can be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element(s), an ASIC or other integrated circuit, a digital signal processor, a hard-wired electronic or logic circuit such as discrete element circuit, a programmable logic device such as PLD, PLA, FPGA, PAL, a modem, a transmitter/receiver, any comparable means, or the like. In general, any device capable of implementing a state machine that is in turn capable of implementing the methodology illustrated herein can be used to implement the various communication methods, protocols and techniques according to this invention.

Furthermore, the disclosed methods may be readily implemented in software using object or object-oriented software development environments that provide portable source code that can be used on a variety of computer or workstation platforms. Alternatively, the disclosed system may be implemented partially or fully in hardware using standard logic circuits or VLSI design. Whether software or hardware is used to implement the systems in accordance with this invention is dependent on the speed and/or efficiency requirements of the system, the particular function, and the particular software or hardware systems or microprocessor or microcomputer systems being utilized. The communication systems, methods and protocols illustrated herein can be readily implemented in hardware and/or software using any known or later developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

Moreover, the disclosed methods may be readily implemented in software that can be stored on a storage medium, executed on programmed general-purpose computer with the cooperation of a controller and memory, a special purpose computer, a microprocessor, or the like. In these instances, the systems and methods of this invention can be implemented as program embedded on personal computer such as an applet, JAVA® or CGI script, as a resource residing on a server or computer workstation, as a routine embedded in a dedicated communication system or system component, or the like. The system can also be implemented by physically incorporating the system and/or method into a software and/or hardware system, such as the hardware and software systems of a communications transceiver.

It is therefore apparent that there has been provided, in accordance with the present invention, systems and methods for packet retransmission and memory sharing. While this invention has been described in conjunction with a number of embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable arts. Accordingly, it is intended to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and scope of this invention.

The invention claimed is:

1. A method of packet retransmission, in a transceiver, comprising:

transmitting, by the transceiver, a first type of packet; and

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transmitting, by the transceiver, a second type of packet, wherein the first type of packet is stored in a retransmission buffer after transmission and the second type of packet is not stored in a retransmission buffer after transmission,

wherein the first and second types of packet comprise a header field that indicates whether a transmitted packet is a first type of packet or a second type of packet, and wherein the header field of the first type of packet comprises a sequence identifier (SID) that is incremented after the first type of packet is transmitted and the header field of the second type of packet does not comprise the SID of the first type of packet.

2. The method of claim 1, wherein the transceiver is connected to a second transceiver using a wired or wireless channel and the transceivers are used to transport one or more of video and voice data.

3. The method of claim 1, wherein the method is performed in a linecard that is operable to transport video.

4. The method of claim 1, wherein the method is performed in a customer premises modem that is operable to transport video.

5. The method of claim 1, wherein the transceiver includes at least one digital signal processor.

6. The method of claim 1, wherein the transceiver includes at least one ASIC (Application Specific Integrated Circuit).

7. The method of claim 1, wherein the first type of packet comprises one or more PTM-TC (Packet Transfer Mode-Transmission Convergence) codewords.

8. The method of claim 1, wherein the first type of packet comprises one or more ATM (Asynchronous Transfer Mode) cells.

9. The method of claim 1, wherein the first type of packet comprises one or more Reed Solomon codewords.

10. The method of claim 1, wherein the first type of packet is a low-PER (Packet Error Rate) packet and the second type of packet is a low-latency packet.

11. A transceiver operable to transmit a first type of packet and to transmit a second type of packet, wherein the first type of packet is stored in a retransmission buffer after transmission and the second type of packet is not stored in a retransmission buffer after transmission, and wherein the first and second types of packet comprise a header field that indicates whether a transmitted packet is a first type of packet or a second type of packet, and wherein the header field of the first type of packet comprises a sequence identifier (SID) that is incremented after the first type of packet is transmitted and the header field of the second type of packet does not comprise the SID of the first type of packet.

12. The transceiver of claim 11, wherein the transceiver is connected to a second transceiver using a wired or wireless channel and the transceivers are used to transport one or more of video and voice data.

13. The transceiver of claim 11, wherein the transceiver is located in a linecard that is operable to transport video.

14. The transceiver of claim 11, wherein the transceiver is located in a customer premises modem that is operable to transport video.

15. The transceiver of claim 11, wherein the transceiver includes at least one digital signal processor.

16. The transceiver of claim 11, wherein the transceiver includes at least one ASIC (Application Specific Integrated Circuit).

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17. The transceiver of claim 11, wherein the first type of packet comprises one or more PTM-TC (Packet Transfer Mode-Transmission Convergence) codewords.

18. The transceiver of claim 11, wherein the first type of packet comprises one or more ATM (Asynchronous Transfer Mode) cells. 5

19. The transceiver of claim 11, wherein the first type of packet comprises one or more Reed Solomon codewords.

20. The transceiver of claim 11, wherein the first type of packet is a low-PER (Packet Error Rate) packet and the 10 second type of packet is a low-latency packet.

* * * * *

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EXHIBIT 12



US010567112B2

(12) **United States Patent**
Tzannes

(10) **Patent No.:** **US 10,567,112 B2**

(45) **Date of Patent:** **Feb. 18, 2020**

(54) **IMPULSE NOISE MANAGEMENT**

(56) **References Cited**

(71) Applicant: **TQ DELTA, LLC**, Austin, TX (US)

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(72) Inventor: **Marcos C. Tzannes**, Petaluma, CA (US)

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(73) Assignee: **TQ DELTA, LLC**, Austin, TX (US)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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Primary Examiner — Jean B Corrielus

(74) *Attorney, Agent, or Firm* — Jason H. Vick; Sheridan Ross, PC

Related U.S. Application Data

(63) Continuation of application No. 14/757,630, filed on Dec. 23, 2015, now abandoned, which is a
(Continued)

(57) **ABSTRACT**

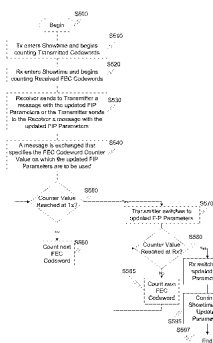
(51) **Int. Cl.**
H04L 1/00 (2006.01)
H04L 1/20 (2006.01)
(Continued)

A discrete multitone transceiver (DMT) includes a deinterleaver operable to de-interleave a plurality of bits. The DMT further includes: a forward error correction decoder operable to decode the plurality of bits, a module operable to determine, during Showtime, an impulse noise protection value, wherein the impulse protection value specifies a number corrupted DMT symbols that can be corrected by the forward error correction decoder in combination with the deinterleaver, and a receiver coupled to the deinterleaver. The receiver receives using a first interleaver parameter value, receives a flag signal, and changes to receiving using a second interleaver parameter value that is different than the first interleaver parameter value, wherein the second interleaver parameter value is used for reception on a pre-defined forward error correction codeword boundary following reception of the flag signal.

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CPC ... H04L 1/0015; H04L 1/0009; H04L 1/0025;
H04L 1/20; H04L 1/0075; H04L 5/006;
H04L 1/0023; H04L 1/0071; H04B 15/00
See application file for complete search history.

21 Claims, 7 Drawing Sheets



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Related U.S. Application Data

continuation of application No. 14/285,911, filed on May 23, 2014, now abandoned, which is a continuation of application No. 14/075,077, filed on Nov. 8, 2013, now Pat. No. 8,743,932, which is a continuation of application No. 13/914,852, filed on Jun. 11, 2013, now Pat. No. 8,594,162, which is a continuation of application No. 12/769,193, filed on Apr. 28, 2010, now Pat. No. 8,462,835, which is a continuation of application No. 10/597,482, filed as application No. PCT/US2005/006842 on Mar. 3, 2005, now abandoned.

- (60) Provisional application No. 60/549,804, filed on Mar. 3, 2004, provisional application No. 60/555,982, filed on Mar. 24, 2004.

(51) Int. Cl.

H04B 15/00 (2006.01)

H04L 5/00 (2006.01)

(52) U.S. Cl.

CPC H04L 1/0023 (2013.01); H04L 1/0025 (2013.01); H04L 1/0075 (2013.01); H04L 1/20 (2013.01); H04L 5/006 (2013.01); H04L 1/0071 (2013.01)

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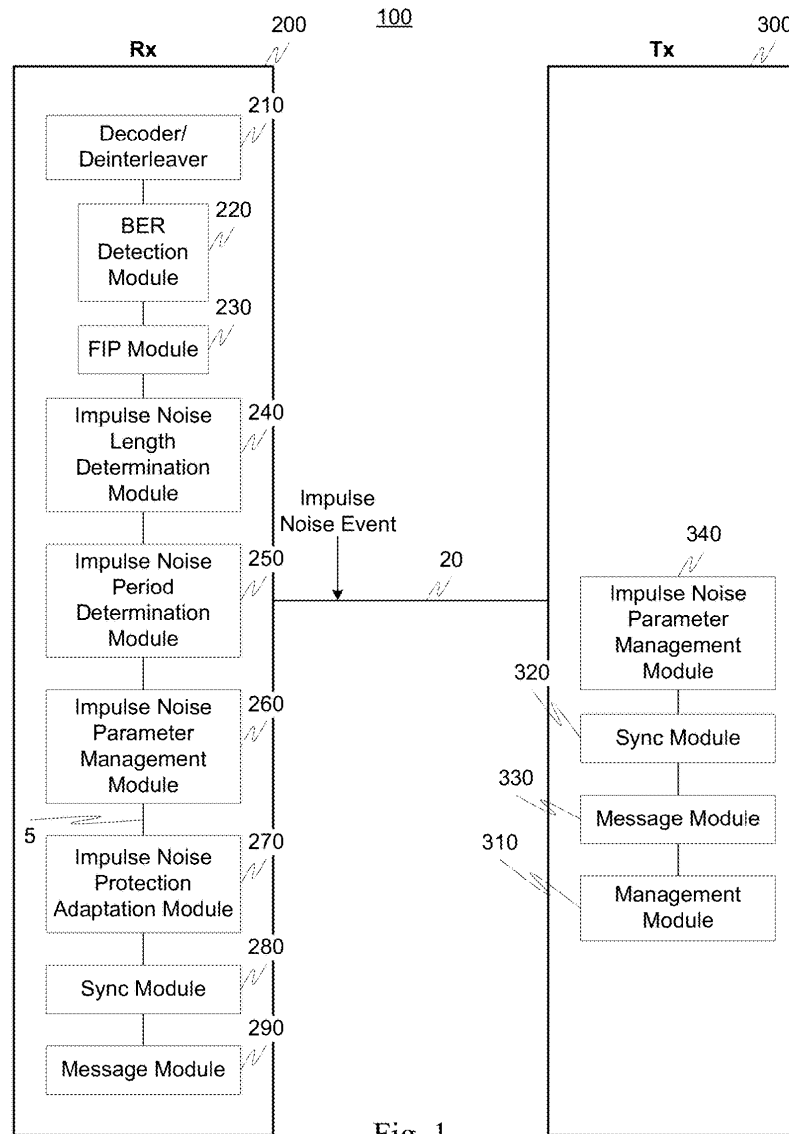


Fig. 1

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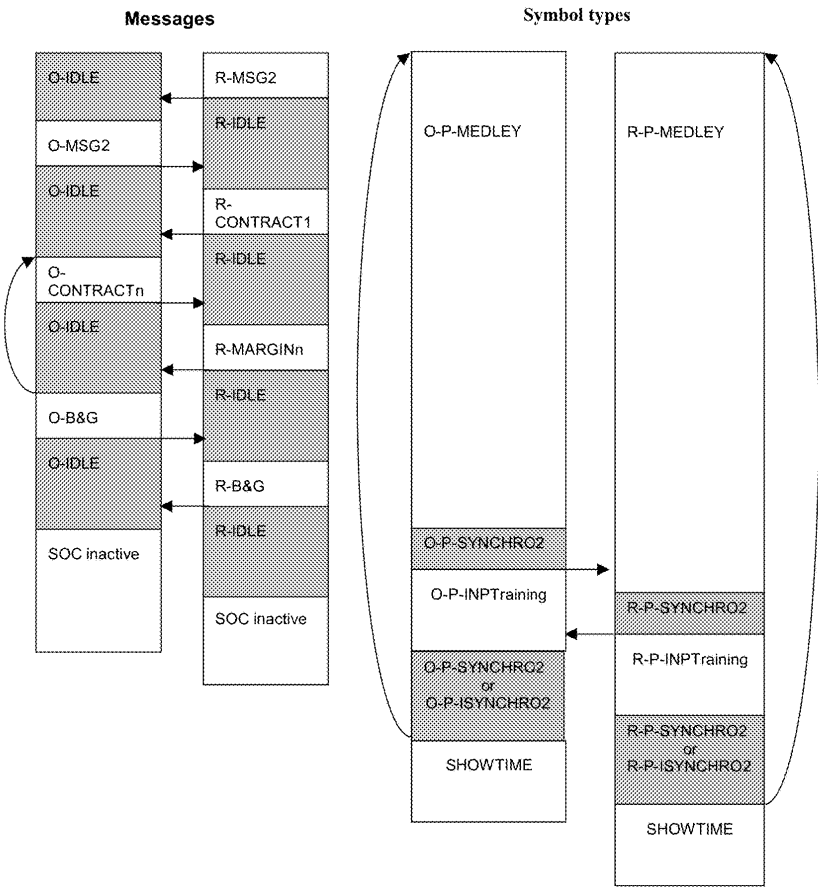


Fig. 2

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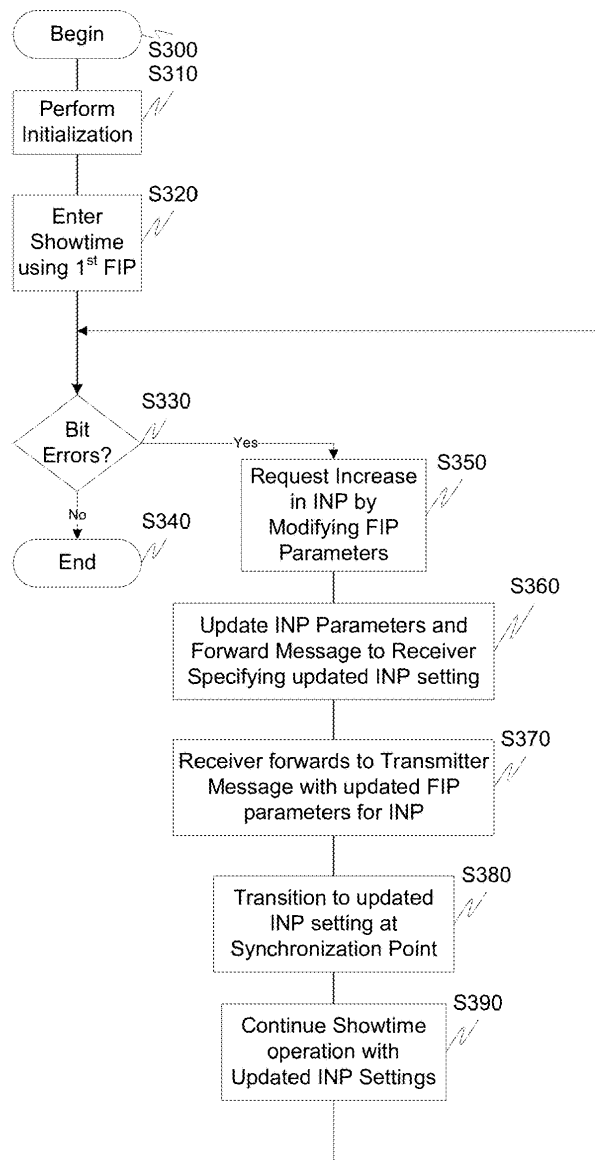


Fig. 3

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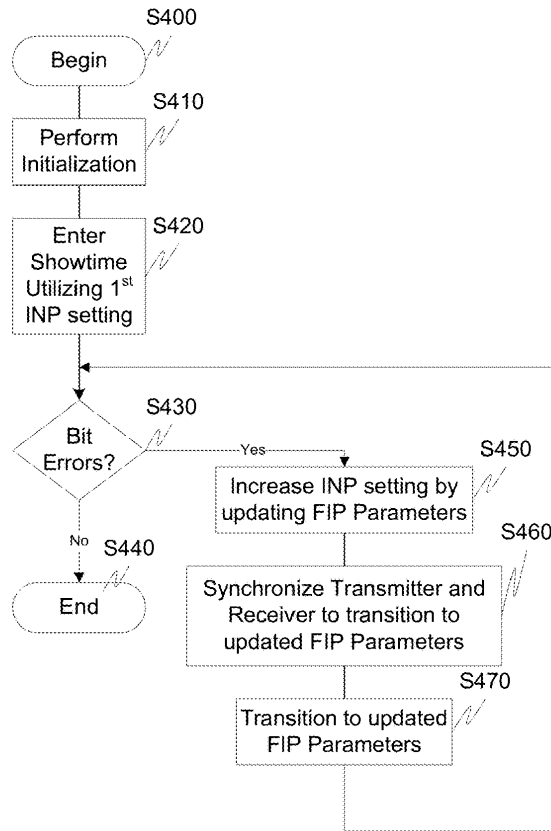


Fig. 4

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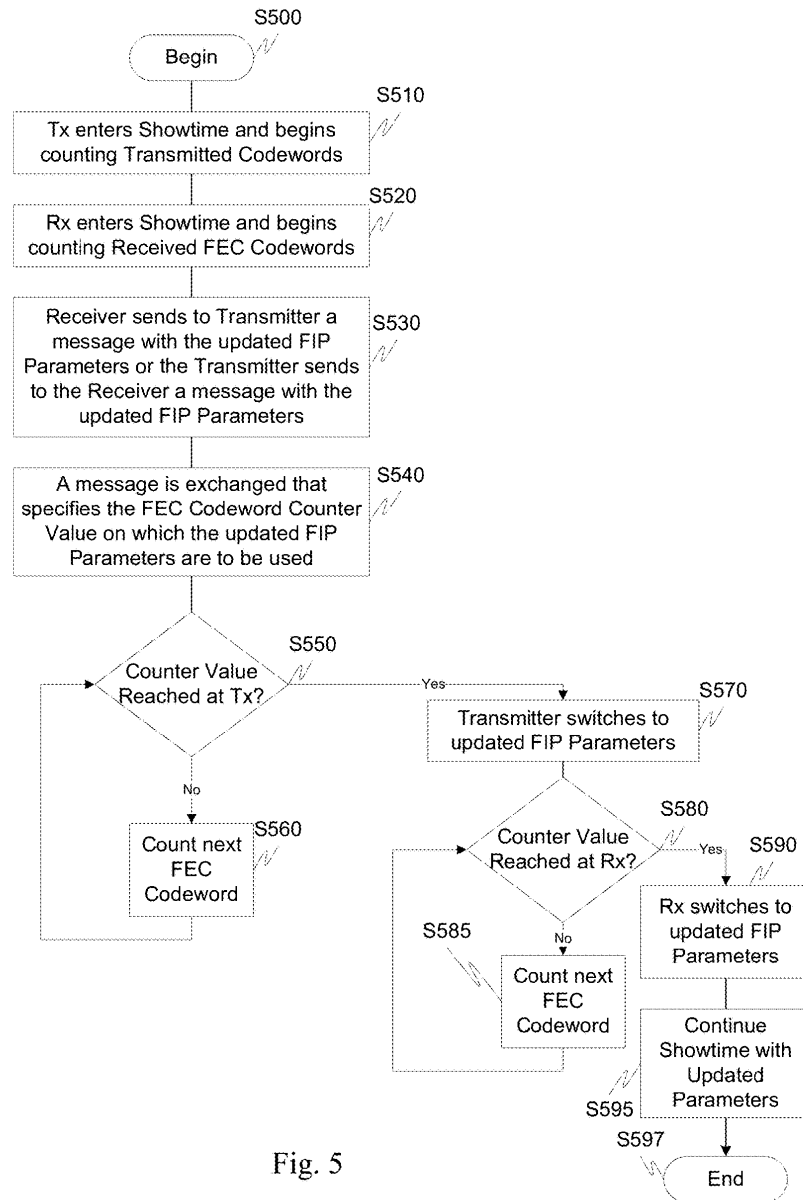


Fig. 5

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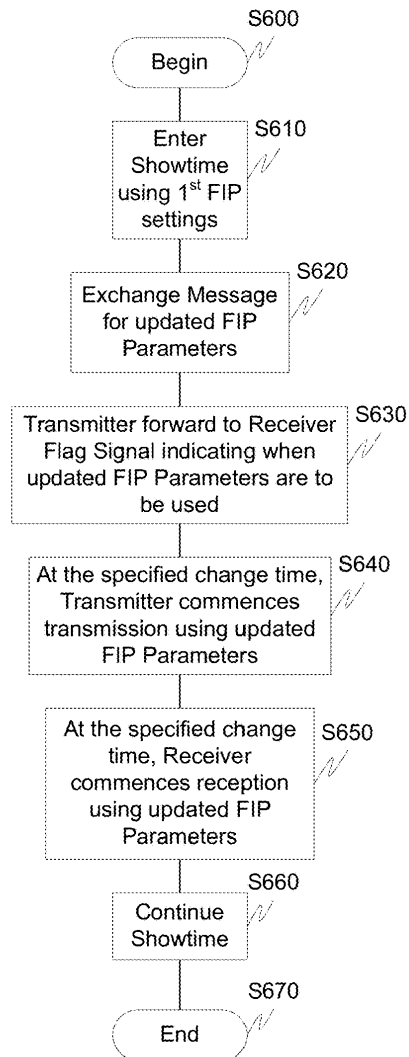


Fig. 6

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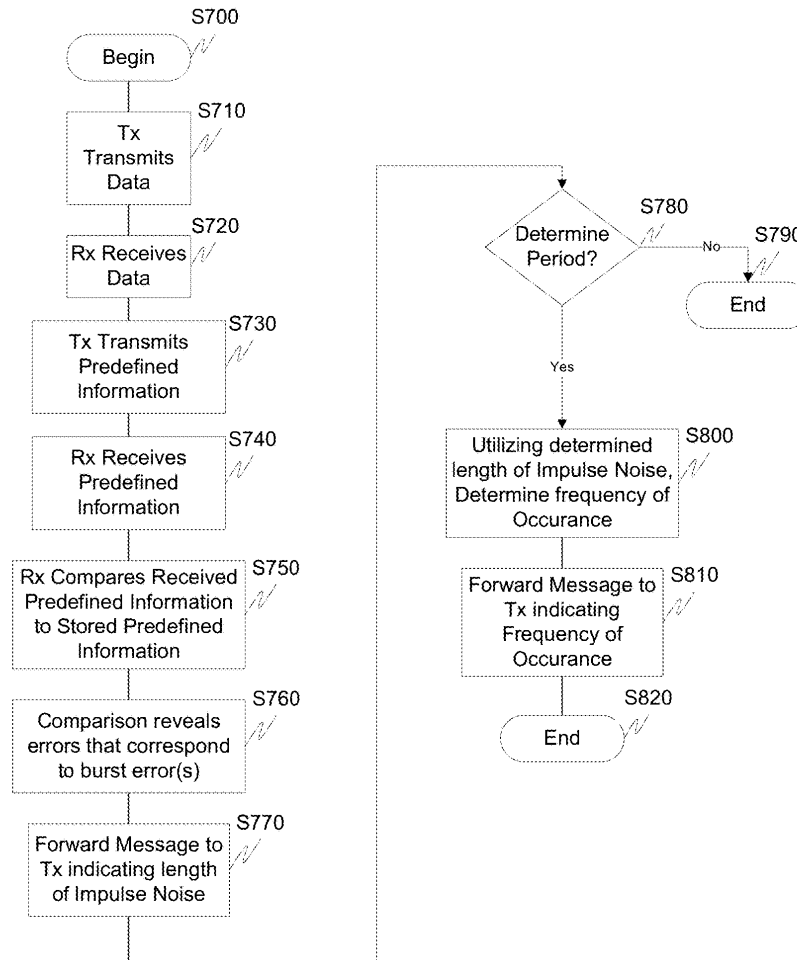


Fig. 7

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IMPULSE NOISE MANAGEMENT

RELATED APPLICATION DATA

This application is a Continuation of now abandoned U.S. application Ser. No. 14/757,630, filed Dec. 23, 2015, which is a Continuation of U.S. application Ser. No. 14/285,911, filed May 23, 2014, which is a Continuation of U.S. application Ser. No. 14/075,077, filed Nov. 8, 2013, now U.S. Pat. No. 8,743,932, which is a Continuation of U.S. application Ser. No. 13/914,852, filed Jun. 11, 2013, now U.S. Pat. No. 8,594,162, which is a Continuation of U.S. application Ser. No. 12/769,193 filed Apr. 28, 2010, now U.S. Pat. No. 8,462,835, which is a Continuation of U.S. application Ser. No. 10/597,482, filed Jul. 27, 2006, which is a national stage application under 35 U.S.C. 371 of PCT Application No. PCT/US2005/006842, filed Mar. 3, 2005, which claims the benefit of and priority under 35 U.S.C. § 119(e) to U.S. Provisional Application No. 60/549,804, entitled "On-Line Impulse Noise Protection (INP) Adaptation," filed Mar. 3, 2004, and U.S. Provisional Application No. 60/555,982, entitled "Impulse Noise Protection (INP) Training," filed Mar. 24, 2004, each of which are incorporated herein by reference in their entirety.

BACKGROUND

Field of the Invention

This invention generally relates to communication systems. In particular, an exemplary aspect of this invention relates to impulse noise protection adaptation. Another exemplary aspect of this invention relates to impulse noise length and period determination and use thereof for impulse noise protection adaptation.

Description of Related Art

Communications systems often operate in environments that produce impulse noise. Impulse noise is a short-term burst of noise that is higher than the normal noise that typically exists in a communication channel. For example, DSL systems operate on telephone lines and experience impulse noise from many external sources including telephones, AM radio, HAM radio, other DSL services on the same line or in the same bundle, other equipment in the home, etc. It is standard practice for communications systems to use interleaving in combination with Forward Error Correction (FEC) to correct the errors caused by impulse noise. Standard initialization procedures in ADSL and VDSL systems are designed to optimize performance (data rate/reach) in the presence "stationary" crosstalk or noise. Impulse noise protection is handled with interleaving and FEC, but the current xDSL procedure at least does not provide specific states to enable training for the selection of the appropriate interleaving and FEC parameters.

An exemplary problem associated with traditional communication systems is that they use traditional Signal to Noise Ratio (SNR) measurement techniques to determine the SNR of the channel. These traditional techniques assume that the noise is stationary and does not contain non-stationary components such as impulse noise. The most common method for measuring the SNR is to calculate the mean-square error of the received signal based on a known transmitted signal, which is described in the ADSL series of ITU G.992.x standards and the VDSL series of ITU G.993.x standards, which are incorporated herein by reference in

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their entirety. These traditional methods for measuring SNR do not correctly measure the impact of impulse noise and do not have the noise capability to determine how the system should be configured to handle impulse noise.

There has been proposed that there is a need in ADSL and VDSL systems to provide robust error-free performance in the presence of high, real-world impulse noise. A specific proposal recommends that the standard impulse noise protection (INP) values are extended to values of 4, 8, 16 and 32 in order to handle high levels of impulse noise. Impulse noise protection is defined in the ADSL2 Standard G.992.3, which is incorporated herein by reference in its entirety, as the number of impulse noise corrupted DMT symbols that can be corrected by the FEC and interleaving configuration. Specifically, G.992.3 defines the following variables:

$$INP = \frac{1}{2} * (S * D) * R / N$$

$$S = 8 * N / L$$

$$Latency(or\ delay) = S * D / 4$$

$$Line\ Rate(in\ kbps) = L * 4$$

where N is the codeword size in bytes, R is the number of parity (or redundancy) bytes in a codeword, D is the interleaver depth in number of codewords, and L is the number of bits in a DMT symbol.

If K is the number of information bytes in a codeword then:

$$N = K + R$$

and the user data rate is approximately equal to:

$$L * 4 * K / N.$$

In general, DSL systems (such as the one defined in ADSL G.992.x or VDSL G.993.x) use the FEC and Interleaving Parameters (FIP) characterized by the set of parameters (N, K, R, D). Using these parameters, the Burst Error Correction Capability (BECC) in bytes can be simply calculated as:

$$BECC = D * R / 2 \text{ bytes}$$

where BECC is defined as the number of consecutive byte errors that can be corrected by the receiver. Note that if the receiver uses more intelligent decoding schemes, such as erasure detection, it is possible to correct even more than $D * R / 2$ bytes. It also follows from above that $INP = BECC / L$.

The proposal further recommends that the higher INP values are achieved by increasing the amount of FEC redundancy while keeping the same system latency and the same interleaver memory at the expense of user data rate or excess margin. Since, on phone lines without excess margin, there is clearly a trade-off between high impulse noise protection values and user data rate, it would be advantageous to try to maximize the user data rate by finding the minimum impulse noise protection value that can provide adequate impulse noise protection. The current technique includes the steps of an operator, or service provider, configuring the ADSL connection with a specific noise protection value, the ADSL connection is initialized and the transceivers enter into steady state data transmission (i.e., Showtime), and if the connection is stable, i.e., error-free, then the service is acceptable and the process ends. If there are bit errors, then the process is repeated with the operator, or service provider, configuring the ADSL connection with another specific INP value.

One exemplary problem with this approach is that it is time consuming and can result in sub-optimum user rates. This is illustrated with reference to the following examples:

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Example 1: Assume that for a particular DSL connection there is high impulse noise and the required INP is 8. As a result, if the service provider uses a first INP configuration of 2, the DSL connection will not be error free. Therefore, the service provider needs to configure a higher INP value and reinitialize the connection. If a value of 4 is used as a second INP value, it still will not provide adequate impulse noise protection and bit errors will occur. Again, the service provider will need to configure a higher INP value until the correct value of 8 is configured. Clearly, the connection needs to be re-initialized every time there is a new INP configuration chosen and this trial and error technique proves to be very time consuming.

Example 2: Assume that for a particular DSL connection there is high-impulse noise and the required INP is 4. As a result, if the service provider uses a first INP configuration of 2, the connection will not be error free. Therefore, the service provider needs to configure a higher INP value and reinitialize the connection. In order to save time and not go through the number of initializations has occurred in Example 1, the service provider simply configures the system to the maximum INP value of 32. Obviously, there will be no bit errors with INP=32 since this connection needs only an INP value of 4. As a result, user data throughput is greatly degraded since the additional FEC redundancy will be three times higher than what is actually needed. For example, if the INP of 4 requires 10 percent FEC redundancy, an INP of 32 requires 40 percent FEC redundancy which results in a 30 percent decrease in user data rate.

SUMMARY

In addition to the above drawbacks, the related systems do not have the ability to actually measure the length or repetition period of impulse noise which can both be used to determine an appropriate impulse noise protection setting.

Exemplary aspects of this invention relate to determining the impact of impulse noise on a communication system and the capability to determine how the system should be configured to handle the impulse noise event.

An exemplary aspect of this invention determines the impact of impulse noise by transmitting and receiving using a plurality of different FEC and interleaving parameter settings. For each FEC and Interleaving Parameter (FIP) setting, the received signal quality is determined by, for example, detecting if there are bit errors after the receiver performs the FEC decoding and deinterleaving. Based on this, the appropriate FIP setting is selected and used for transmission and reception.

A plurality of FIP settings can be used for transmission and reception. In accordance with one particular aspect of this invention, the system can transition from one FIP setting to another FIP setting without going through the startup initialization procedure such as the startup initialization sequence utilized in traditional xDSL systems. For example, an xDSL system that implements the systems and methods described herein could start using an FIP setting of (N=255, K=247, R=8, D=64) and then transition to an FIP setting of (N=255, K=239, R=16, D=64) without re-executing the startup initialization procedure.

Knowing that the first FIP setting has a BECC=256 bytes and the second setting has a BECC=512 bytes, means, for example, that the second setting can correct an impulse that causes twice as many bit errors as the first FIP setting. On the other hand, the first FIP setting has less FEC parity (overhead) which results in a higher information (net) data rate for the user during Showtime. This is also illustrated by

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the fact that K, the number of information bytes per code word, is higher for the first FIP setting. For each of the FIP settings, the receiver detects whether there are bit errors after the decoding and deinterleaving process. This detection can be done by, for example, by performing a cyclic redundancy check (CRC) after the decoding and deinterleaving process is complete as defined in the ITU standard G.992.x. In general, the CRC is a well-known method for detecting bit errors. Since impulse noise occurs at random times, this system can operate using a particular FIP setting for a period of time that is sufficient to encounter the impulse noise. In the simple example illustrated above, only the K and R values were modified. It should be appreciated however, that the systems and methods of this invention are not limited thereto but rather can be extended to include the modification of any one or more FIP parameter(s).

The process of determining the impact of impulse noise by transmitting and receiving using a plurality of FIP settings can be done while in steady-state transmission, i.e., Showtime for DSL systems, when user information bits are being transmitted.

The process of determining the impact of impulse noise by transmitting and receiving using a plurality of FIP settings, can be done during a special impulse noise training period during which the system is not actually transmitting user data. In accordance with this exemplary aspect of the invention, the standard xDSL procedure is modified to include the capability of measuring the effectiveness of a chosen impulse noise protection (INP) setting during initialization and having receiver-controlled updates of transmission parameters that control the INP setting, e.g., FEC parameters and interleaving parameters, during initialization.

A new initialization state is included in the xDSL initialization procedure that provides the capability to measure the effectiveness of the current INP settings. The new initialization state will be referred to as the INPTraining state and it can, for example, follow the exchange of the Showtime transmission parameters such as the bi/gi table, trellis coding, tone reordering, FEC/interleaving parameters, etc. It is important to note that steady-state transmission during which user information is transmitted is known as "Showtime" in xDSL systems and that standard ITU G.992.3 ADSL systems and ITU VDSL G.993.3 systems include an exchange phase in initialization during which the Showtime parameters are exchanged, see, for example, G.992.3 and G.993.1.

During this INPTraining state, the transceivers transmit and receive using at least one of the standard Showtime functions using the Showtime parameters, e.g., bi/gi table, FEC/interleaving parameters, etc., that are exchanged during the previous exchange phase. These functions include at least one of Showtime PMD functions, e.g., bi/gi table, trellis coding, tone reordering, etc., PMS-TC functions, such as framing and FEC/interleaving, and TPS-TC functions. During the INPTraining state, the TPS-TC can transmit idle ATM cells, HDLC flags, or 64/65 idle packets depending on the TPS-TC type.

At the receiver, the CRC, the FEC, the TPS-TC error detection capabilities, and other receiver functions can be used to determine whether the INP setting is adequate for the current impulse noise conditions on the line. The receiver can also use these receiver functions to automatically and dynamically determine what the correct INP setting should be. If the current INP setting is not adequate, a new set of Showtime transmission parameters can be exchanged and the process repeated by reentering the INPTraining state

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using the newly exchanged Showtime transmission parameters. If, on the other hand, the current INP setting is adequate, the transceivers can enter into Showtime.

An exemplary advantage associated with this aspect of the invention is that the receiver can measure the effectiveness of the current INP setting and can make updates to the INP setting based on these measurements during initialization. This is important because the receiver generally has the most knowledge of channel conditions, receiver functionality, and processing capability. In general, the receiver has the best capability to make the necessary trade offs between data rate, latency, excess margin, FEC redundancy, coding gain, and the like. Current related ADSL systems have the operator servicing lines that are experiencing high impulse noise by trying various INP settings in an attempt to find an error-free operating mode. However, since the operator is not capable of making the receiver trade offs stated above, such as the data rate, latency, and the like, the process will often lead to a sub-optimum result.

Another exemplary aspect of this invention relates to determining the length and/or repetition period of impulse noise events in order to select an appropriate INP setting.

For example, the transceivers can transmit and receive using at least one of the standard Showtime functions and parameters such as the bi/gi table, FEC/interleaving parameters, and the like. These functions include the Showtime PMD functions, such as the bi/gi table, trellis coding, tone reordering and the like, PMS-TC functions (such as framing and FEC interleaving) and TPS-TC functions. The TPS-TC may transmit ATM cells, HDLC packets, or 64/65 packets depending on, for example, the TPS-TC type.

At the receiver, the CRC, the FEC, the TPS-TC error detection capabilities, and other receiver functions can be used to determine the length and the period of the impulse noise and whether an INP setting is adequate for the current impulse noise conditions on the line.

For example, the receiver can determine the length of an impulse noise event. The length of impulse noise events can be determined in a number of ways. For example, they can be determined as:

1. The length of the impulse in time, e.g., how many microseconds the impulse power is above a specific noise level (e.g. the above the stationary channel noise)
2. The number received bits that are affected by the impulse noise, e.g. how many received bits are in error in a specific sliding time window or how many consecutive bits are in error in a stream
3. The number of received ATM cells that are affected by the impulse noise, e.g. how many ATM cells contain bits that are in error. This may be detected using a standard ATM HEC, which is a CRC that covers the ATM header bits. Alternatively this may be detected by checking the ATM payload bits by, for example, transmitting a predefined bit pattern that is known by the receiver
4. The number of 64/65 packets that are affected by the impulse noise, e.g. how many packets contain bits that are in error (the 64/65 CRC can be used for this)
5. The number of received DMT symbols that are affected by the impulse noise, e.g., the measured noise in a DMT symbol is above a predefined threshold which results in most (if not all) the bits in that DMT symbol being in error
6. The number of FEC codewords that are affected by the impulse noise, e.g., how many codewords have an uncorrectable number of bit errors, i.e., the number of

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bit errors in a codeword exceeds the number of bit that are correctable by the FEC code

In accordance with one exemplary aspect, the FEC correction capability and interleaving is turned off when trying to determine the length of the impulse noise. For example, the FEC may be configured so that there are no parity bits (i.e., $R=0$) or the FEC may be disabled altogether (i.e., no codewords are sent). Additionally, for example, the interleaving may be disabled by setting the interleaver depth to 1 (i.e., $D=1$). Disabling the FEC and interleaving is beneficial when trying to determine the length of the impulse noise based on affected bits, affected code words and/or affected packets. This is true since when the FEC/interleaving is enabled, the impulse noise event will be spread over a large time period and it will be more difficult to determine the length of the original impulse.

The exemplary techniques discussed herein that are used to determine the length of the impulse event can also be extended to determining the repetition period of the impulse noise event, i.e., how often is impulse noise occurring. The repetition period can be important, because the period has an effect on the FIP setting that is used. For example, if the interleaving spreads an impulse noise event over a period of time that exceeds the impulse period, then the interleaver could combine multiple impulse noise events together. As a result, the FEC correction capability may have to be increased. In order to determine the repetition period of an impulse noise event, the receiver can first detect the impulse noise event as discussed above and then determine how often the impulse noise events occur. For example, periodic impulse noise due to AC power lines occurs at a 120 Hz reception rate, or approximately every 8 ms.

In the case where the impulse noise does not have a fixed length, i.e., where the impulse noise varies over time, the receiver can attempt to determine the maximum impulse noise length. This involves measuring several impulse noise events and determining the impulse noise event with the maximum length. In practice, it is likely that the impulse noise will have varying length and it is important that the FEC/interleaving settings be configured to handle the maximum, e.g., worst case, impulse noise event.

Once the receiver determines the (maximum) length of the impulse noise and/or the repetition period of the impulse noise, this information can be sent to the transmitting modem. In particular, when the receiving modem, such as a Customer-Premises (CPE) modem determines the (maximum) length of the impulse and/or the repetition period of the impulse, the CPE modem could send the information to a Central Office (CO) modem in a message. The length of the impulse length event can be defined and specified in the message in terms of time, received bits, ATM cells, 64/65 packets, DMT symbols, or the like. The CO modem could then, for example, provide this information to the CO-MIB, which is the management interface that is used by the operator or service provider to configure the modems. For example, based on this information, the operator may configure the modems to a different INP value, data rate, latency, or the like. This process could also be automated such that the message received by the CO modem allows automatic reconfiguration to adjust, for example, INP values, data rate, latency, or the like.

The exemplary aspects of the invention that are used to determine the length and/or repetition period of the impulse noise event can be performed during initialization and/or Showtime. During initialization, the method can perform during an INP Training state such as the one described

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herein. During Showtime the method can be performed, for example, during a Showtime INP adaptation phase as described herein.

These and other features and advantages of this invention are described in, or are apparent from, the following description of the embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of this invention will be described in relation to the figures, wherein:

FIG. 1 is a functional block diagram illustrating an exemplary impulse noise adaptation system according to this invention;

FIG. 2 illustrates an exemplary initialization state machine that includes an INP training state according to this invention;

FIG. 3 is a flowchart outlining an exemplary method for impulse noise protection adaptation during Showtime according to this invention;

FIG. 4 is a flowchart illustrating an exemplary receiver optimized method for impulse noise protection adaptation according to this invention;

FIG. 5 is a flowchart illustrating an exemplary method for forward error correction synchronization according to this invention;

FIG. 6 is a flowchart illustrating an exemplary method for flag signal synchronization according to this invention; and

FIG. 7 is a flowchart illustrating an exemplary method for determining impulse noise length and period according to this invention.

DETAILED DESCRIPTION

The exemplary embodiments of this invention will be described in relation to adapting impulse noise parameters as well as measuring impulse noise length and repetition period within an xDSL environment. However, it should be appreciated that, in general, the systems and methods of this invention can be applied and will work equally well with any type of communication system in any environment.

The exemplary systems and methods of this invention will be described in relation to xDSL modems and associated communication hardware, software, and communication channels. However, to avoid unnecessarily obscuring the present invention, the following description omits well-known structures and devices that may be shown in block diagram form or otherwise summarized.

For purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the present invention. It should be appreciated however, that the present invention may be practiced in a variety of ways beyond the specific details set forth herein. For example, the systems and methods of this invention can generally be applied to any type of system within any environment in which the impulse noise length and/or period is desired, or for which impulse noise adaptation is desired.

Furthermore, while the exemplary embodiments illustrated herein show the various components of the system collocated in specific locations, it is to be appreciated that the various components of the system can be located or relocated at distant portions of a distributed network, such as a telecommunications network and/or the Internet, or within a dedicated secure, unsecured and/or encrypted system. Thus, it should be appreciated that the components of the system can be combined into one or more devices, such as a modem, or collocated on a particular node of a distributed

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network, such as a telecommunications network. As will be appreciated from the following description, and for reasons of computational efficiency, the components of the system can be arranged at any location within a distributed network without effecting the operation of the system. For example, the various components can be located in a central office (CO or ATU-C) modem, a customer premises modem (CPE or ATU-R), or some combination thereof. Similarly, the functionality of the system could be distributed between one or more of the modems and an associated computing device.

Furthermore, it should be appreciated that the various links, including communications link 20, connecting the elements can be wired or wireless links, or any combination thereof or any other known or later-developed element(s) that is capable of supplying and/or communicating data to and from the connected elements. The term module as used herein can refer to any known or later-developed hardware, software, or combination of hardware and software that is capable of performing the functionality associated with that element. Furthermore, as used herein, the term "transmitter" has the same meaning as the term "transmitting modem" or "transmitting transceiver" and the term "receiver" has the same meaning as "receiving modem" or "receiving transceiver."

FIG. 1 illustrates an exemplary embodiment of an impulse noise adaptation system 100 according to an exemplary embodiment of this invention. In particular, the system 100 comprises a receiving modem 200 and a transmitting modem 300. The exemplary receiving modem 200 comprises a decoder/deinterleaver 210, a bit error rate (BER) detection module 220, a forward error correction and interleaving parameter (FIP) module 230, an impulse noise length determination module 240, an impulse noise period determination module 250, an impulse noise parameter management module 260, an impulse noise protection adaptation module 270, a synchronization module 280, a message module 290 and a controller and memory (not shown) all interconnected by a link 5. The exemplary transmitting modem 300 comprises a management module 310, a synchronization module 320, a message module 330, and may optionally include an impulse noise parameter management module 340.

In operation, the exemplary communication system adapts the impulse noise parameters on-line by operating using a series of different FIP settings. For each FIP setting, the system can dynamically determine if the appropriate amount of impulse noise protection is being provided. Based on these determinations, the system can select a particular FIP setting for regular, i.e., Showtime, operation. As will be discussed in greater detail hereinafter, this impulse noise protection adaptation can be performed during Showtime and/or during initialization.

Impulse noise protection adaptation during Showtime includes the following exemplary steps. First, the DSL system, i.e., the transmitting and receiving modems, completes regular initialization and commences transmission and reception using a first FIP setting. For DSL systems, this first FIP setting is selected by the receiver 200 and is based on the minimum/maximum data rate, maximum latency, and minimum INP parameters as configured by, for example, the service provider via the management module 310. A detailed explanation of this procedure can be seen in G.992.3.

The system will use this first FIP setting for a period of time T1. During this period, and in conjunction with the BER detection module 220, the receiver 200 detects if bit errors have occurred using this first FIP setting for the decoding and deinterleaving performed by the decoder/

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deinterleaver 210. For example, the receiver 200 can use a CRC to detect bit errors. If there are no bit errors, then the current INP setting is adequate and there is no need to modify the INP setting and Showtime communication can continue as normal.

However, if bit errors have been detected by the BER detection module 220, an adjustment to the INP setting may be appropriate. For example, a service provider, a user, or the system can choose an updated INP setting. Since bit errors have been detected, the INP setting could be increased by an on-line modification to the FIP parameters. Specifically, the transmitter 300, and for example the management module 310, in response to an indication from the receiver 200 that bit errors have been detected, can send a message to the receiver 200 to initiate a change in the INP settings. The receiver 200, in cooperation with the message module 290, the FIP module 230, the impulse noise parameter management module 260 and impulse noise protection adaptation module 270, can return a message to the transmitter 300 that specifies a newly determined FIP setting that satisfies the new INP requirement.

The transmitter 300 and receiver 200 can then transition to the new INP setting by starting to use the new FIP parameters for transmission and reception, respectively, at a synchronized point in time. This synchronization can be done in accordance with a number of exemplary methods that are discussed hereinafter.

Upon synchronization, the system 100 continues communication using the updated FIP settings for a second period of time T2. If the receiver detects that bit errors are occurring using this updated FIP setting during the decoding and deinterleaving performed by the decoder/deinterleaver 210 the steps can be repeated with the selection of another updated INP setting. However, if there are no bit errors detected by the receiver 200 during the time period T2, then the new INP setting is adequate and there is no need for further change at which point the INP adaptation procedure can end.

This Showtime-based INP adaptation process can be repeated as many times as necessary until an INP setting is obtained that provides the required impulse noise immunity and/or bit error rate.

One advantage of this technique is that the transition between different FIP settings can be accomplished without reinitializing the transceivers using the lengthy standard initialization procedure that is typically used in ADSL and VDSL systems. In contrast, the transition can occur without the standard initialization since the transition between FIP settings can be synchronized between the transmitter and the receiver such that the receiver 200 can determine when to start FEC decoding using the new FIP settings for K and R. As will be discussed hereinafter, this transition can be synchronized using a number of different exemplary methods.

The transition can also be accomplished without synchronization in which case the receiver 200 will determine when the new FIP settings are used by some alternative means. For example, the receiver could determine when the new FIP settings are being used by FEC decoding using both the old and updated FIP settings and determining which one is currently being utilized by the transmitter by determining with which FIP setting the codeword is correct. Other receiver functions such as CRCs, ATM HEC errors and the like could also be used.

This impulse noise protection adaptation procedure can be performed during regular steady-state transmission, i.e., Showtime in ADSL, using actual user data or, for example,

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idle ATM cells. This methodology can also be performed during a special impulse noise training period during which the system is not actually transmitting user data. For example, this impulse noise training period could utilize transmitted predefined pseudorandom bit streams or, for example, idle ATM cells or HDLC flags for determining an appropriate INP value.

The length of the time periods T1, T2, . . . can be controlled by, for example, the receiving modem 200. The receiving modem 200 could control the length of these time periods by, for example, sending a message that specifies how long the transmitter should transmit using a particular FIP setting. This length can be defined, for example, in terms of the number of DMT symbols or the number of FEC codewords. For example, a message could indicate that 200 DMT symbols should be sent for all FIP settings or 300 FEC code words should be sent for all FIP settings. Alternately, the message can indicate a different number of DMT symbols or FEC code words for each FIP setting. This technique could further be used to aid in determining an appropriate INP setting by forwarding a predetermined number of DMT symbols at a first FIP value, followed by a second number of DMT symbols at a second FIP value, and so on. For each of these sets of DMT symbols and associated FIP values, the receiver could determine the bit error rate, with the cooperation of the BER detection module 220, and then forward a message, with the cooperation of the message module 290, to the transmitter 300 specifying which FIP setting provided the appropriate impulse noise protection.

Similarly, the transmitting modem 300 and receiving modem 200 could cooperate such that an optimum impulse noise protection value is converged upon. For example, the transmitting modem 300, with the cooperation of the message module 330, could forward a message to the receiving modem 200 specifying a first INP setting. If there are no bit errors, a message could be sent via the message module 290 to the transmitting modem 300 indicating that there are no bit errors and a lower INP value could be attempted. The impulse noise parameter management module 260 and FIP module 230 could then determine an appropriate lower INP setting and forward it to the transmitter 300. As discussed above, since a lower INP value is inversely proportional to the user data rate, it is advantageous to optimize the INP value based on detected errors. The transmitting modem 300, in cooperation with the message module 330, could then send another message to the receiving modem 200 indicating that the lower INP value will be transitioned to at which point the procedure repeats itself through detection of bit errors in cooperation with the bit error rate detection module 220 and the decoder/deinterleaver 210. This reduction in the INP parameters can continue until bit errors are detected at which point a message is sent, with the cooperation of the message module 290, to the transmitting modem 300 indicating a higher INP value is required since bit errors were detected. Then, for example, based on an evaluation of a convergence of bit errors vs. impulse noise protection parameters, an optimum INP value can be determined and transitioned to by the receiver 300 and transmitter 200. This procedure could also be used to increase the INP parameters in a similar fashion.

The length of the time periods T1, T2, . . . can also be controlled by the transmitter 300. For example, the transmitter 300 could control the length of these time periods, by, for example, sending a message to the receiver 200 that specifies the length of time the transmitter will transmit using a particular FIP setting. This length could be defined in terms of the number of DMT symbols or, for example, the

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number of FEC codewords. The exemplary message could indicate that, for example, 200 DMT symbols would be sent for all FIP settings or 300 FEC codewords will be sent for all FIP settings. The message could also indicate a different number of DMT symbols or FEC codewords for each FIP setting. In general, the message could contain any type of information relating to how long the transmitter will be using a specific FIP setting(s).

The length of the time periods T1, T2 . . . can also be controlled by, for example, a service provider or a user. For example, the service provider could configure through the management module 310 a minimum time X=10 seconds to be used for testing each FIP setting. The service provider could use the knowledge of the nature of the impulse noise, such as how often impulse noise event occurs, to determine the times. However, in general, the length of the time periods could be configured to be any length of time as appropriate.

As discussed above, when a determination is made that there are bit errors and an increase in the INP setting is desirable, the receiving modem 200 can determine the new INP settings. However, it should be appreciated that the transmitting modem 300, in cooperation with the impulse noise parameter management module 340 could also determine updated INP settings. For example, either modem could continually adapt the INP values as discussed above until no bit errors that are the result of impulse noise are detected by the BER detection module 220.

As alluded to above, the receiver and transmitter can synchronize the modification of the FEC and interleaving parameters such that the both the transmitter and receiver start using the parameters at the same instant in time. This synchronization can be based on, for example, a synchronization using FEC codeword counters or a flag signal.

For synchronization using FEC codeword counters, the receiver 200 and transmitter 300 can synchronize the change in cooperation with the sync modules 280 and 320, by counting the FEC codewords from the beginning of Showtime and the transition would occur when a specific FEC codeword counter value that is known by both the transmitter 300 and the receiver 200 is reached. Prior to the transition point, the transmitter 300 or receiver 200 in cooperation with the message module 290 and message module 330, would send a message indicating the FEC codeword count value on which the FIP parameters will be updated. For example, the transmitting modem 300 can enter into Showtime and the synchronization module 320 commences counting the number of transmitted FEC codewords. For example, the first codeword transmitted has a count value of 0, the second transmitted codeword has a count value of 1 The counter can optionally be defined as having a finite length, for example, 0 to 1023 (10 bits) such that when the value of 1023 is reached, on the next FEC code word that is transmitted, the counter restarts at the value of 0.

Similarly, the receiving modem 200 upon entering Showtime starts a counter in cooperation with the synchronization module 280 that counts the number of received FEC codewords. The first received FEC codeword has a count value of 0, the second received FEC codeword to the count value of 1 As with the synchronization module 320, the synchronization module 280 can have a counter with a finite length, for example 0-1023, such that when the value of 1023 is reached, on the next FEC codeword the counter restarts at 0.

At some point, for example, based on detected bit errors, the user, a service provider, or the like, it is determined that an updated FIP setting is needed. The receiving modem 200

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can send a message, via the message module 290, to the transmitting modem 300, and in particular the message module 330 and impulse noise parameter management module 340. The updated FIP setting can alternatively be sent from the transmitting modem to the receiving modem.

The synchronization module 280 and message module 290 then cooperate to send a message to the transmitting modem 300 specifying the FEC codeword counter value on which the new FIP settings are to be used for transmission and reception. Alternatively, the transmitting modem, in cooperation with the message module 330, can send a message to the receiving modem indicating the FEC codeword counter value on which the FIP settings are to be used for transmission and reception. For example, the message can indicate that when the code word counter equals 501, the new FIP setting will be used for transmission and reception.

When the transmitter FEC codeword counter equals the value indicated in the message, the synchronization module 220 instructs the transmitting modem 300 to transition to the new FIP settings. Similarly, when the synchronization module 280 in the receiving modem 200 counts the FEC codeword that equals the value indicated in the message, the receiving modem 200 transitions to using the new FIP settings for reception.

Synchronization can also be performed through the use of a flag signal (sync flag). For this exemplary embodiment, the receiving modem 200 and transmitting modem 300, in cooperation with the synchronization module 280 and synchronization module 320, synchronize the change in FIP settings using a flag or marker signal that is similar to that used in the ADSL2 G.992.3 ORL protocol. This protocol may be more desirable than using an FEC codeword counter because, for example, it has greater impulse noise immunity.

For synchronization using a flag signal, the receiver and transmitter would start using updated FEC and interleaving parameters on a pre-defined FEC codeword boundary following the sync flag. For example, while transmitting using a first INP setting, a determination is made by, for example, the BER detection module 220 that a new FIP setting is needed due to the presence of impulse noise on the line. This determination can be performed by the receiving modem, in cooperation with the FIP module 230, the transmitting modem, a user, a service provider, or the like. The receiving modem 200, in cooperation with the message module 290, sends a message to the transmitting modem 300 indicating the new FIP settings to be used for transmission and reception. Alternatively, the transmitting modem, in cooperation with the message module 330, prepares and sends a message to the receiving modem indicating the updated FIP settings to be used for transmission and reception.

The transmitting modem then sends a flag or marker signal to the receiving modem 200 indicating that the new FIP settings are to be used on a predetermined number of DMT symbols following the transmission of the flag or marker signal. For example, the flag signal could be an inverted sync symbol, or sync FLAG, as used in the ADSL2 G.992.3 ORL protocol. The transmitting modem 300 then starts using the new FIP settings for transmission on the predetermined number of DMT symbols following the transmission of the flag or marker signal. Similarly, the receiving modem starts using the new FIP settings for reception once the predetermined number of DMT symbols following the receipt of the flag or marker signal have been received.

EXAMPLE 1

On-Line INP Adaptation FIP Setting

This section describes an example of FIP settings for On-Line INP adaptation for DSL. In this example only the

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number of information bytes in a codeword (K) and the number of parity bytes in a codeword (R) are updated on-line. The Codeword Size (N) and Interleaver Depth (D) are not changed. This means that the latency (and interleaver memory size) and the line rate are not modified on-line. Since $N=K+R$ this places restrictions on the allowed values for K and R.

1st Setting—{Approximate User Data Rate=3.968 Mbps, Line Rate=4.096 Mbps, N=128, K=124, R=4, S=1, D=64, Latency=16 msec, INP=1}

2nd Setting—{Approximate User Data Rate=3.840 Mbps, Line Rate=4.096 Mbps, N=128, K=120, R=8, S=1, D=64, Latency=16 msec, INP=2}

3rd Setting—{Approximate User Data Rate=3.584 Mbps, Line Rate=4.096 Mbps, N=128, K=112, R=16, S=1, D=64, Latency=16 msec, INP=4}

The On-line INP adaptation process is restricted to only modify the number of information bytes in a codeword (K) and the number of parity bytes in a codeword (R). The FEC Codeword Size ($N=K+R$) and Interleaver Depth (D) are not changed. This means that the latency (or interleaver memory size) and the line rate are not modified on-line. However the user data rate will change during the process since K is being modified. Also since the line rate and the FEC codeword size are not modified, the S value does not change in the process. It is important to note that with these constraints, the On-line INP adaptation process can be done in as seamless manner (no bit errors and service interruption). This means provided that the modification if the FIP setting is restricted to K and R, the transition between FIP settings can be done in a seamless manner. This is the case because if the codeword size N and the interleaver depth D are not modified, the transition can happen without the problem of "interleaving memory flushing." Interleaver memory flushing is a well-known problem in which errors occur because interleaver and deinterleaver memory locations are overwritten due to on-line changes in the codeword size (N) and or interleaver depth (D).

EXAMPLE 2

On-Line INP Adaptation FIP Setting

This section describes an example of FIP settings for On-Line INP adaptation for DSL. In this example only the Codeword Size (N) and the number of parity bytes in a codeword (R) are updated on line. The number of information bytes in a codeword (K) and Interleaver Depth (D) are not changed and therefore the user data rate does not change. This means that the latency (and interleaver memory size) and the line rate are modified on-line. Since $N=K+R$ this places restrictions on the allowed values for K and R.

1st Setting—{Approximate User Data Rate=3.968 Mbps, Line Rate=4.096 Mbps, N=128, K=124, R=4, S=1, D=64, Latency=16 msec, INP=1}

2nd Setting—{Approximate User Data Rate=3.968 Mbps, Line Rate=4.224 Mbps, N=132, K=124, R=8, S=1, D=64, Latency=16 msec, INP=2}

3rd Setting—{Approximate User Data Rate=3.968 Mbps, Line Rate=4.480 Mbps, N=128, K=124, R=16, S=1, D=64, Latency=16 msec, INP=4}

In this example the Line Rate is modified on-line. For this reason it is necessary to also complete a rate adaptation process in order to complete this On-Line INP adaptation. A method for Seamless Rate Adaptation is described in U.S. Pat. No. 6,498,808.

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While these examples restrict the changes to a subset of the FIP parameters, they can obviously be extended to cover any combination of the FIP parameters (N, K, R and D). For example, the value of D could also be modified in addition to the values of K, R and N. This could result in a change in the required interleaver memory and latency. In order to keep the memory and latency constant it is necessary to change the codeword size (N) accordingly when changing the interleaver depth (D). For example, if the interleaver depths is changed from D=64 to D=128, the Codeword size would have to be decreased by a factor of 2 so that overall latency is constant.

FIG. 2 illustrates an exemplary modified initialization state machine that includes the INPTraining state prior to Showtime. This state machine is based on the VDSL G.993.1 ITU standard. As defined in G.993.1, VTU-O is the VDSL Transceiver Unit at the Optical Network Unit (ONU) and VTU-R is the VDSL Transceiver Unit at the Remote terminal. The Initialization state machine in FIG. 2 is an example of how INPTraining states could be included in a modified VDSL initialization procedure. While exemplary FIG. 1 includes the INPTraining state at a specific time in the initialization sequence, the INPTraining state can be included at any time during initialization provided that it is preceded by a state during which Showtime parameters are exchanged between the transceivers.

O-P-INPTrain

During the O-P-INPTrain State the VTU-O transmitter transmits DMT Symbols using the standard PMD, PMS-TC and TPS-TC SHOWTIME functions with parameters exchanged during the previous Exchange Phase. During this state, the TPS-TC transmits idle ATM cells, HDLC flags or 64/65 idle packets. SOC is inactive during this state.

This state is used by the VTU-R to determine the correct DS INP setting based on Impulse Noise conditions on the line. For example, the downstream CRC, FEC error detection, TPS-TC error detection capabilities, and other receiver functions can be used to determine whether the INP setting is adequate. The receiver can also use these receiver functions to determine the correct INP setting.

If the VTU-R determines that the current INP setting is not adequate, the VTU-R transmits the R-P-ISYNCHRO2 signal to indicate the need to transition back to the Exchange Phase in order to exchange new transmission parameters.

If the VTU-R determines that the current INP setting is not adequate, the VTU-R transmits the R-P-SYNCHRO2 signal to indicate that it is OK to transition to Showtime with the current transmission parameters.

R-P-INPTrain

During the R-P-INPTrain State the VTU-R transmitter transmits DMT Symbols using the standard PMD, PMS-TC and TPS-TC Showtime functions with parameters exchanged during the previous Exchange Phase. During this state, the TPS-TC transmits idle ATM cells, HDLS flags or 64/65 idle packets. SOC is inactive during this state.

This state is used by the VTU-O to determine the correct US INP setting based on Impulse Noise conditions on the line. For example, the upstream (US) CRC, FEC error detection, TPS-TC error detection capabilities, and other receiver functions can be used to determine whether the INP setting is adequate. The receiver can also use these receiver functions to determine the correct INP setting.

If the VTU-O determines that the current INP setting is not adequate, the VTU-O transmits the O-P-ISYNCHRO2 signal to indicate the need to transition back to the Exchange Phase in order to exchange new transmission parameters.

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If the VTU-O determines that the current INP setting is not adequate, the VTU-O transmits the O-P-SYNCHRO2 signal to indicate that it is OK to transition to Showtime with the current transmission parameters.

O-P-SYNCHRO2

The O-P-SYNCHRO2 is the same as defined in the current VDSL1. As in VDSL1, the VTU-O transmitter enters Showtime after transmitting the O-P-SYNCHRO2 signal.

But, if the VTU-R has not also entered into Showtime, the VTU-O waits for receipt of the R-P-SYNCHRO2 or R-P-ISYNCHRO2. If the VTU-O receives the R-P-SYNCHRO2 it continues in Showtime. If the VTU-O receives the R-P-ISYNCHRO2, the VTU-O transmitter transitions back to the beginning of the O-P-MEDLEY state.

R-P-SYNCHRO2

The O-P-SYNCHRO2 is the same as defined in the current VDSL1. As in VDSL1, the VTU-R transmitter enters Showtime after transmitting the R-P-SYNCHRO2 signal.

But, if the VTU-O has not also entered into Showtime, the VTU-R waits for receipt of the O-P-SYNCHRO2 or O-P-ISYNCHRO2. If the VTU-R receives the O-P-SYNCHRO2 it continues in Showtime. If the VTU-R receives the O-P-ISYNCHRO2, the VTU-R transmitter transitions back to the beginning of the R-P-MEDLEY state.

O-P-ISYNCHRO2

The O-P-ISYNCHRO2 is phase-inverted version of the O-P-SYNCHRO2, i.e., a subcarrier-by-subcarrier 180 degrees phase reversal. The VTU-O transmitter transitions to the beginning of the O-P-MEDLEY state after transmitting the O-P-ISYNCHRO2 signal.

R-P-ISYNCHRO2

The R-P-ISYNCHRO2 is phase-inverted version of the R-P-SYNCHRO2, i.e., a subcarrier-by-subcarrier 180 degrees phase reversal. The VTU-R transmitter transitions to the beginning of the R-P-MEDLEY state after transmitting the R-P-ISYNCHRO2 signal.

Exemplary Overview State Transition Rules Based on SYNCHRO2 and the ISYNCHRO2 signals:

If either the VTU-O or the VTU-R transmits the ISYNCHRO2 signal then both VTU-R and VTU-O transition back to beginning of the MEDLEY state.

If both the VTU-O and the VTU-R transmit the SYNCHRO2 signal then both the VTU-R and the VTU-O transition into Showtime.

There are several important points regarding this exemplary embodiment. First, the receiver can measure the efficiency of the plurality of INP settings without completing a new initialization procedure such as is used in ADSL and VDSL systems. Second, the length of the time of the O-P-INPTrain and R-P-INPTrain states can be controlled by the VTU-R and VTU-O respectively. In this way the receivers have adequate time to determine if the current INP setting is correct. In order to accomplish this, prior to entering the R-P-INPTrain state, the VTU-O can transmit a message to the VTU-R indicating the minimum length of the R-P-INPTrain state. Likewise, prior to entering the O-P-INPTrain state, the VTU-R can transmit a message to the VTU-O indicating the minimum length of the O-P-INPTrain state. For example, the message could indicate that a minimum of 20000 DMT symbols should be sent during the O-P-INPTrain state. Additionally, the length of the time of the O-P-INPTrain and R-P-INPTrain states could be set by the DSL service provider in order to make sure that the initialization does not take too long or because the service provider may have some knowledge of the statistics of the impulse noise which require setting the length of the INP-Train states. In this exemplary case a message could be sent

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from the VTU-O to the VTU-R indicating the minimum and/or maximum length of the O-P-INPTrain and/or the R-P-INPTrain states. For example, the message could indicate that a minimum of 20000 DMT symbols should be sent during the R-P-INPTrain state. Also, for example, the message could indicate that a maximum of 40000 DMT symbols should be sent during the R-P-INPTrain state.

The length of the time of the O-P-INPTrain and R-P-INPTrain states could also be controlled by the VTU-O and VTU-R respectively. In this case, the transmitters will have control of the state lengths. In order to accomplish this, prior to entering the R-P-INPTrain state, the VTU-R can transmit a message to the VTU-O indicating the minimum length of the R-P-INPTrain state. Likewise, prior to entering the O-P-INPTrain state, the VTU-O can transmit a message to the VTU-R indicating the minimum length of the O-P-INPTrain state. For example, the message could indicate that a minimum of 20000 DMT symbols should be sent during the O-P-INPTrain state.

As discussed above, another exemplary aspect of this invention relates to determining the length and/or repetition period of impulse noise events in order to select an appropriate INP setting.

The INP length can be determined using any one of a plurality of metrics. For example, the INP length can be determined based on one or more of:

- 1) The length of the impulse in time
- 2) The number of received bits that are affected by the impulse noise
- 3) The number of received ATM cells that are affected by the impulse noise
- 4) The number of 64/65 packets that are affected by the impulse noise
- 5) The number of received DMT symbols that are affected by the impulse noise
- 6) The number of FEC codewords that are affected by the impulse noise

As an example, assume that length of the impulse noise is 700 microseconds (Example 1). At a data rate of 1 Mbps this could correspond to an impulse noise length of 700 bits (Example 2) assuming that all impulse noise was high enough to affect all 700 bits in the 700 microsecond period. This also could correspond to a impulse noise length of $700/(53*8)=1.65$ ATM cells since there are 53 bytes in a ATM cell (Example 3). This also could correspond to an impulse noise length of $700/(65*8)=1.35$ 64/65 packets since there are 65 bytes in a 64/65 packet (Example 4). This also could correspond to an impulse noise length of $700/(250)=2.8$ DMT symbols (INP=2.8) assuming the DMT symbol rate is 4 kHz (250 microseconds DMT symbol length) (Example 5).

As an example, the determination of the INP length with the number of received bits that are affected by impulse noise can be performed in accordance with the following procedure. Initially, the transmitting modem 300 transmits data using at least one of the Showtime functions. In accordance with a first exemplary embodiment, at least the bit allocation table is used. In addition, or alternatively, the trellis coder, framer, and TPS-TC functions may also be used. Additionally, or alternatively still, the interleaving and FEC may also be used.

The receiving modem 200 receives data using at least one of the Showtime functions, such as the bit allocation table as discussed above. Similarly, the trellis coder, framer, TPS-TC and/or interleaving and FEC can be used.

The transmitter 300 then transmits a predefined bit pattern that is used for determining or measuring the impulse noise

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length based on detected erroneous bits. The receiving modem 200 compares, with the assistance of the impulse noise length determination module 240, the predefined bit pattern to the received bit pattern in order to detect bit errors. Since impulse noise events typically cause a burst of errors in a bit stream, the receiving modem 200 determines the length of the impulse noise event by detecting and determining the length of the error burst.

Once the receiver 200 determines the length of the impulse noise, the receiving modem 200, in cooperation with the message module 290, sends a message to the transmitter 300 that indicates the determined length of the impulse noise.

In accordance with an exemplary embodiment, the FEC correction capability and interleaving is turned off when trying to determine the length of the impulse noise, e.g., $R=0$ and $D=1$. Disabling the FEC and interleaving is beneficial when trying to determine the length of the impulse noise based on affected bits, affected code words, or affected packets. This is the case because if the FEC/interleaving is enabled, the impulse event can be spread over a large time period which makes it more difficult to determine the length of the original impulse.

The exemplary methodology discussed above can also be used to determine the length of the impulse event using other metrics. For example, a predefined bit pattern could be used in the payload of the ATM cells or the 64/65 packets. Idle packets or cells, which carry a predefined pattern, could also be used. In these cases, the receiver would compare the received data to the predefined data to determine the length of the impulse or to determine if an INP setting is adequate. Alternatively, the CRC of the ATM cell or 64/65 packet could be used to determine the length of the impulse noise. This would provide a coarser measurement of the impulse noise length since it would be an integer number of packets or cells. In this example, a 700 bit impulse would cause CRC errors in two ATM cells so the length of the impulse noise would be two ATM cells, as opposed to the more precise measurement of 1.64 above. Likewise, in this example, a 700 bit impulse would cause CRC errors in two 64/65 packets so the length of the impulse noise would be two packets, as opposed to the more precise measure of 1.35 above.

Likewise, a predefined bit pattern could also be used to modulate the carriers in the DMT symbols so that the receiver would know what DMT symbols were transmitted. In this case, the receiver 200 would determine how many DMT symbols were corrupted by comparing the received signal with a known transmitted signal.

The exemplary techniques used to determine the length of the impulse noise event could also be extended to determine the repetition rate of the impulse noise event in cooperation with the impulse noise period determination module 250. In order to determine the repetition period of an impulse noise event, the receiver 200 detects the impulse noise event as discussed above and then determines how often they occur. For example, periodic impulse noise due to AC power lines occur at 120 Hz reception rates or approximately every 8 ms. The receiver 200 could, for example, also store information about past impulse noise events and compare detected impulse noise events to historical events. The impulse noise period determination module 250 could then determine which events of a similar duration are occurring at what interval. This information could then be used in determining an appropriate INP setting.

Once the receiver 200 determines the (maximum) length of the impulse and/or the repetition period of the impulse,

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the information, with the cooperation of the message module 290 can be sent to the transmitting modem. For example, when the receiving modem 200 determines the (maximum) length of the impulse and/or the repetition period of the impulse, the impulse noise period determination module 250, in cooperation with the message module 290 can forward information to the transmitting modem that quantifies this period. The transmitting modem 300 could provide this information to, for example, the management module 310, that would allow, for example, an operator or service provider to configure the modems. For example, based on the period information contained in the message, the operator may configure the modems to different INP values, data rates, latency, or the like.

The receiver 200 could also test a specific INP setting by detecting how many received bits are errored in a specific time period. For example, if the specific INP setting enables the correction of 100 bits in an 8 msec. time period then the receiver 200 could detect how many bits are errored in a sliding 8 msec. window. If less than 100 bits are detected in error in the 8 ms sliding window, then the INP setting is adequate.

If more than 100 bits are detected in error in a sliding window, then the INP setting is not adequate, and the FEC/interleaving needs to be changed to provide more error correction capability.

Likewise, instead of using the received number of bits that are effected by the impulse noise, the receiver could test a specific INP setting by detecting how many received ATM cells, 64/65 packets, DMT symbols, and/or FEC corrections are affected in a specific time period.

FIG. 3 outlines an exemplary method for performing impulse noise protection adaptation during Showtime according to this invention. In particular, control begins in step S300 and continues to step S310. In step S310, traditional DSL initialization occurs. Next, in step S320, Showtime is entered between the two modems using the first FIP setting that was determined during the initialization in step S310. Then, in step S330, a determination is made whether bit errors are occurring using the first FIP setting. If bit errors are not occurring, control continues to step S340 where the control sequence ends. Otherwise, control jumps to step S350.

In step S350, a determination is made that an increase of the INP setting is required that requires modification of the FIP parameters. Next, in step S360, updated INP parameter is determined and a message forwarded to the receiver specifying the new INP setting. Then, in step S370, the receiver forwards to the transmitter updated FIP parameters for the new impulse noise protection requirements. Control then continues to step S380.

In step S380, the transmitter and receiver transition to using the updated INP parameters at a synchronization point. Next, in step S390 Showtime operation continues. Control then continues back to step S330.

FIG. 4 outlines an exemplary method for receiver optimized impulse noise protection adaptation during Showtime. In particular, control begins in step S400 and continues to step S410. In step S410, the DSL system completes regular initialization. In particular, control begins in step S400 and continues to step S410. In step S410, the DSL system completes startup initialization and continues into Showtime in step S420 using a first FIP setting. Control then continues to step S430 where a determination is made whether bit errors are occurring using the first FIP setting. If bit errors are not occurring, control continues to step S440 where the control sequence ends.

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Otherwise, control jumps to step S450 where the receiver increases the impulse noise protection by modifying the FIP parameters. Next, in step S460, a synchronization point is determined between the transmitter and receiver, and when the synchronization point is reached both the transmitter and the receiver transition to the updated FIP setting in step S470 and Showtime communications continue and control returns back to step S430.

FIG. 5 illustrates an exemplary method for synchronization of the modified FEC and interleaving parameters according to this invention. In particular, control begins in step S500 and continues to step S510. In step S510, the transmitter enters Showtime and counts the number of transmitted FEC codewords. Next, in step S520, the receiver enters Showtime and counts the number of received FEC codewords. Then, in step S530, after a determination is made that an updated FIP setting is needed, the receiving modem sends a message to the transmitting modem indicating a new FIP setting that is to be used for transmitting and reception or, alternatively, the transmitting modem sends a message to the receiving modem indicating the new FIP setting to be used for transmission and reception. Control then continues to step S540.

In step S540, a message with the FEC codeword counter value on which the new FIP values are to be used is exchanged. Next, in step S550, a determination is made whether the counter value has been reached at the transmitter. If the counter value has not been reached, the next codeword is counted in step S560 and control continues back to step S550.

Otherwise, if the counter value has been reached, control jumps to step S570. In step S570, the transmitter transitions to the new FIP setting. Next, in step S580, a determination is made whether the counter value has been reached at the receiving modem. If the counter value has not been reached, the next received FEC codeword is counted in step S585 and control continues back to step S580. However, when the counter value has been reached in the receiving modem, control jumps to step S590 where the receiving modem switches to the new FIP value. Control then continues to step S595 where the modems continue Showtime communication and control continues to step S597 where the control sequence ends.

FIG. 6 illustrates an exemplary method of synchronization using a flag signal according to this invention. In particular, control begins in step S600 and continues to step S610. In step S610, the modems enter Showtime using the first FIP parameters. Next, in step S620, a message is exchanged indicating the new FIP settings. Then, in step S630, the transmitter forwards to the receiver a flag signal indicating when the new FIP settings are to be used.

At step S640, and at a predefined change time following the transmission of the flag signal, the transmitter begins transmission using the new FIP parameters. Next, at step S650, at the predefined change time following the reception of the flag signal, the receiver commences reception utilizing the new FIP parameters. Control then continues to step S660 where Showtime communication continues with the control sequence ending at step S670.

FIG. 7 illustrates an exemplary method of impulse noise length and period determination. In particular, control begins in step S700 and continues to step S710. In step S710, the transmitter transmits data using at least one Showtime function. Next, in step S720, the receiver receives data using at least one Showtime function. Then, in step S730, the transmitter transmits predefined information to the receiver. Control then continues to step S740.

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In step S740, the receiver receives the predefined information from the transmitter. Next, in step S750, the receiver compares the received predefined information to the predefined information and determines the differences (i.e., errors) between the two. Then, in step S760, and based on the detected errors, the length of the burst error is determined. Next, in step S770, a message is forwarded to the transmitter indicating the length of the impulse noise event. Control then continues to step S780 where a determination is made whether the period of the impulse noise event is also to be determined. If the period is not to be determined, control continues to step S790 where the control sequence ends. Otherwise, control jumps to step S800.

In step S800, and once the length of the impulse noise event is known, the receiver detects how often the impulse noise events occur. For example, historical information regarding the length and timing of previous impulse noise events can be stored in a memory (not shown). Then, a comparison can be made with the aid of a processor (not shown) to compare an impulse noise event to the historical information to determine the period of repetition (if any) of similar impulse noise events and, for example, a message indicating the period as well as the timing forwarded to, for example, another transceiver, the CO, or in general any destination as appropriate. Thus, in a similar manner, this information can be forwarded in step S810 to, for example, the transmitter in a message specifying the repetition frequency of the impulse noise event. Control then continues to step S820 where the control sequence ends.

The above-described system can be implemented on wired and/or wireless telecommunications device(s), such as a modem, a multicarrier modem, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a linecard, test equipment, a multicarrier transceiver, a wired and/or wireless wide/local area network system, a satellite communication system, a modem equipped with diagnostic capabilities, or the like, or on a separate programmed general purpose computer having a communications device.

Additionally, the systems, methods and protocols of this invention can be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element(s), an ASIC or other integrated circuit, a digital signal processor, a hard-wired electronic or logic circuit such as discrete element circuit, a programmable logic device such as PLD, PLA, FPGA, PAL, modem, transmitter/receiver, or the like. In general, any device capable of implementing a state machine that is in turn capable of implementing the methodology illustrated herein can be used to implement the various communication methods, protocols and techniques according to this invention.

Furthermore, the disclosed methods may be readily implemented in software using object or object-oriented software development environments that provide portable source code that can be used on a variety of computer or workstation platforms. Alternatively, the disclosed system may be implemented partially or fully in hardware using standard logic circuits or VLSI design. Whether software or hardware is used to implement the systems in accordance with this invention is dependent on the speed and/or efficiency requirements of the system, the particular function, and the particular software or hardware systems or microprocessor or microcomputer systems being utilized. The communication systems, methods and protocols illustrated herein however can be readily implemented in hardware and/or software, or any means, using any known or later developed systems or structures, devices and/or software by

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those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

Moreover, the disclosed methods may be readily implemented in software, that can be stored on a storage medium, and executed on programmed general-purpose computer, a special purpose computer, a microprocessor, or the like. In these instances, the systems and methods of this invention can be implemented as a program embedded on personal computer such as JAVA® or CGI script, as a resource residing on a server or computer workstation, as a routine embedded in a dedicated communication system or system component, or the like. The system can also be implemented by physically incorporating the system and/or method into a software and/or hardware system, such as the hardware and software systems of a communications transceiver.

It is therefore apparent that there has been provided, in accordance with the present invention, systems and methods for impulse noise adaptation. While this invention has been described in conjunction with a number of embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable arts. Accordingly, it is intended to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and scope of this invention.

The invention claimed is:

1. In a transceiver, a method of adapting an impulse noise protection capability during steady-state communication comprising:

receiving, during steady-state communication, using a first forward error correction and interleaving parameter (FIP) setting that comprises a forward error correction (FEC) codeword size and a first number of FEC coding parity bytes; and

switching, during the steady-state communication, to receiving using a second FIP setting that comprises a second FEC codeword size that is different than the first FEC codeword size and a second number of FEC coding parity bytes that is different than the first number of FEC coding parity bytes,

wherein the switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes is based on a counter reaching a value.

2. The method of claim 1, wherein the counter is a counter of FEC codewords.

3. The method of claim 1, wherein the switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes does not cause bit errors or service interruption.

4. The method of claim 1, wherein the switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes is associated with at least one of an impulse noise protection value, a data rate and a latency value.

5. The method of claim 1, wherein the switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes is associated with a service provider configuration.

6. The method of claim 1, wherein an interleaver depth does not change during the switching.

7. The method of claim 1, wherein a data rate and/or latency do not change when switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes.

8. A transceiver comprising:

a receiver operable to receiving, during steady-state communication, using a first forward error correction and

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interleaving parameter (FIP) setting that comprises a forward error correction (FEC) codeword size and a first number of FEC coding parity bytes; and

the receiver further operable to switch, during the steady-state communication, to receiving using a second FIP setting that comprises a second FEC codeword size that is different than the first FEC codeword size and a second number of FEC coding parity bytes that is different than the first number of FEC coding parity bytes,

wherein the switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes is based on a counter reaching a value.

9. The transceiver of claim 8, wherein the counter is a counter of FEC codewords.

10. The transceiver of claim 8, wherein the switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes does not cause bit errors or service interruption.

11. The transceiver of claim 8, wherein the switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes is associated with at least one of an impulse noise protection value, a data rate and a latency value.

12. The transceiver of claim 8, wherein the switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes is associated with a service provider configuration.

13. The transceiver of claim 8, wherein an interleaver depth does not change during the switching.

14. The transceiver of claim 8, wherein a data rate and/or latency do not change when switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes.

15. A transceiver comprising:

means for receiving, during steady-state communication, using first forward error correction and interleaving parameter (FIP) setting that comprises a forward error correction (FEC) codeword size and a first number of FEC coding parity bytes; and

means for switching, during the steady-state communication, to receiving using a second FIP setting that comprises a second FEC codeword size that is different than the first FEC codeword size and a second number of FEC coding parity bytes that is different than the first number of FEC coding parity bytes, wherein the switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes is based on a counter reaching a value.

16. The transceiver of claim 15, wherein the counter is a counter of FEC codewords.

17. The transceiver of claim 15, wherein the switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes does not cause bit errors or service interruption.

18. The transceiver of claim 15, wherein the switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes is associated with at least one of an impulse noise protection value, a data rate and a latency value.

19. The transceiver of claim 15, wherein the switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes is associated with a service provider configuration.

20. The transceiver of claim 15, wherein an interleaver depth does not change during the switching.

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21. The transceiver of claim 5, wherein a data rate and/or latency do not change when switching to receiving using the second FEC codeword size and the second number of FEC coding parity bytes.

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EXHIBIT 13



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(12) **United States Patent**
Tzannes

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(54) **TECHNIQUES FOR PACKET AND MESSAGE COMMUNICATION IN A MULTICARRIER TRANSCIEVER ENVIRONMENT**

(71) Applicant: **TQ DELTA, LLC**, Austin, TX (US)

(72) Inventor: **Marcos C. Tzannes**, Petaluma, CA (US)

(73) Assignee: **TQ DELTA, LLC**, Austin, TX (US)

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None
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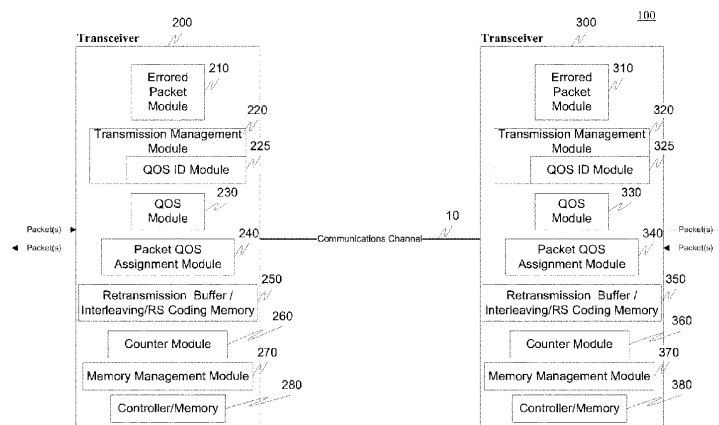
Primary Examiner — Justin R Knapp

(74) *Attorney, Agent, or Firm* — Jason H. Vick; Sheridan Ross, PC

(57) **ABSTRACT**

Through the identification of different packet-types, packets can be handled based on an assigned packet handling identifier. This identifier can, for example, enable forwarding of latency-sensitive packets without delay and allow error-sensitive packets to be stored for possible retransmission. In another embodiment, and optionally in conjunction with retransmission protocols including a packet handling identifier, a memory used for retransmission of packets can be shared with other transceiver functionality such as, coding, decoding, interleaving, deinterleaving, error correction, and the like.

28 Claims, 4 Drawing Sheets



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Related U.S. Application Data

continuation of application No. 14/742,334, filed on Jun. 17, 2015, now Pat. No. 9,749,235, which is a continuation of application No. 14/075,194, filed on Nov. 8, 2013, now Pat. No. 9,094,348, which is a continuation of application No. 12/760,728, filed on Apr. 15, 2010, now Pat. No. 8,595,577, which is a division of application No. 12/295,828, filed as application No. PCT/US2007/066522 on Apr. 12, 2007, now Pat. No. 8,335,956.

- (60) Provisional application No. 60/849,650, filed on Oct. 5, 2006, provisional application No. 60/792,236, filed on Apr. 12, 2006.

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U.S. Patent

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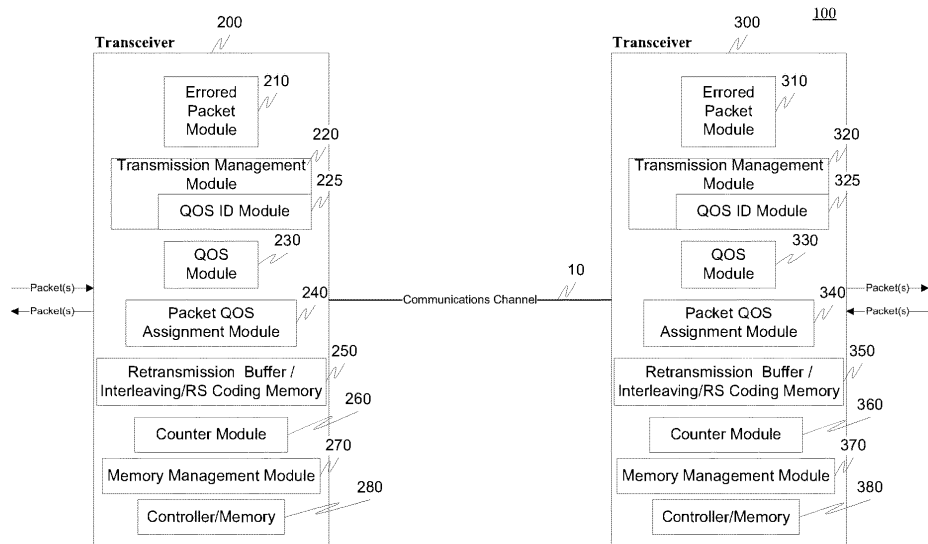


Fig. 1

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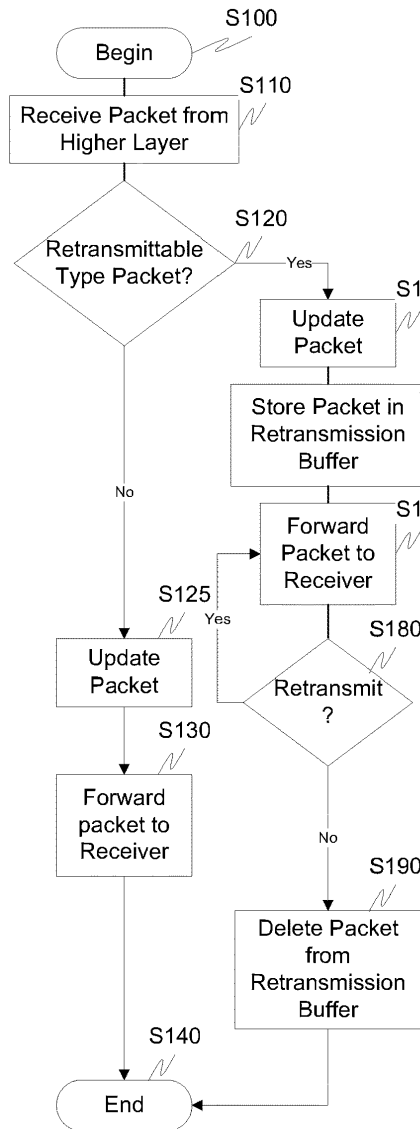


Fig. 2

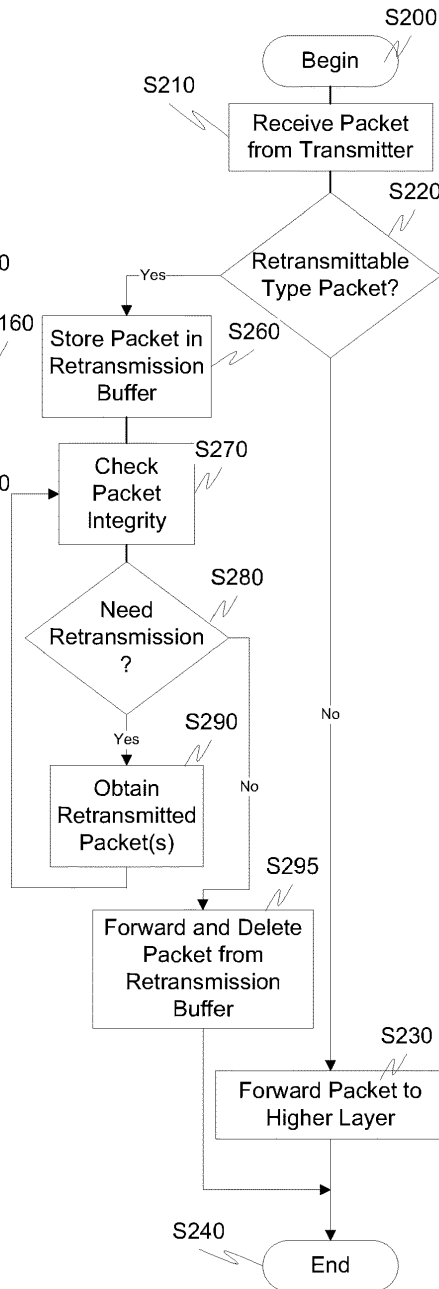


Fig. 3

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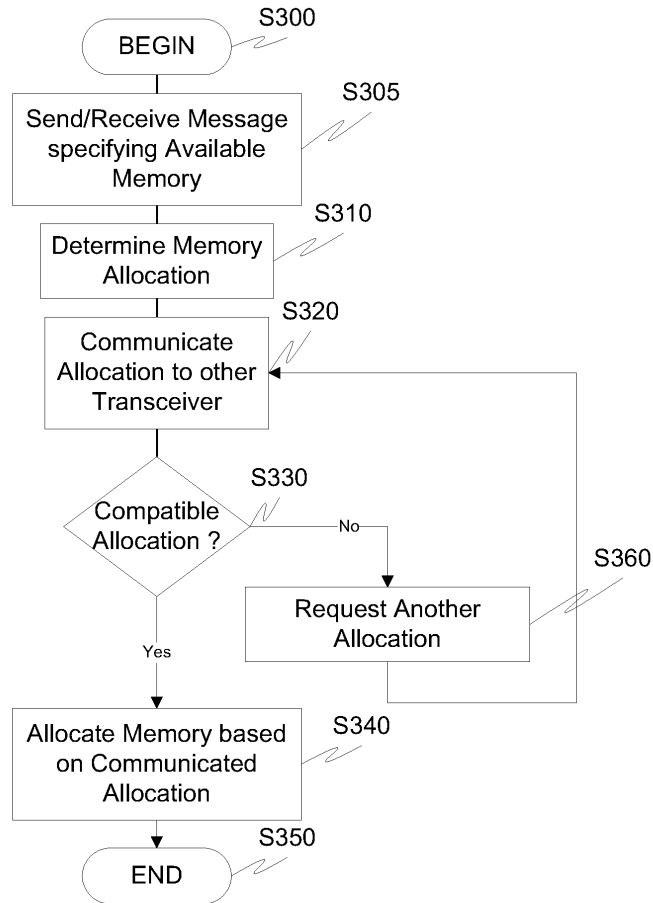


Fig. 4

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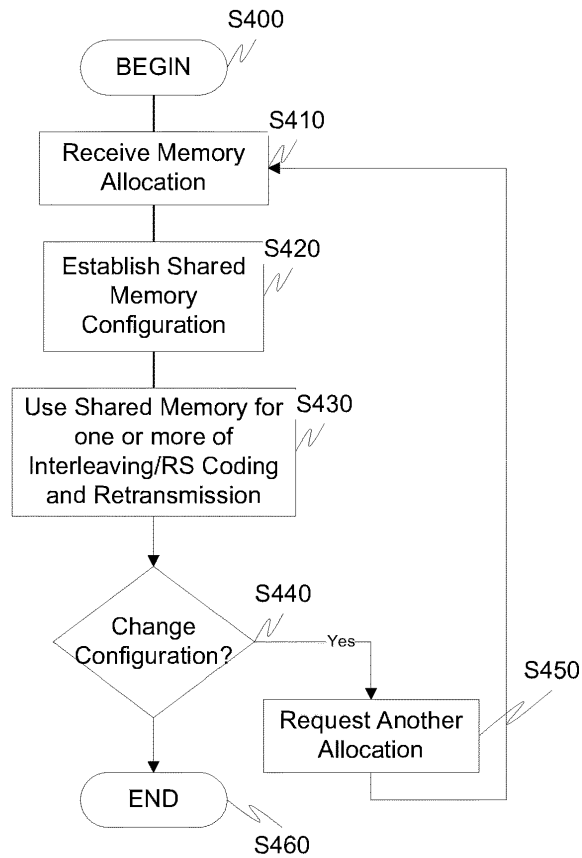


Fig. 5

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TECHNIQUES FOR PACKET AND MESSAGE COMMUNICATION IN A MULTICARRIER TRANSCIEVER ENVIRONMENT

RELATED APPLICATION DATA

This application is a Continuation of U.S. patent application Ser. No. 15/678,870, filed Aug. 16, 2017, now U.S. Pat. No. 10,498,495, which is a Continuation of U.S. patent application Ser. No. 14/742,334, filed Jun. 17, 2015, now U.S. Pat. No. 9,749,235, which is a Continuation of U.S. patent application Ser. No. 14/075,194, filed Nov. 8, 2013, now U.S. Pat. No. 9,094,348, which is a Continuation of U.S. patent application Ser. No. 12/760,728, filed Apr. 15, 2010, now U.S. Pat. No. 8,595,577, which is a Divisional of U.S. patent application Ser. No. 12/295,828, filed Oct. 2, 2008, now U.S. Pat. No. 8,335,956, which is a national stage application under 35 U.S.C. 371 of PCT Application No. PCT/US007/066522 having, an international filing date of Apr. 12, 2007, which designated the United States, which PCT application claims the benefit of and priority under 35 U.S.C. § 119(e) to U.S. Patent Application Nos. 60/792,236, filed Apr. 12, 2006, entitled "xDSL Packet Retransmission Mechanism," and 60/849,650, filed Oct. 5, 2006, entitled "xDSL Packet Retransmission Mechanism with Examples," each of which are incorporated herein by reference in their entirety.

BACKGROUND

Field of the Invention

This invention generally relates to communication systems. More specifically, an exemplary embodiment of this invention relates to retransmission of packets in a communication environment. An exemplary embodiment of this invention also relates to memory sharing between transmission functions and other transceiver functions.

SUMMARY

Exemplary aspects of the invention relate to handling of packets and the assignment of a packet handling identifier. Exemplary aspects relate to sharing of resources between retransmitted packets and other transceiver functions. In addition, exemplary aspects relate to sharing of resources between packets associated with the packet handling identifier and other transceiver functions.

More specifically, aspects of the invention relate to assigning a packet handling identifier to one or more packets. Based on the packet handling identifier, a packet can either be, for example, forwarded directly to another communication device (or layer) or, alternatively, held for possible retransmission protocols. For example, packets received from, for example, a higher-layer of a communication device, can be designated to have a specific packet handling identifier, such as a Quality of Service (QOS) level. The QOS level of a packet indicates the importance of certain service metrics (or characteristics) of one or more packets.

Two exemplary QOS metrics are delay (or latency) and Packet Error Rate (PER). While these two metrics are used for illustrative purposes herein, it should be appreciated that other metrics can also be used with this invention. For example, other QOS metrics could include one or more of a

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Bit Error Rate (BER), data rate, delay variation (or jitter), packet loss rate, time between error events (TBE), or the like.

As an example, in the case where the two QOS metrics are latency and PER, packets containing, for example, video information (such as IPTV) may have the requirement for a very low packet error rate but can often tolerate higher delay. In contrast, voice or data (e.g., gaming) traffic may have very low latency requirements but can tolerate a higher packet error rate. For this particular example, the video packets could be designated as "low-PER" QOS packets and the voice or data packets could be designated as "low-latency" QOS packets. For example, a specific QOS identifier could be assigned to the low-latency packets while a different QOS identifier could be assigned to the low-PER packets. The low-latency packets could be forwarded directly to another transceiver, or a higher layer, while the low-PER packets can be stored in a retransmission buffer, e.g., memory, that can be used to reduce packet error.

As mentioned above, exemplary aspects also relate to sharing of resources between a retransmission function and other transceiver functions.

The exemplary systems and methods of this invention can utilize memory, such as a retransmission buffer, for the storing of packets for retransmission functions. Since other transceiver functions may also require memory to perform certain functionality, an exemplary aspect of this invention also relates to sharing the memory for retransmission functions with the memory required for other transceiver functions. For example, memory can be dynamically allocated based on configuration settings or noise conditions and, for example, the memory divided between one or more of interleaving/deinterleaving, RS Coding/Decoding functionality and the functionality used retransmission.

Aspects of the invention thus relate to identification of one or more packets.

Additional aspects of the invention relate to identifying one or more packets that can be retransmitted.

Still further aspects of the invention relate to identifying one or more packets that should not be retransmitted.

Aspects of the invention also relate to retransmission of one or more of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-data frame, a PTM-TC codeword, and RS codeword and a DMT symbols.

Still further aspects of the invention relate to appending an identifier to a packet.

Still further aspects of the invention relate to appending a sequence identifier to at least one packet.

Aspects of the invention also relate to routing one or more packets based on a packet handling identifier.

Aspects of the invention also relate to retransmitting a packet.

Aspects of the invention further relate to retransmit a packet based on a retransmission request.

Still further aspects of the invention relate to sharing memory between a retransmission function and one or more of an interleaver, deinterleaver, coder, decoder and other transceiver functionalities.

Other more specific aspects of the invention relate to sharing memory between a retransmission buffer (or memory) and interleaving/deinterleaving and/or coding/decoding functionality.

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Additional exemplary, non-limiting aspects of the invention are:

1. A method of packet retransmission comprising: transmitting or receiving a plurality of packets; identifying at least one packet of the plurality of packets as a packet that should not be retransmitted.
2. The method of aspect 1, wherein the packet is any grouping of bytes.
3. The method of aspect 1, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.
4. The method of aspect 1, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.
5. The method of aspect 4, wherein the identifying step comprises using a special value for a sequence identifier (SID).
6. The method of aspect 4, wherein the appended bit field comprises a dedicated CRC.
7. The method of aspect 1, wherein the at least one packet is not stored for retransmission.
8. The method of aspect 1, wherein the at least one packet is passed immediately to a high layer.
9. A packet retransmission module capable of transmitting or receiving a plurality of packets and capable of identifying at least one packet of the plurality of packets as a packet that should not be retransmitted.
10. The module of aspect 9, wherein the packet is any grouping of bytes.
11. The module of aspect 9, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.
12. The module of aspect 9, wherein the module is capable of appending a bit field comprising a sequence identifier (SID) to each packet.
13. The module of aspect 12, wherein the identifying comprises using a special value for the SID.
14. The module of aspect 12, wherein the appended bit field comprises a dedicated CRC.
15. The module of aspect 9, wherein the at least one packet is not stored by the module for retransmission.
16. The module of aspect 9, wherein the at least one packet is passed by the module immediately to a high layer.
17. The module of aspect 9, wherein the module is implemented in one or more of a wireless transceiver, a wireless LAN station, a wired transceiver, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a multicarrier transceiver, a general purpose computer, a special purpose computer, a programmed microprocessor, a microcontroller and peripheral integrated circuit element(s), an ASIC, a digital signal processor, a hard-wired electronic or logic circuit and a programmable logic device.
18. The module of aspect 9, wherein the module is implemented in one or more of a PTM-TC, ATM-TC, PMD and PMS-TC.
19. A method comprising sharing memory between an interleaving and/or deinterleaving memory and a packet retransmission memory.
20. A method comprising allocating a first portion of shared memory for retransmission and a second portion of the shared memory for interleaving and/or deinterleaving.
21. The method of aspect 20, further comprising transmitting or receiving a message indicating how to allocate the shared memory.

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22. The method of aspect 19 or 20, further comprising transmitting or receiving a message indicating how to share the memory.

23. A memory capable of being shared between an interleaving and/or deinterleaving buffer and a packet retransmission buffer.

24. A module capable of allocating a first portion of shared memory for retransmission and a second portion of the shared memory for interleaving and/or deinterleaving.

25. The module of aspect 24, wherein the module is capable of transmitting or receiving a message indicating how to allocate the shared memory.

26. The module of aspect 24, wherein the module is capable of transmitting or receiving a message indicating how to share the memory.

27. The module of aspect 24, wherein the module is one or more of a wireless transceiver, a wireless LAN station, a wired transceiver, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a multicarrier transceiver, a general purpose computer, a special purpose computer, a programmed microprocessor, a microcontroller and peripheral integrated circuit element(s), an ASIC, a digital signal processor, a hard-wired electronic or logic circuit and a programmable logic device.

28. A method of packet retransmission comprising: transmitting or receiving a plurality of packets; identifying at least one packet of the plurality of packets as a packet that should be retransmitted and at least one packet of the plurality of packets as a packet that should not be retransmitted.

29. The method of aspect 28, wherein the packet is any grouping of bytes.

30. The method of aspect 28, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

31. The method of aspect 28, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

32. The method of aspect 31, wherein the identifying step comprises using a special value for a sequence identifier (SID).

33. The method of aspect 31, wherein the appended bit field comprises a dedicated CRC.

34. The method of aspect 28, wherein at least one packet is stored for retransmission.

35. The method of aspect 28, wherein at least one packet is passed immediately to a high layer.

36. A packet handling method comprising: receiving a stream of packets; identifying a first number of packets in the stream of packets as low-latency packets; identifying a second number of packets in the stream of packets as low-error packets;

forwarding the low-latency and low-error packets to a transceiver or a higher layer; and storing the low-error packets for error correction.

37. The method of aspect 36, further comprising appending the low-error packets with an identifier.

38. A method of allocating memory in a transceiver comprising:

analyzing one or more communication parameters; identifying a memory allocation; and allocating memory based on the memory allocation to a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding.

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39. A memory sharing method in a transceiver comprising:

receiving a memory allocation;
establishing a shared memory for one or more of interleaving, deinterleaving, RS coding, RS decoding and packet retransmission functions; and

sharing the shared memory between a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functions.

40. The method of aspect 39, further comprising determining a compatibility of the memory allocation.

41. The method of aspect 39, wherein the compatibility of the memory allocation is based on channel performance metrics.

42. Means for performing the functionality of any of the aforementioned aspects.

43. An information storage media comprising information that when executed performs the functionality of any of the aforementioned aspects.

44. Any one or more of the features as substantially described herein.

45. Means for packet retransmission comprising:
means for transmitting or receiving a plurality of packets;
means for identifying at least one packet of the plurality of packets as a packet that should not be retransmitted.

46. The means of aspect 45, wherein the packet is any grouping of bytes.

47. The means of aspect 45, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

48. The means of aspect 45, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

49. The means of aspect 48, wherein the means for identifying comprises using a special value for a sequence identifier (SID).

50. The means of aspect 48, wherein the appended bit field comprises a dedicated CRC.

51. The means of aspect 45, wherein the at least one packet is not stored for retransmission.

52. The means of aspect 45, wherein the at least one packet is passed immediately to a high layer.

53. Means for sharing memory between an interleaving and/or deinterleaving function and a packet retransmission function.

54. Means for allocating a first portion of shared memory for retransmission and a second portion of the shared memory for interleaving and/or deinterleaving.

55. The means of aspect 54, further comprising means for transmitting or receiving a message indicating how to allocate the shared memory.

56. The means of aspect 54, further comprising means for transmitting or receiving a message indicating how to share the memory.

57. Means for sharing a memory between an interleaving and/or deinterleaving function and a packet retransmission function.

58. Means for packet retransmission comprising:
means for transmitting or receiving a plurality of packets;
means for identifying at least one packet of the plurality of packets as a packet that should be retransmitted and at least one packet of the plurality of packets as a packet that should not be retransmitted.

59. The means of aspect 58, wherein the packet is any grouping of bytes.

60. The means of aspect 58, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM

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packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

61. The means of aspect 58, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

62. The means of aspect 61, wherein the means for identifying comprises using a special value for the sequence identifier (SID).

63. The means of aspect 58, wherein the appended bit field comprises a dedicated CRC.

64. The means of aspect 58, wherein at least one packet is stored for retransmission.

65. The means of aspect 58, wherein at least one packet is passed immediately to a high layer.

66. A packet handling means comprising:

means for receiving a stream of packets;
means for identifying a first number of packets in the stream of packets as low-latency packets;
means for identifying a second number of packets in the stream of packets as low-error packets;
means for forwarding the low-latency and low-error packets to a transceiver or higher layer; and
means for storing the low-error packets for error correction.

67. The means of aspect 66, further comprising means for appending the low-error packets with an identifier.

68. Means for allocating memory in a transceiver comprising:

means for analyzing one or more communication parameters;
means for identifying a memory allocation; and
means for allocating memory based on the memory allocation to a retransmission function and one or more of an interleaving, deinterleaving, RS coding and RS decoding function.

69. Means for memory sharing in a transceiver comprising:

means for receiving a memory allocation;
means for establishing a shared memory for one or more of interleaving, deinterleaving, RS coding, RS decoding and packet retransmission function; and
means for sharing the shared memory between a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functionality.

70. The means of aspect 69, further comprising means for determining a compatibility of the memory allocation.

71. The means of aspect 69, wherein the compatibility of the memory allocation is based on channel performance metrics.

72. A transceiver capable of performing packet retransmission comprising:

a transmission management module configurable to transmit or receive a plurality of packets; and
a QOS module configurable to identify at least one packet of the plurality of packets as a packet that should not be retransmitted.

73. The transceiver of aspect 72, wherein the packet is any grouping of bytes.

74. The transceiver of aspect 72, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

75. The transceiver of aspect 72, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

76. The transceiver of aspect 75, wherein the QOS module uses a special value for a sequence identifier (SID).

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77. The transceiver of aspect 75, wherein the appended bit field comprises a dedicated CRC.

78. The transceiver of aspect 72, wherein the at least one packet is not stored for retransmission.

79. The transceiver of aspect 72, wherein the at least one packet is passed immediately to a high layer.

80. A memory capable of being shared between interleaving and/or deinterleaving and packet retransmission.

81. A memory management module capable of allocating a first portion of shared memory for retransmission and capable of allocating a second portion of the shared memory to one or more of interleaving and deinterleaving functionality.

82. The module of aspect 81, further comprising a module for transmitting or receiving a message indicating how to allocate the shared memory.

83. The module of aspect 81, further comprising a module for transmitting or receiving a message indicating how to share the memory.

84. A module capable of being shared between interleaving and/or deinterleaving and packet retransmission.

85. A transceiver capable of performing packet retransmission comprising:

a transmission management module configurable to transmit or receive a plurality of packets; and

a QOS module configurable to identify at least one packet of the plurality of packets as a packet that should be retransmitted and at least one packet of the plurality of packets as a packet that should not be retransmitted.

86. The transceiver of aspect 85, wherein the packet is any grouping of bytes.

87. The transceiver of aspect 85, wherein the packet is one of an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data Frame, a PTM-TC codeword, an RS codeword and a DMT symbol.

88. The transceiver of aspect 85, wherein a bit field comprising a sequence identifier (SID) is appended to each packet.

89. The transceiver of aspect 88, wherein the identifying step comprises using a special value for a sequence identifier (SID).

90. The transceiver of aspect 88, wherein the appended bit field comprises a dedicated CRC.

91. The transceiver of aspect 85, wherein at least one packet is stored for retransmission.

92. The transceiver of aspect 85, wherein at least one packet is passed immediately to a high layer.

93. A transceiver capable of handling a stream of packets comprising:

a QOS module capable of identifying a first number of packets in the stream of packets as low-latency packets and a second number of packets in the stream of packets as low-error packets;

a transmission management module capable of forwarding the low-latency and low-error packets to another transceiver; and

a buffer module capable of storing the low-error packets for error correction.

94. The transceiver of aspect 93, further comprising a packet QOS assignment module capable of appending the low-error packets with an identifier.

95. A transceiver capable of having an allocatable memory comprising:

a controller capable of analyzing one or more communication parameters; and

a memory management module capable of identifying a memory allocation and allocating a shared memory based on

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the memory allocation to a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functions.

96. A transceiver capable of sharing memory comprising: a controller capable of receiving a memory allocation; and a memory management module capable of establishing a shared memory for a retransmission function and one or more of interleaving, deinterleaving, RS coding and RS decoding functions.

97. The transceiver aspect 96, wherein the memory management module further determines a compatibility of the memory allocation.

98. The transceiver of aspect 96, wherein the memory allocation is based on one or more communication channel performance metrics.

99. In a communication environment where packets are being transmitted, a method for allocating a first portion of shared memory for retransmission of packets and a second portion of the shared memory for interleaving and/or deinterleaving.

100. The method of aspect 99, wherein all errored packets are retransmitted.

101. The method of aspects 19, 20 and 99, wherein a retransmission function identifies packets that should not be retransmitted.

102. The method of aspect 99, wherein all packets are being transmitted without an assigned a QOS level.

103. A packet communication method comprising:

in a first mode of operation: transmitting or receiving a plurality of packets; identifying at least one packet of the plurality of packets as a packet that should not be retransmitted;

in a second mode of operation: transmitting or receiving a plurality of packets; allocating a first portion of shared memory for retransmission of packets and a second portion of the shared memory for one or more of interleaving, deinterleaving, coding, decoding and error correction; and

in a third mode of operation: transmitting or receiving a plurality of packets; identifying at least one packet of the plurality of packets as a retransmittable-type packet; identifying at least one packet of the plurality of packets as a non-retransmittable-type packet;

allocating a first portion of shared memory for retransmission of the retransmittable-type packets and a second portion of the shared memory for one or more of interleaving, deinterleaving, coding, decoding and error correction.

104. The method of aspect 103, wherein the retransmittable-type packet is a low-latency packet.

105. The method of aspect 103, wherein the retransmittable-type packet is a low-error packet.

These and other features and advantages of this invention are described in, or are apparent from, the following detailed description of the exemplary embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The exemplary embodiments of the invention will be described in detail, with reference to the following figures wherein:

FIG. 1 illustrates an exemplary communication system according to this invention.

FIG. 2 is a flowchart outlining an exemplary method for packet retransmission according to this invention.

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FIG. 3 is a flowchart outlining an exemplary method for retransmitted packet reception according to this invention.

FIG. 4 is a flowchart outlining an exemplary method for memory allocation according to this invention.

FIG. 5 is a flowchart outlining an exemplary method for memory sharing according to this invention.

DETAILED DESCRIPTION

The exemplary embodiments of this invention will be described in relation to packet retransmission and/or memory sharing in an xDSL environment. However, it should be appreciated, that in general, the systems and methods of this invention will work equally well for any type of communication system in any environment.

The exemplary systems and methods of this invention will also be described in relation to multicarrier modems, such as xDSL modems and VDSL modems, and associated communication hardware, software and communication channels. However, to avoid unnecessarily obscuring the present invention, the following description omits well-known structures and devices that may be shown in block diagram form or otherwise summarized.

For purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the present invention. It should be appreciated however that the present invention may be practiced in a variety of ways beyond the specific details set forth herein.

Furthermore, while the exemplary embodiments illustrated herein show the various components of the system collocated, it is to be appreciated that the various components of the system can be located at distant portions of a distributed network, such as a communications network and/or the Internet, or within a dedicated secure, unsecured and/or encrypted system. Thus, it should be appreciated that the components of the system can be combined into one or more devices, such as a modem, or collocated on a particular node of a distributed network, such as a telecommunications network. As will be appreciated from the following description, and for reasons of computational efficiency, the components of the system can be arranged at any location within a distributed network without affecting the operation of the system. For example, the various components can be located in a Central Office modem (CO, ATU-C, VTU-O), a Customer Premises modem (CPE, ATU-R, VTU-R), an xDSL management device, or some combination thereof. Similarly, one or more functional portions of the system could be distributed between a modem and an associated computing device.

Furthermore, it should be appreciated that the various links, including communications channel 10, connecting the elements (not shown) can be wired or wireless links, or any combination thereof, or any other known or later developed element(s) that is capable of supplying and/or communicating data to and from the connected elements. The term module as used herein can refer to any known or later developed hardware, software, firmware, or combination thereof that is capable of performing the functionality associated with that element. The terms determine, calculate and compute, and variations thereof, as used herein are used interchangeably and include any type of methodology, process, mathematical operation or technique. Transmitting modem and Transmitting transceiver as well as Receiving modem and Receiving transceiver are used interchangeably herein.

Moreover, while some of the exemplary embodiments described herein are directed toward a transmitter portion of

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a transceiver performing interleaving and/or coding on transmitted information, it should be appreciated that a corresponding deinterleaving and/or decoding is performed by a receiving portion of a transceiver. Thus, while perhaps not specifically illustrated in every example, this disclosure is intended to include this corresponding functionality in both the same transceiver and/or another transceiver.

Communication system 100 comprises a portion of a transceiver 200 and a portion of a transceiver 300. The transceiver 200, in addition to well known componentry, comprises an errored packet module 210, a transmission management module 220, a QOS ID module 225, a QOS module 230, a packet QOS assignment module 240, a retransmission buffer/interleaving/deinterleaving/RS coding/RS Decoding memory 250, a counter module 260, a memory management module 270 and a controller/memory 280.

Connected via communication channel 10 to transceiver 200 is transceiver 300. The transceiver 300, in addition to well known componentry, comprises an errored packet module 310, a transmission management module 320, a QOS ID module 325, a QOS module 330, a packet QOS assignment module 340, a retransmission buffer/interleaving/deinterleaving/RS coding/RS Decoding memory 350, a counter module 360, a memory management module 370 and a controller/memory 380.

As discussed above, the systems, methods and protocols discussed herein will be described in relation to xDSL systems, such as those specified in ADSL2 ITU-T G.992.3, ADSL2+ITU G.992.5, and VDSL2 ITU G.993.2, which are incorporated herein by reference in their entirety.

In operation, a first aspect of the invention relates to retransmission of one or more packets, the retransmission identifier being implemented at any transmission layer where packet boundaries are defined. For example, it can be implemented in the Packet Transmission Mode TC (PTM-TC) of xDSL systems. For reference, "Annex A" which is of record in the identified provisional filing and incorporated by reference herein contains the PTM-TC of ADSL2 and VDSL2 systems as specified in the ITU-T G.992.3 ADSL2 standard.

As discussed herein, the invention will generally be described in relation to the retransmission mechanism being incorporated as part of the PTM-TC however, it should be appreciated that it can also be implemented inside other layer(s) of a communication device, such as an xDSL transceiver, such as within the PMD or PMS-TC.

The retransmission techniques disclosed herein can also be performed at a layer above the PTM-TC, for example, in a new layer between the PTM-TC and the next higher layer, or at any layer above the physical layer, e.g., layers 2, 3, 4, 5, etc.

Additionally, while "packet" is used herein, the term "packet" includes any basic data unit, i.e., a grouping of bytes. For example, a packet could be an IP packet, an Ethernet packet, an ATM cell, a PTM packet, an ADSL Mux-Data frame, a PTM-TC codeword, an RS Codeword, a DMT symbol, or, in general, any grouping of data bytes or information. A packet could also be a combination of one or more of the above. For example, a packet could be constructed by concatenating any number of ATM cells to create a larger grouping of bits. For example, five 53-byte ATM cells could be combined into a 265 byte packet or four 65 PTM-TC codewords could be combined into a 260 byte packet. A packet could also be based on dividing any of the above groupings of bytes. For example, larger IP or Ethernet packets could be divided into smaller groups of bytes to be

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used as a “packet” with the retransmission functionality described herein. For example, a 1500 byte IP packet could be divided into three 500 byte packets and used by the retransmission protocol. If the retransmission function is implemented as part of the PTM-TC, packets are received from a higher-layer in the xDSL transmitter PTM-TC and sent via the xDSL transmitter PMS-TC and PMD over the communication channel to the xDSL receiver. The xDSL receiver PMD and PMS-TC process the received signal and pass the results to the PTM-TC, which processes the information and passes the received packet up to a higher layer(s).

Packets received from the higher layer at the xDSL transmitter PTM-TC can be designated to have a QOS level. The QOS level of a packet can indicate the importance of certain service metrics (or characteristics) of this (or more) packet(s). Two exemplary QOS metrics are delay (or latency) and PER. Although, as discussed above, these two characteristics are the focus of the invention, any number of different QOS metrics could also be used.

As an example, in the case where the 2 QOS metrics are latency and PER, a first set of packets carrying certain information may have a requirement for very low PER but may be able to tolerate higher delay. Other packets containing information such as voice or data traffic may have very low delay requirements but can tolerate a higher PER. According to an exemplary embodiment of this invention, the first set of packets would be designated as “low-PER” QOS packets whereas voice or data packets would be designated as “low-latency” QOS packets. The QOS level (or metric) of a packet could be designated in a number of ways. For example:

i) Certain bit fields in the header of data portions of each packet could contain certain values that specify the QOS requirements a packet. For example, the packet header could contain bit fields that indicate if the packet has a “low-PER” QOS requirement or a “low-latency” QOS requirement. These fields could be read by the transmitting modem and/or receiving modem to determine the QOS level of each packet.

ii) When sending packets from higher layer to the PTM-TC, the higher layer could indicate on a packet by packet basis the QOS requirements of each packet. For example, there could be a separate signal on the interface that indicates if a packet being transferred has a “low-PER” QOS requirement or a “low-latency” QOS requirement.

iii) When sending packets from higher layer to the PTM-TC, there could be a separate interface (or channel) for packets with different QOS requirements. For example, one channel could be used to transfer packets that have a “low-PER” QOS requirement and a second channel could be used to transfer packets that have a “low-latency” QOS requirement. This general concept could also be scaled to accommodate a plurality of different QOS requirements and a plurality of channels.

iv) As in the case of Pre-Emption in the PTM-TC (see Annex A), two logically separated y-interfaces could be used for the transport of a low-PER and low-latency packet flow through a single bearer channel. This general idea could then be scaled to support any number of packet types.

Other mechanisms can also be used to designate the QOS level of a packet—provided the transmitter and/or receiver retransmission protocol is capable of knowing the QOS level for one or more packets.

Once the QOS level is known by the PTM-TCs, an efficient packet retransmission can be designed. The exem-

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plary packet retransmission methods and protocols can be designed to include any one or more of the following system level characteristics:

All packets are received from the higher layer and passed to the higher layers in the correct order.

“Low-latency” QOS packets will not incur any extra delay due to retransmission.

Only packets with “low-PER” QOS should be retransmitted, and therefore only low-PER packets will incur the extra delay due to the retransmission mechanism.

Flow control can be minimized such that the transmitter can generally accept all packets from the higher layer at the required data rate without holding-off (or “blocking”) packets from the higher layer during the retransmission process.

Packet delay-variation/jitter can be minimal.

A “DRR-like” functionality in a single bearer without requiring latency/interleaver OLR.

The transceiver 200, in cooperation with the QOS module 230, receives packets from a higher-layer. In cooperation with the packet QOS assignment module 240, a packet Sequence ID (SID) is appended to the received packets. The packets, in cooperation with the transmission management module 220, can then be transmitted in the order in which they were received.

The QOS Module 230, if not already performed by a high layer, also identifies packets based on the QOS requirement of the packet(s). Then, in cooperation with the packet QOS assignment module 240, a QOS identifier is associated with the packet as discussed hereinafter.

If, for example, the packet is identified as a low-PER packet, and assigned such an identifier by the QOS module 230, when the transmission management module 220 receives the packet, the packet is identified by the QOS ID module 225 as being a low-PER packet and the packet is forwarded for storage in the retransmission buffer 250. Alternatively, if the packet has been labeled as a low-latency packet, and identified as such by the QOS ID module 225, the packet can be transmitted to the receiving modem in cooperation with the transmission management module 220.

The low-PER packets can be stored for a sufficient amount of time to wait for a retransmission message from the receiver PTM-TC. During this time, the transmitting modem can continue to receive packets from one or more higher layers, label these packets, if needed, and store these packets, if they are identified as low-PER packets, in the same way. The resulting minimum storage requirements for the transmitter PTM-TC are estimated below.

For successful retransmission, the receiving modem should be able to inform the transmitting modem which packet, or packets, need to be retransmitted. One exemplary way of performing this is by transmitting packets with an appended bit field that contains a counter indicating the place of each packet in a stream of packets. This counter value is also known as a Sequence ID (SID). For example, a bit field containing a 16-bit counter could be appended to each packet and the counter module 260 would be incremented by one after each packet was transmitted. In cooperation with the packet assignment module 240, a packet counter field could be appended to the packet in a number of places, for example, at the beginning or end of the packet, or at the beginning or end of the packet header.

Packets received from a higher-layer may already have information in a header or data field of the packet that contains the packet count, or sequence, information. In addition, the packet counter field may be appended with an

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additional CRC field that contains a cyclic redundancy check that is computed on the packet counter field bits only. This CRC can be used by the receiver to determine if the packet counter field is received correctly, i.e., without bit errors. This CRC can be in addition to the standard CRC inserted by the standard PTM-TC (the standard packet PTM-TC CRC is a CRC that covers all bits in a packet). The standard packet CRC may also cover the new packet counter field in its CRC as well. This helps if the receiving modem uses the presence or absence of the packet counter field in a packet to detect if the packet has a low-PER or low-latency requirement (discussed below).

Alternatively, or in addition, the packet counter field (with or without a dedicated CRC) can be appended only to the packets with a specific QOS requirement, whereas all other packets can be transmitted without modification. For example, all video packets with low-PER QOS could contain the appended packet counter field whereas all the voice/data low-latency packets could be transmitted unchanged. One exemplary benefit of this is that the overhead (rate loss) due to adding the packet counter field is incurred only when transmitting low-PER packets.

Alternatively, or in addition, all low-PER and low-latency packets can be transmitted with the low packet counter field (with or without a dedicated CRC). In this case, the packet counter field of the low-latency packets may contain a special value indicating that a packet is not a low-PER packet. Also, the packet counter field of the low-latency packet may not even contain a count value, since the low-latency packets are not intended to be retransmitted. In this case, the packet counter field could contain a counter value only for low-PER packets and the counter value would only be incremented when a low-PER packet was transmitted. As an example, if the packet counter field is 16 bits, the special value of all zeros could be used to indicate that a packet is a low-latency packet. In this case, low-PER packets could contain counter values from one up to $2^{16}-1$, but not including all zeros, since this special zero value can be used to indicate a low-latency packet.

The receiving modem, e.g., receiver PTM-TC, which in this case is illustrated as the transceiver 300 and includes comparable functionality to that described in relation to transceiver 200, receives packets from the transmitting modem via the PMS-TC. If the received packet is identified as a low-latency packet by the QOS ID module 325, the packet is passed to a higher-layer. If a received packet is identified by the QOS ID module 325 as a low-PER packet, the packet is forwarded, with the cooperation of the transmission management module 320, to the retransmission buffer 350 for a minimum amount of time before passing to a higher-layer.

The storage time in the retransmission buffer 350 helps ensure that the retransmission protocol provides a constant delay, e.g., no delay variation seen by the upper layers. This way, if a packet needs to be retransmitted, the receiving modem can continue to provide packets to the higher-layers at a constant rate while waiting for the retransmitted packet(s) to arrive from the transmitting modem. The resulting minimum memory (or storage) requirements for the receiving PTM-TC are estimated below.

Alternatively, low-PER packets without errors may not be stored for a minimum amount of time before passing to a higher-layer. The error-free low-PER packets can be passed to the higher-layer immediately just like the low-latency packets. However, when a low-PER packet is in error, it is stored along with all of the following low-PER packets before passing to a higher-layer in order to wait for the

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retransmitted packet(s) to arrive. This will cause a delay variation on the low-PER packets whenever a retransmission occurs. However, this delay variation would not apply to the low-latency packets.

The QOS ID module 325 can detect that a packet is either low-PER or low-latency using several different methods. For example, if all low-PER and low-latency packets contain the appended packet counter field, then the receiving modem, in cooperation with the counter module 360, detects a low-latency packet when a packet counter field contains the designated special value, which was inserted by the transmitting modem, indicating the packet is a low-latency packet.

Alternatively, or in addition, the receiver could detect a low-PER packet when the packet counter field contains a valid packet counter value. Additionally, if a dedicated CRC is appended to the packet counter field, the CRC could be used to detect if the packet counter field bits are in error.

If the packet counter field, including the CRC, is only appended to low-PER packets, the absence or presence of this field in a packet can be used by the receiving modem, and in particular the QOS ID module, to detect a low-delay packet. For example, the receiving modem can examine the position in the packet where the packet counter field would be, if it was a low-PER packet, and if the packet counter field CRC fails while the standard whole packet CRC is correct, the receiving modem could determine that the packet is a low-delay packet, since it does not contain the packet counter field. Likewise, for example, the receiving modem can examine the position in the packet where the packet counter field would be, if it was a low-PER packet, and if the packet counter field CRC is correct, the receiving modem would determine that the packet is a low-PER packet, regardless of the status of the standard whole packet CRC.

The receiving modem, in cooperation with the retransmission buffer 350, and the errored packet module 310, can be used to detect missing or errored packets in a number of exemplary ways. For example, the errored packet module 310 can detect bit errors in the packet using the standard/whole packet PTM-TC CRC. Alternatively, or in addition, the errored packet module 310 can detect bit errors in the packet counter field if the transmitting modem appended a dedicated CRC to the packet counter field. This CRC is valuable because it can be used by the errored packet module in the receiving modem to determine if a packet has the correct packet number, even if the standard whole packet CRC happens to be in error.

Alternatively, or in addition, the errored packet module 310, can detect an errored or missing packet by receiving a packet with a correct CRC, either in the standard or packet counter field, which contains a packet counter number that is not the expected packet counter number. For example, if the errored packet module 310, in cooperation with the counter module 360, detects the receipt of a packet with a counter number equal to 5, wherein the errored packet module 310 is expecting to receive a packet with a counter equal to 3, the errored packet module 310 can determine that two packets, namely packets numbered 3 and 4, were lost due to errors.

Once a packet(s) is found to be in error, there are several exemplary ways in which a receiving modem can communicate information to the transmitting modem indicating that a retransmission of one or more packets is required. For example, the receiving modem, in cooperation with the errored packet module 310, can send an acknowledgment (ACK) message to the transmitting modem for every correctly received message or every predetermined number of

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packets. As long as the transmitting modem, and in particular the errored packet module 210, receives messages acknowledging receipt of packets in sequential order, there is no need for retransmission of information to the receiving modem. However, if the transmitting modem, and in particular the errored packet module 210, receives a message from the receiving modem, and in particular the errored packet module 310, indicating that a packet was correctly received with a counter value that is out of order, a retransmission by the transmitting modem is required. In the above example, where the receiving modem received a packet with a counter value equal to 5, without receiving packets numbered 3 and 4, the transmitting modem could receive an ACK for the packet with counter value of 2 and then an ACK for the packet with a counter value of 5. The transmitting modem would then determine that it was necessary to retransmit packets with counter values of 3 and 4 since they were not received.

Alternatively, or in addition, a timeout value could be specified for the transmitting modem. This timeout value could correspond to the amount of time that the transmitting modem should wait for an ACK for particular packet before retransmitting the packet. The timeout value could be set to be at least as long as the round-trip delay required for the transmitting modem to send a packet to the receiving modem and for the receiving modem to send an ACK back to the transmitting modem. If an ACK is not received by the timeout value, the transmitting modem could retransmit the packet.

Alternatively, or in addition, a negative acknowledgment (NAK) could be sent to the transmitting modem when a packet is detected as errored or missing. In the above example, when the receiving modem received the packet with a counter value of 5, while expecting a counter value of 3, the receiving modem could send a NAK message to the transmitting modem indicating that packets with counter values of 3 and 4 were not correctly received and needed to be retransmitted.

Alternatively, or in addition, if a packet was received with a correct packet counter CRC and a valid packet counter value and an incorrect standard whole packet CRC, the receiving modem could send a NAK message to the transmitting modem indicating that a packet with a value of x was incorrectly received and needed to be retransmitted.

Assuming that errored packets are infrequent, any methodology that sends an ACK for each correctly received packet can require a larger amount of data rate in the message channel that communicates this information back to the transmitting modem. In this case, sending only NAKs has the benefit that it requires sending a message only when an errored or missing packet is detected. Depending on the data rate capabilities of the message channel, and the PER, a retransmission system may use only ACKs, only NAKs, or both ACKs and NAKs at the same time.

The ACK and NAK messages sent back to the transmitting modem can be transmitted over the same physical channel i.e., phone line, in the opposite direction as the received packets. Since the channel has a limited data rate and is not necessarily error-free, it is important to make sure that these messages are as robust as possible and consume the least amount of data rate. Additionally, since the transmit and receive retransmission memory requirements depend on the round-trip latency of the connection, is important to minimize latency requirements for the message channel. There are several ways these requirements can be addressed.

The messages can be sent over a separate "low-latency" or "fast" path between the xDSL transceivers. This fast path

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could include little or even no delay due to interleaving and can be specified to have a latency that is less than 2 ms.

Alternatively, or in addition, the messages can be sent with increasing robustness by repeating transmission of each message a number of times. For example, the message could be repeated x times in order to make sure that even if $x-1$ messages were corrupted by the channel, at least one message would be received correctly.

Alternatively, or in addition, the messages can be sent such that each message is repeated a number of times and each repeated message is sent in a different DMT symbol. For example, the message can be repeated x times and each message sent in one of x DMT symbols. This way, even if $x-1$ DMT symbols were corrupted by the channel, at least one message would be received correctly.

Alternatively, or in addition, the messages can be sent such that each message is repeated a number of times and each repeated message is sent in different DMT symbols. For example, the message could be repeated x times and each message sent in one of x DMT symbols. This way, even if $x-1$ DMT symbols were corrupted by the channel, at least one message would be received correctly.

Alternatively, or in addition, the messages can be sent such that each message is repeated a number of times and each repeated message is sent a plurality of times in each DMT symbol. For example, the message could be repeated x times and each repeated message sent y times in one of x DMT symbols. This way, even if $x-1$ DMT symbols were corrupted by the channel and/or large portions of a DMT symbol were corrupted by a channel, the least one message would be received correctly.

Alternatively, or in addition, the messages can include multiple packet count values in order to reduce the data rate requirements. For example, if packets with counter values of 3-9 are correctly (or incorrectly) received an ACK (or NAK) message would be sent to indicate these packet values. For example, the message could contain the values 3 and 9 and the receiver of the message would automatically know that all intermediate values (4, 5, 6, 7, 8) are also been indicated in the message.

Alternatively, or in addition, the DMT sub-carriers that modulate these messages could operate with a much higher SNR margin e.g., 15 dB, as compared to the normal 6 dB margin of xDSL systems. This way, the messages would have a higher immunity to channel noise.

Alternatively, or in addition, a receiving modem may need to send an additional ACK or NAK message after already in the process of sending a repeated message. For example, a receiving modem may detect that packets with values 3 to 9 have been correctly received and send an ACK message back to the transmitting modem indicating this information. This message can be repeated x times with each repeated message being transmitted (at least once) on different DMT symbols. While sending the second repeated message on the second DMT symbol, the receiver could detect that packets with values 10 to 17 have now also been correctly received. In this case, the receiving modem could just append this information to the previous message or, alternatively, send a new separate message that is repeated as well x times with each repeated message being transmitted (at least once) on a different DMT symbol.

Alternatively, or in addition, when repeating a message x times on x DMT symbols, each repeated message can be modulated on a different set of DMT sub-carriers on each DMT symbol. This way, if one or more sub-carriers have a low SNR, the message will still be correctly received.

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For low-PER packets, the delay due to this retransmission protocol is equal to the delay that results from storing these packets at the receiving modem (RX PTM-TC) to pass in the packets to a higher layer. Low-latency packets do not incur extra delay.

The transmitting modem must store a packet for retransmission for a time equal to the round trip delay from when the packet is sent to when the retransmission message is received. During this time the transmitting modem continues to receive packets from the higher layer and continues to store these packets in the same way. Therefore the storage requirements in octets can be computed as:

$$\text{Minimum TX memory (octets)} = \text{roundtripdelay} * \text{data rate},$$

where the roundtripdelay is the time equal to the round trip delay from when the packet is sent to when the retransmission message is received, and the data rate is the data rate of the connection that is transferring the packets. For ITU-T G.993.2 VDSL2, which is incorporated herein by reference, this can be computed using the VDSL2 profile parameters as:

$$\begin{aligned} \text{Minimum TX memory (octets)} = & (\text{DS} + \text{US Interleaving} \\ & \text{Delay in octets}) + (\text{US} + \text{DS alpha/beta delay} \\ & \text{without interleaving}) * (\text{Bidirectional Net data} \\ & \text{rate}) - \text{MAXDELAYOCTET} + (4 \text{ ms}) * \text{MBDC}, \end{aligned}$$

where MAXDELAYOCTET and MBDC are as specified in the VDSL2 profiles.

For the receiver, the minimum receiver storage requirements can be determined in a similar manner. More specifically, the RX PTM-TC must store a packet before passing it to the higher layer for a time equal to the round trip delay from when a retransmission message is transmitted to when the retransmitted packet is received. This is equal to storage requirements in octets (same as transmitter):

$$\text{Minimum RX memory (octets)} = \text{roundtripdelay} * \text{data rate},$$

where the roundtripdelay is the time equal to the round trip from when a retransmission message is transmitted to when the retransmitted packet is received and the data rate is the data rate of the connection that is transferring the packets. For ITU-T G.993.2 VDSL2 this can be computed using the VDSL2 profile parameters as:

$$\begin{aligned} \text{Minimum RX memory (octets)} = & (\text{DS} + \text{US Interleaving} \\ & \text{Delay in octets}) + (\text{US} + \text{DS alpha/beta delay} \\ & \text{without interleaving}) * (\text{Bidirectional Net data} \\ & \text{rate}) - \text{MAXDELAYOCTET} + (4 \text{ ms}) * \text{MBDC}, \end{aligned}$$

where MAXDELAYOCTET and MBDC are as specified in the ITU-T G.993.2 VDSL2 profiles.

TABLE 1

Minimum TX or RX memory requirements for VDSL2				
VDSL2 PROFILE	8a, 8b, 8c, 8d	12a, 12b	17a	30a
TX or RX memory requirements (octets) = MAXDELAYOCTET + .002MBDC	90,536	99,536	123,304	231,072

The estimates in Table 1 assume that all the entire MAXDELAYOCTET and MBDC are used for the transfer of the packet stream, i.e., the reverse channel has a very low data rate and no interleaving.

Some xDSL standards specify minimum storage, i.e., memory, requirements for interleaving of RS codewords.

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Interleaving with RS coding is an effective way of correcting channel errors due to, for example, impulse noise. For example, VDSL2 requires support of an aggregate bidirectional interleaver and de-interleaver memory of 65 Kbytes for the 8a VDSL2 profile. This corresponds to storage requirement of approximately 32 Kbytes in a single transceiver.

Sharing of Memory Between the Retransmission Function and One or More of the Interleaving/Deinterleaving/RS Coding/RS Decoding Functions

From Table 1, it is apparent that the memory requirements to support the retransmission protocol may be more than double the storage requirements of a single transceiver. Additionally, the retransmission protocol provides a different method for correcting channel errors due to, for example, impulse noise.

Moreover, interleaving and RS coding methods and retransmission protocols provide different advantages with respect to error correction capabilities, latency, buffering requirements, and the like. For example, under certain configuration and noise conditions the interleaving/RS coding provides error correction/coding gain with less delay and overhead than the retransmission protocol (for packets that can be retransmitted). While under other conditions the retransmission protocol will provide better error correction with less delay and overhead than the interleaving/RS coding.

In some cases, a first portion of the memory can be used for one function and a second portion of the memory for some other function. For example, if the configuration and noise conditions are such that the interleaving/RS coding would not provide good error correction/coding gain, then all the available memory could be used for the retransmission function and none allocated to the interleaving/deinterleaving/RS coding/RS decoding functionality, e.g., the interleaving/deinterleaving could be disabled.

Likewise, if the configuration and noise conditions are such that the retransmission protocol would not provide good error correction/coding gain, then all the available memory could be used for the interleaving/deinterleaving/RS coding/RS decoding functionality and no memory would be used for the retransmission function, e.g., the retransmission function would be disabled.

Alternatively, or addition, both methods could be used because both have their advantages, with the system, e.g., the memory management module 370, being able to dynamically allocate a first portion of the memory 250/350 to the interleaving/deinterleaving/RS coding/RS decoding functionality and a second portion of the memory to the retransmission functionality. For example, 40% of the memory could be allocated to the interleaving/deinterleaving/RS coding/RS decoding functionality with the remaining 60% allocated to the retransmission of functionality. However, it should be appreciated, that in general, the memory can be divided, i.e., shared, in any manner.

The sharing of memory between the retransmission function and the interleaving/deinterleaving/RS coding/RS decoding functions is not restricted to retransmission protocols described in other embodiments that utilize QOS metrics to determine which packets should be retransmitted. In other words, the sharing of memory between the retransmission function and the interleaving/deinterleaving/RS coding/RS decoding functions can be utilized for retransmission systems where all errored packets are retransmitted, i.e., there is no QOS identifier in the retransmission protocol. For example, the FEC/interleaving could be used to meet the INPmin requirement specifically targeting the impulse noise

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that occurs frequently (e.g., on the order of minutes or seconds) but is short in duration and can therefore be corrected by the FEC/interleaving. For example, the retransmission protocol can be used to correct infrequent errors (on the order of hours) that are long in duration and would not be correctable by the FEC/interleaving. As another example, the FEC/interleaving function may be used in combination with the retransmission function because it is well known that FEC with minimal interleaving provides a 1 dB to 3 dB coding gain when used with a trellis code (as is often the case in xDSL systems). This means that even when the majority of the shared memory is allocated to a retransmission function to address channel noise (such as impulse noise), a smaller amount of memory may be allocated to the FEC/interleaving function for the coding gain advantage.

Associated with the ability to allocate or partition memory between one or more of the interleaving/deinterleaving/RS coding/RS decoding functionality and retransmission functionality, is the ability to exchange information between transceivers on how to establish this allocation. For example, the transmitting modem may send a message to the receiving modem indicating how much of the available memory is to be allocated to one or more of the interleaving/deinterleaving/RS coding/RS decoding functionality and how much memory is to be allocated to the retransmission functionality. For example, if the receiving modem contains 100 kBytes of available memory, the transmitting modem could send a message to the receiving modem indicating that 25 kBytes should be allocated to RS coding functionality and 75 kBytes should be allocated to the retransmission functionality. Since the receiving modem generally determines the interleaving/RS coding parameters that are used, the receiving modem could use this information to select parameters, e.g., interleaver depth and codeword size, that would result in an interleaving memory requirement that is no more than the amount indicated in the message.

Alternatively, or addition, the receiving modem can send a message to the transmitting modem indicating how much of the available memory is to be allocated to one or more of the interleaving/deinterleaving/RS coding/RS decoding functionality, and how much memory should be allocated to the retransmission functionality.

Sharing of Memory Between a Retransmission Function with Identification of Low-PER and/or Low-Latency Packets and One or More of Interleaving/Deinterleaving/RS Coding/RS Decoding Functions.

A way of reducing the total memory requirement of a transceiver that supports the retransmission functionality with the identification of the low-PER and/or the low-latency packets is to define a limit, such as a maximum value, for the data rate of the low-PER packet stream, i.e., the packets requiring retransmission to meet a specific PER requirement. For example, if the total data rate is 50 Mbps, and the roundtrip delay is 10 ms, the minimum TX or RX memory requirement is $50,000,000 \times 0.01/8 = 62500$ bytes if the retransmission function must support the case where all the transmitted packet (all 50 Mbps) are low-PER packets. If however, only a portion of the 50 Mbps data rate is allocated to the low-PER packet stream (e.g. 30 Mbps), whereas the remainder of the data rate is allocated to the low-latency packet stream (e.g. 20 Mbps), the minimum TX or RX memory requirement would be $30,000,000 \times 0.01/8 = 37500$ bytes (assuming a roundtrip delay of 10 ms). In this case, the transmitting modem (or receiving modem) may send a message to the receiving modem (or transmitting modem) that indicates the maximum data rate of the packet traffic that will be used in the retransmission function. Using

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the example above, the transmitting modem (or receiving modem) would send a message indicating that the low-PER traffic will not exceed 30 Mbps, in which case the receiving modem (or transmitting modem) will allocate memory to the retransmission functionality and the interleaving/RS coding (or deinterleaving/RS decoding) functionality accordingly.

One exemplary advantage of indicating the low-PER and low-latency packets as part of the retransmission protocol is that it provides a DDR-like functionality without the overhead of dynamically re-allocating latency paths. For example, when a video application is turned off (less low-PER packets on the connection), the data application data rate can be increased (more low-latency packets on the connection) without any changes in the transmission parameters.

The retransmission protocol can also be used with or without underlying FEC/interleaving (or deinterleaving). An exemplary approach is to use the FEC/interleaving to meet the INPmin requirement specifically targeting the impulse noise that occurs frequently, e.g., on the order of minutes or seconds. The retransmission protocol can be used to correct infrequent errors (on the order of hours) that will only typically be a problem for very-low PER applications, such as video.

When a retransmission protocol is combined with underlying FEC/interleaving (or deinterleaving), the retransmission protocol latency will grow in proportion to the additional FEC/interleaving delay. This is due to the fact that the required receiver buffering corresponds approximately to the round-trip delay time of packet transmission and message acknowledgment.

As an example of utilizing the retransmission protocol that identifies one or more of low-PER and low-latency packets with underlying FEC/Interleaving (or deinterleaving), the FEC/interleaving is used to achieve the INPmin requirements within the latency constraint and the retransmission function is used to provide another layer of error correction. The low-PER packets are passed through both the retransmission function and the FEC/interleaver and, as a result, a very low PER is achieved. The low-latency packets are passed through the FEC/Interleaver but not passed through the retransmission function. Since low-latency packets are passed through the FEC/interleaver, they will meet the INPmin and MaxDelay requirements without incurring the extra delay from the retransmission protocol.

Example Configuration Parameters:

DS Data rate=25 Mbps, INPmin=2, MaxDelayDS=8 ms

Example FEC/Interleaving Parameters:

NFEC=128, R=16 which results in an interleaver memory of approximately 14 Kbytes for INP=2 with 8 ms of delay.

Retransmission Protocol:

If we assume the US latency is 2 ms, the retransmission protocol will add a minimum of $8+2=10$ ms of latency. This means that the total DS latency (FEC/interleaving+Retransmission) will be approximately $8+10=18$ ms.

Memory Requirements:

The memory requirements for the retransmission protocol can be calculated as: $(10 \text{ ms}) \times (25 \text{ Mbps})/8 = 31$ Kbytes. Therefore the transmitter and receiver will both need a total memory of $(31+14)=45$ Kbytes for the retransmission protocol and FEC/Interleaving function.

Low-PER Packets:

Latency=18 ms. The PER is very low because INPmin=2 (from FEC/interleaving) is combined with the error correction of the retransmission function.

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Low-Latency Packets:

Latency=8 ms. INP=2 from FEC/interleaving. No additional delay due to retransmission function.

Although this invention describes the retransmission being done as part of the PTM-TC, it could also be done inside other layer(s) of the xDSL transceiver, such as the PMD or the PMS-TC. Alternatively, it could be performed at a layer(s) above the PTM-TC, for example, in a new layer between the PTM-TC and the next higher layer, or in general any layer above the physical layer, e.g., layer 1, 2, 3, 4 or 5.

In this invention, the term "transmitter" generally refers to the transceiver that transmits the packets. Likewise the term "receiver" generally refers to the transceiver that receives the packets. Therefore the "transmitter" also receives the ACK/NAK messages and the "receiver" also transmits the ACK/NAK messages.

FIG. 2 outlines an exemplary method of operation of a transmitting modem utilizing the retransmission protocol. In particular, control begins in step S100 and continues to step S110. In step S110, a packet is received from a higher layer. Then, in step S120, a decision is made as to whether the received packet is a retransmitted type packet. If the packet is not a retransmitted type packet, such as a low-latency packet, control jumps to step S125 where the packet is optionally updated (as discussed above) with control continuing to step S130 where the packet is forwarded to the receiver. Control then continues to step S140 where the control sequence ends.

If the packet is a retransmitted type packet, such as a low-PER packet, control continues to step S150. In step S150, the packet can be updated with information such as a sequence identifier or other information that allows a receiver to be able to determine which packet (or packets) need to be retransmitted. Next, in step S160, the updated packet is stored in the retransmission buffer. Then, in step S170, the packet is forwarded to the receiver. Control then continues to step S180.

In step S180, a determination is made whether the packet needs to be retransmitted. If the packet needs to be retransmitted, control jumps back to step S170. Otherwise, control continues to step S190.

In step S190, the packet is deleted from the retransmission buffer. Control then continues to step S140 where the control sequence ends.

FIG. 3 outlines an exemplary method of operation of a receiving modem utilizing the retransmission protocol. In particular, control begins in step S200 and continues to step S210. In step S210, a packet is received from the transmitter. Next, in step S220, a determination is made whether the packet has been identified as a retransmitted type packet. If the packet has not been identified as a retransmittable type packet, control jumps to step S230.

In step S230, the packet is forwarded to a higher layer. Control then continues to step S240 where the control sequence ends.

Alternatively, if the received packet is a retransmittable type packet, the packet is stored in the retransmission buffer in step S260. Next, in step S270, the integrity of the packet can be checked, for example utilizing a CRC. Then, in step S280, a determination is made whether the packet needs retransmission. If the packet needs retransmission, control continues to step S290 where the retransmitted packet is obtained, for example, based on the sending of a message(s), one or the other transceiver determining a packet is missing, or the like, as discussed above, with control continuing back to step S270 for an integrity check.

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If the packet does not need retransmission, control continues to step S295 where the packet is forwarded to a higher layer and deleted from the retransmission buffer. Control then continues to step S240 where the control sequence ends.

FIG. 4 outlines an exemplary memory allocation method for sharing memory between the retransmission function and one or more of the interleaving/deinterleaving functionality and coding functionality. In particular, control begins in step S300 and continues to step S305. In step S305, a message is sent/received specifying the available memory. Typically, the receiver will send a message to the transmitter specifying the available memory, but the transmitter could also send a message to the receiver. Next, in step S310, a determination is made as to how the memory should be allocated. As discussed, this allocation can be based on one or more of error correction capability, latency, buffering requirements, SNR, impulse noise, or in general, any communication parameter. Next, in step S320, the memory allocation is communicated to another transceiver. Then, in step S330, a determination can be made as to whether the allocation is compatible. If the received allocation is not compatible, control continues to step S360 wherein another allocation can be requested, with control continuing back to step S320.

Alternatively, if the allocation is compatible, in step S340 the memory is allocated based on the received allocation. Control then continues to step S350 where the control sequence ends.

FIG. 5 illustrates an exemplary memory sharing methodology for use with a retransmission function and one or more of interleaving/deinterleaving functionality, RS coding/decoding functionality. In particular, control begins in step S400 and continues to step S410. In step S410, the memory allocation is received from, for example, a memory management module that may be located in the same transceiver, or at a remote transceiver. Next, in step S420, the memory sharing configuration is established and then, in step S430, the memory is shared between a retransmission function and one or more of the interleaving/deinterleaving functionality, RS coding/decoding functionality. Control then continues to step S440.

In step S440, a determination is made whether the memory sharing configuration should be changed. For example, the memory sharing configuration can be dynamically changed based on changes in the communication channel or data type(s) being sent on the communication channel. More specifically, for example, if the communications channel was not performing well, e.g., an increase in bit errors, it may be advantageous to increase the retransmission capability while decreasing the FEC/interleaving capability or vice-versa, which could have an impact on how the memory sharing should be configured.

If the memory sharing configuration should be changed, control continues to step S450 where another allocation can be requested, with control continuing back to step S410. Otherwise, control continues to step S460 where the control sequence ends.

While the above-described flowcharts have been discussed in relation to a particular sequence of events, it should be appreciated that changes to this sequence can occur without materially affecting the operation of the invention. Additionally, the exact sequence of events need not occur as set forth in the exemplary embodiments, but rather the steps can be performed by one or the other transceiver in the communication system provided both transceivers are aware of the technique being used for initialization. Additionally, the exemplary techniques illus-

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trated herein are not limited to the specifically illustrated embodiments but can also be utilized with the other exemplary embodiments and each described feature is individually and separately claimable.

The above-described system can be implemented on wired and/or wireless telecommunications devices, such as a modem, a multicarrier modem, a DSL modem, an ADSL modem, an xDSL modem, a VDSL modem, a linecard, test equipment, a multicarrier transceiver, a wired and/or wireless wide/local area network system, a satellite communication system, network-based communication systems, such as an IP, Ethernet or ATM system, a modem equipped with diagnostic capabilities, or the like, or on a separate programmed general purpose computer having a communications device or in conjunction with any of the following communications protocols: CDSL, ADSL2, ADSL2+, VDSL1, VDSL2, HDSL, DSL Lite, IDSL, RADSL, SDSL, UDSL or the like.

Additionally, the systems, methods and protocols of this invention can be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element(s), an ASIC or other integrated circuit, a digital signal processor, a hard-wired electronic or logic circuit such as discrete element circuit, a programmable logic device such as PLD, PLA, FPGA, PAL, a modem, a transmitter/receiver, any comparable means, or the like. In general, any device capable of implementing a state machine that is in turn capable of implementing the methodology illustrated herein can be used to implement the various communication methods, protocols and techniques according to this invention.

Furthermore, the disclosed methods may be readily implemented in software using object or object-oriented software development environments that provide portable source code that can be used on a variety of computer or workstation platforms. Alternatively, the disclosed system may be implemented partially or fully in hardware using standard logic circuits or VLSI design. Whether software or hardware is used to implement the systems in accordance with this invention is dependent on the speed and/or efficiency requirements of the system, the particular function, and the particular software or hardware systems or microprocessor or microcomputer systems being utilized. The communication systems, methods and protocols illustrated herein can be readily implemented in hardware and/or software using any known or later developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the functional description provided herein and with a general basic knowledge of the computer and telecommunications arts.

Moreover, the disclosed methods may be readily implemented in software that can be stored on a storage medium, executed on programmed general-purpose computer with the cooperation of a controller and memory, a special purpose computer, a microprocessor, or the like. In these instances, the systems and methods of this invention can be implemented as program embedded on personal computer such as an applet, JAVA® or CGI script, as a resource residing on a server or computer workstation, as a routine embedded in a dedicated communication system or system component, or the like. The system can also be implemented by physically incorporating the system and/or method into a software and/or hardware system, such as the hardware and software systems of a communications transceiver.

It is therefore apparent that there has been provided, in accordance with the present invention, systems and methods for packet retransmission and memory sharing. While this

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invention has been described in conjunction with a number of embodiments, it is evident that many alternatives, modifications and variations would be or are apparent to those of ordinary skill in the applicable arts. Accordingly, it is intended to embrace all such alternatives, modifications, equivalents and variations that are within the spirit and scope of this invention.

The invention claimed is:

1. An apparatus comprising:

a multicarrier transceiver including a processor and memory capable of:

transmitting a packet using forward error correction encoding and interleaving, wherein the packet comprises a header field and a plurality of Reed-Solomon codewords, and wherein the header field comprises a sequence identifier (SID); and

receiving a message using forward error correction decoding and without using deinterleaving, wherein the message is received in a single DMT symbol, and wherein the message includes an acknowledgement (ACK) or a negative acknowledgement (NACK) of the transmitted packet.

2. The apparatus of claim 1, wherein the received message has a higher immunity to noise than the transmitted packet.

3. The apparatus of claim 1, wherein the transceiver is capable of retransmitting the packet using forward error correction encoding and interleaving.

4. The apparatus of claim 1, wherein a physical layer of the transceiver is capable of generating the packet and the message.

5. The apparatus of claim 1, wherein a layer above a physical layer of the transceiver is capable of generating the packet and the message.

6. The apparatus of claim 2, wherein a physical layer of the transceiver is capable of generating the packet and the message.

7. The apparatus of claim 2, a layer above a physical layer of the transceiver is capable of generating the packet and the message.

8. An apparatus comprising:

a multicarrier transceiver including a processor and memory capable of:

receiving a packet using forward error correction decoding and deinterleaving, wherein the packet comprises a header field and a plurality of Reed-Solomon codewords, and wherein the header field comprises a sequence identifier (SID); and

transmitting a message using forward error correction encoding and without using interleaving, wherein the message is transmitted in a single DMT symbol and wherein the message includes an acknowledgement (ACK) or a negative acknowledgement (NACK) of the received packet.

9. The apparatus of claim 8, wherein the transmitted message has a higher immunity to noise than the received packet.

10. The apparatus of claim 8, wherein the transceiver is capable of receiving a retransmitted packet using forward error correction decoding and deinterleaving.

11. The apparatus of claim 8, wherein a physical layer of the transceiver is capable of generating the packet and the message.

12. The apparatus of claim 8, wherein a layer above a physical layer of the transceiver is capable of generating the packet and the message.

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13. The apparatus of claim 9, wherein a physical layer of the transceiver is capable of generating the packet and the message.

14. The apparatus of claim 9, wherein a layer above a physical layer of the transceiver is capable of generating the packet and the message.

15. A non-transitory computer-readable information storage media having stored thereon instructions, that when executed by one or more processors in a transceiver, cause the transceiver to:

transmit a packet using forward error correction encoding and interleaving, wherein the packet comprises a header field and a plurality of Reed-Solomon codewords, and wherein the header field comprises a sequence identifier (SID); and

receive a message using forward error correction decoding and without using deinterleaving, wherein the message is received in a single DMT symbol, and wherein the message includes an acknowledgement (ACK) or a negative acknowledgement (NACK) of the transmitted packet.

16. The media of claim 15, wherein the received message has a higher immunity to noise than the transmitted packet.

17. The media of claim 15, wherein instructions further cause the transceiver to retransmit the packet using forward error correction encoding and interleaving.

18. The media of claim 15, wherein instructions further cause a physical layer of the transceiver to generate the packet and the message.

19. The media of claim 15, wherein instructions further cause a layer above a physical layer of the transceiver to generate the packet and the message.

20. The media of claim 16, wherein instructions further cause a physical layer of the transceiver to generate the packet and the message.

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21. The media of claim 16, wherein instructions further cause a layer above a physical layer of the transceiver to generate the packet and the message.

22. A non-transitory computer-readable information storage media having stored thereon instructions, that when executed by one or more processors in a transceiver, cause the transceiver to:

receive a packet using forward error correction decoding and deinterleaving, wherein the packet comprises a header field and a plurality of Reed-Solomon codewords, and wherein the header field comprises a sequence identifier (SID); and

transmit a message using forward error correction encoding and without using interleaving, wherein the message is transmitted in a single DMT symbol and wherein the message includes an acknowledgement (ACK) or a negative acknowledgement (NACK) of the received packet.

23. The media of claim 22, wherein the transmitted message has a higher immunity to noise than the received packet.

24. The media of claim 22, wherein the instructions further cause the transceiver to retransmit the packet using forward error correction decoding and deinterleaving.

25. The media of claim 22, wherein instructions further cause a physical layer of the transceiver to generate the packet and the message.

26. The media of claim 22, wherein instructions further cause a layer above a physical layer of the transceiver to generate the packet and the message.

27. The media of claim 23, wherein instructions further cause a physical layer of the transceiver to generate the packet and the message.

28. The media of claim 23, wherein instructions further cause a layer above a physical layer of the transceiver to generate the packet and the message.

* * * * *

CIVIL COVER SHEET

The JS 44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. (SEE INSTRUCTIONS ON NEXT PAGE OF THIS FORM.)

I. (a) PLAINTIFFS

TQ DELTA, LLC

(b) County of Residence of First Listed Plaintiff Travis Co., Texas
(EXCEPT IN U.S. PLAINTIFF CASES)

(c) Attorneys (Firm Name, Address, and Telephone Number)

William E. Davis, III, The Davis Firm, PC 213 N. Fredonia
Street, Suite 230, Longview, TX 75601

DEFENDANTS

COMMSCOPE HOLDING COMPANY, INC., ET AL.

County of Residence of First Listed Defendant

(IN U.S. PLAINTIFF CASES ONLY)

NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF
THE TRACT OF LAND INVOLVED.

Attorneys (If Known)

II. BASIS OF JURISDICTION (Place an "X" in One Box Only)

- ☐ 1 U.S. Government Plaintiff
- ☒ 3 Federal Question
(U.S. Government Not a Party)
- ☐ 2 U.S. Government Defendant
- ☐ 4 Diversity
(Indicate Citizenship of Parties in Item III)

III. CITIZENSHIP OF PRINCIPAL PARTIES (Place an "X" in One Box for Plaintiff and One Box for Defendant)

- | | PTF | DEF | | PTF | DEF |
|---|----------------------------|----------------------------|---|----------------------------|----------------------------|
| Citizen of This State | ☐ 1 | ☐ 1 | Incorporated or Principal Place of Business In This State | ☐ 4 | ☐ 4 |
| Citizen of Another State | ☐ 2 | ☐ 2 | Incorporated and Principal Place of Business In Another State | ☐ 5 | ☐ 5 |
| Citizen or Subject of a Foreign Country | ☐ 3 | ☐ 3 | Foreign Nation | ☐ 6 | ☐ 6 |

IV. NATURE OF SUIT (Place an "X" in One Box Only)

Click here for: [Nature of Suit Code Descriptions.](#)

CONTRACT	TORTS	FORFEITURE/PENALTY	BANKRUPTCY	OTHER STATUTES
☐ 110 Insurance	☐ 310 Airplane	☐ 625 Drug Related Seizure of Property 21 USC 881	☐ 422 Appeal 28 USC 158	☐ 375 False Claims Act
☐ 120 Marine	☐ 315 Airplane Product Liability	☐ 690 Other	☐ 423 Withdrawal 28 USC 157	☐ 376 Qui Tam (31 USC 3729(a))
☐ 130 Miller Act	☐ 320 Assault, Libel & Slander		☐ 424 Intellectual Property Rights	☐ 400 State Reapportionment
☐ 140 Negotiable Instrument	☐ 330 Federal Employers' Liability		☒ 820 Copyrights	☐ 410 Antitrust
☐ 150 Recovery of Overpayment & Enforcement of Judgment	☐ 340 Marine		☐ 830 Patent	☐ 430 Banks and Banking
☐ 151 Medicare Act	☐ 345 Marine Product Liability		☐ 835 Patent - Abbreviated New Drug Application	☐ 450 Commerce
☐ 152 Recovery of Defaulted Student Loans (Excludes Veterans)	☐ 350 Motor Vehicle	☐ 710 Fair Labor Standards Act	☐ 840 Trademark	☐ 460 Deportation
☐ 153 Recovery of Overpayment of Veteran's Benefits	☐ 355 Motor Vehicle Product Liability	☐ 720 Labor/Management Relations	☐ 880 Defend Trade Secrets Act of 2016	☐ 470 Racketeer Influenced and Corrupt Organizations
☐ 160 Stockholders' Suits	☐ 360 Other Personal Injury	☐ 740 Railway Labor Act	☐ 861 HIA (1395ff)	☐ 480 Consumer Credit (15 USC 1681 or 1692)
☐ 190 Other Contract	☐ 362 Personal Injury - Medical Malpractice	☐ 751 Family and Medical Leave Act	☐ 862 Black Lung (923)	☐ 485 Telephone Consumer Protection Act
☐ 195 Contract Product Liability		☐ 790 Other Labor Litigation	☐ 863 DIWC/DIWW (405(g))	☐ 490 Cable/Sat TV
☐ 196 Franchise		☐ 791 Employee Retirement Income Security Act	☐ 864 SSID Title XVI	☐ 850 Securities/Commodities/Exchange
			☐ 865 RSI (405(g))	☐ 890 Other Statutory Actions
				☐ 891 Agricultural Acts
				☐ 893 Environmental Matters
				☐ 895 Freedom of Information Act
				☐ 870 Taxes (U.S. Plaintiff or Defendant)
				☐ 871 IRS—Third Party 26 USC 7609
				☐ 896 Arbitration
				☐ 899 Administrative Procedure Act/Review or Appeal of Agency Decision
				☐ 950 Constitutionality of State Statutes

V. ORIGIN (Place an "X" in One Box Only)

- ☒ 1 Original Proceeding
- ☐ 2 Removed from State Court
- ☐ 3 Remanded from Appellate Court
- ☐ 4 Reinstated or Reopened
- ☐ 5 Transferred from Another District (specify)
- ☐ 6 Multidistrict Litigation - Transfer
- ☐ 8 Multidistrict Litigation - Direct File

VI. CAUSE OF ACTION

Cite the U.S. Civil Statute under which you are filing (Do not cite jurisdictional statutes unless diversity):
35 U.S.C. § 271, et seq.Brief description of cause:
Patent Infringement

VII. REQUESTED IN COMPLAINT:

☐ CHECK IF THIS IS A CLASS ACTION UNDER RULE 23, F.R.Cv.P.

DEMAND \$

CHECK YES only if demanded in complaint:

JURY DEMAND: ☐ Yes ☐ No

VIII. RELATED CASE(S) IF ANY

(See instructions):

JUDGE Honorable Rodney GilstrapDOCKET NUMBER 2:21-cv-309-JRG

DATE

Aug 13, 2021

SIGNATURE OF ATTORNEY OF RECORD

/s/ William E. Davis, III

FOR OFFICE USE ONLY

RECEIPT # _____ AMOUNT _____ APPLYING IFP _____ JUDGE _____ MAG. JUDGE _____

INSTRUCTIONS FOR ATTORNEYS COMPLETING CIVIL COVER SHEET FORM JS 44

Authority For Civil Cover Sheet

The JS 44 civil cover sheet and the information contained herein neither replaces nor supplements the filings and service of pleading or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. Consequently, a civil cover sheet is submitted to the Clerk of Court for each civil complaint filed. The attorney filing a case should complete the form as follows:

- I.(a) Plaintiffs-Defendants.** Enter names (last, first, middle initial) of plaintiff and defendant. If the plaintiff or defendant is a government agency, use only the full name or standard abbreviations. If the plaintiff or defendant is an official within a government agency, identify first the agency and then the official, giving both name and title.
- (b) County of Residence.** For each civil case filed, except U.S. plaintiff cases, enter the name of the county where the first listed plaintiff resides at the time of filing. In U.S. plaintiff cases, enter the name of the county in which the first listed defendant resides at the time of filing. (NOTE: In land condemnation cases, the county of residence of the "defendant" is the location of the tract of land involved.)
- (c) Attorneys.** Enter the firm name, address, telephone number, and attorney of record. If there are several attorneys, list them on an attachment, noting in this section "(see attachment)".
- II. Jurisdiction.** The basis of jurisdiction is set forth under Rule 8(a), F.R.Cv.P., which requires that jurisdictions be shown in pleadings. Place an "X" in one of the boxes. If there is more than one basis of jurisdiction, precedence is given in the order shown below.
- United States plaintiff. (1) Jurisdiction based on 28 U.S.C. 1345 and 1348. Suits by agencies and officers of the United States are included here.
- United States defendant. (2) When the plaintiff is suing the United States, its officers or agencies, place an "X" in this box.
- Federal question. (3) This refers to suits under 28 U.S.C. 1331, where jurisdiction arises under the Constitution of the United States, an amendment to the Constitution, an act of Congress or a treaty of the United States. In cases where the U.S. is a party, the U.S. plaintiff or defendant code takes precedence, and box 1 or 2 should be marked.
- Diversity of citizenship. (4) This refers to suits under 28 U.S.C. 1332, where parties are citizens of different states. When Box 4 is checked, the citizenship of the different parties must be checked. (See Section III below; **NOTE: federal question actions take precedence over diversity cases.**)
- III. Residence (citizenship) of Principal Parties.** This section of the JS 44 is to be completed if diversity of citizenship was indicated above. Mark this section for each principal party.
- IV. Nature of Suit.** Place an "X" in the appropriate box. If there are multiple nature of suit codes associated with the case, pick the nature of suit code that is most applicable. Click here for: [Nature of Suit Code Descriptions](#).
- V. Origin.** Place an "X" in one of the seven boxes.
- Original Proceedings. (1) Cases which originate in the United States district courts.
- Removed from State Court. (2) Proceedings initiated in state courts may be removed to the district courts under Title 28 U.S.C., Section 1441.
- Remanded from Appellate Court. (3) Check this box for cases remanded to the district court for further action. Use the date of remand as the filing date.
- Reinstated or Reopened. (4) Check this box for cases reinstated or reopened in the district court. Use the reopening date as the filing date.
- Transferred from Another District. (5) For cases transferred under Title 28 U.S.C. Section 1404(a). Do not use this for within district transfers or multidistrict litigation transfers.
- Multidistrict Litigation – Transfer. (6) Check this box when a multidistrict case is transferred into the district under authority of Title 28 U.S.C. Section 1407.
- Multidistrict Litigation – Direct File. (8) Check this box when a multidistrict case is filed in the same district as the Master MDL docket.
- PLEASE NOTE THAT THERE IS NOT AN ORIGIN CODE 7.** Origin Code 7 was used for historical records and is no longer relevant due to changes in statute.
- VI. Cause of Action.** Report the civil statute directly related to the cause of action and give a brief description of the cause. **Do not cite jurisdictional statutes unless diversity.** Example: U.S. Civil Statute: 47 USC 553 Brief Description: Unauthorized reception of cable service.
- VII. Requested in Complaint.** Class Action. Place an "X" in this box if you are filing a class action under Rule 23, F.R.Cv.P.
- Demand. In this space enter the actual dollar amount being demanded or indicate other demand, such as a preliminary injunction.
- Jury Demand. Check the appropriate box to indicate whether or not a jury is being demanded.
- VIII. Related Cases.** This section of the JS 44 is used to reference related pending cases, if any. If there are related pending cases, insert the docket numbers and the corresponding judge names for such cases.

Date and Attorney Signature. Date and sign the civil cover sheet.