

1993 IEEE 43rd Vehicular Technology Conference





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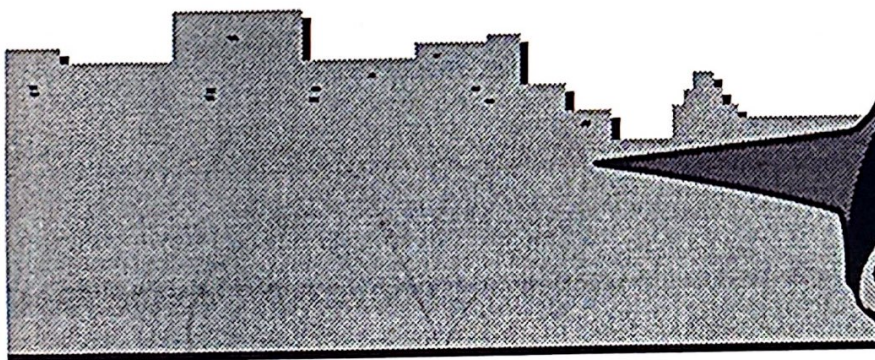
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1993
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Vehicular Technology Conference

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*Personal Communication -
Freedom Through
Wireless Technology*



1993 IEEE 43rd Vehicular Technology Conference

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A New Microcell Architecture Using Digital Optical Transport

Philip M. Wala

Waseca Technology, Inc.

RR4 Box 145, P.O. Box 286

Waseca, MN 56093 USA

Abstract - The performance of microcells which rely on analog modulation of an optical or microwave carrier is limited by the dynamic range of the analog transport. This paper describes a new microcell design which relies on high speed, analog-to-digital conversion to digitize the entire cellular band, enabling transparent RF transport to be accomplished over a digitally modulated optical fiber. Laboratory and field tests of an ADC Kentrox microcell which uses this technique are described. The application of this technology to the future design of an all-digital cellular base station is also discussed.

I. INTRODUCTION

The trend towards a "personal communications" environment requires the ability to deliver sufficient coverage and capacity to provide truly ubiquitous service. Coverage must be provided in areas not served by macrocell antenna installations, including shadow areas, tunnels, and the interiors of high-rise office buildings. Capacity must be sufficient to accommodate high concentrations of users in convention centers and train stations. In addition, as cells continue to decrease in size and increase in number, the cost of real estate becomes significant, requiring that this coverage and capacity be delivered using equipment occupying a minimum amount of space. Finally, the plurality of potential modulation techniques, including FM, TDMA and CDMA, provides incentive for an infrastructure configuration that maintains flexibility for future system upgrades.

II. LIMITATIONS OF TRADITIONAL SOLUTIONS

Solutions to the problem of delivering coverage and capacity fall into three general categories: cellular repeaters, 0-7803-1266-X/93/\$3.00©1993IEEE

distributed radio microcells, and centralized radio microcells [1].

Cellular repeaters increase coverage by re-radiating off-the-air signals. Because existing channels are re-transmitted, there is no capacity increase. Also, system degradation can occur due to the fact that noise and interference are re-radiated, along with the desired signals.

Distributed radio microcells or "mini-cells" are miniature versions of cell sites, incorporating a separate receiver and exciter for each channel served. While such a configuration can add both capacity and coverage, size and cost will increase proportionately to the number of channels. Such a system also lacks the ability to upgrade to new modulation techniques without replacing all of the transceiver modules.

Centralized radio microcells transport a broadband spectrum of combined radio frequency (RF) signals between remote antenna sites and banks of centrally located single-channel transceivers. This configuration has the advantage of transparency to modulation technique and the ability to serve multiple channels without any change to the remote equipment.

Most products of this type, however, suffer from the disadvantage that the transport is accomplished by the analog modulation of an optical or microwave carrier. This severely limits the dynamic range of the system for two reasons.

First of all, there is a tradeoff between signal-to-noise ratio and third-order intermodulation performance, which is a function of the modulation depth per channel [2], [3]. It can be difficult to maintain the optimum operating point, especially in a system where the number of active carriers can be constantly changing. Ultimately, in an optical system, the third-order intermodulation performance of the diode laser becomes the limiting factor [2], [4].

Secondly, the nature of analog modulation is such that the system dynamic range is destined to degrade in proportion to the attenuation on the transport link. In an optical system, this degradation is equal to twice the optical attenuation in dB [5], yielding an optical budget of as little as 10 dB [6] and maximum fiber distances on the order of 10 km [7].

III. A NEW APPROACH: DIGITAL RF TRANSPORT

Many of the problems associated with analog modulation could be circumvented if it were possible to first digitize the information signal and then transport it digitally. Up until now that possibility has not been considered for the transport of the broadband "A" or "B" cellular spectrum because of the difficulty of digitizing the 12.5 MHz bandwidth with enough speed, resolution and linearity to accurately reproduce the dynamic range of signals found in the mobile environment. Recently, however, analog-to-digital converters with sufficient performance capabilities have become available [8], and have been successfully incorporated into a newly announced fiber-fed microcell product [9].

This digital microcell system consists of two main components: a donor or "host" site interface, and a remote microcell unit (Fig.1)

In the forward or "downlink" path, the host interface takes the combined channels from the cell site transmitters and digitizes the broadband signal at a sample rate of 30.72 MHz. An optical transmitter adds overhead and signaling information and creates a 552.96 Mbps serial data stream which is used to digitally modulate an optical carrier. At the remote site, an optical receiver demodulates the incoming optical carrier, and reconstructs the original 30.72 MHz parallel word, which is then converted back to RF by a digital-to-RF converter. At this point, the combined forward link channels have been reconstructed, and are ready to be linearly amplified for transmission.

In the reverse or "uplink" path, signals coming in through the antenna from mobiles or handhels are filtered to remove out-of-band signals. The 12.5 MHz spectrum is then digitized in much the same way as the forward link spectrum, and a similar serial data stream is constructed for digital optical transport. At the host site, the optical carrier is demodulated, and the original RF signal is reconstructed and sent on to the individual channel receivers.

This particular configuration also incorporates the use of two different wavelength lasers and a wavelength division multiplexer (WDM) in order to enable bi-directional transport of forward and reverse path RF over a single fiber.

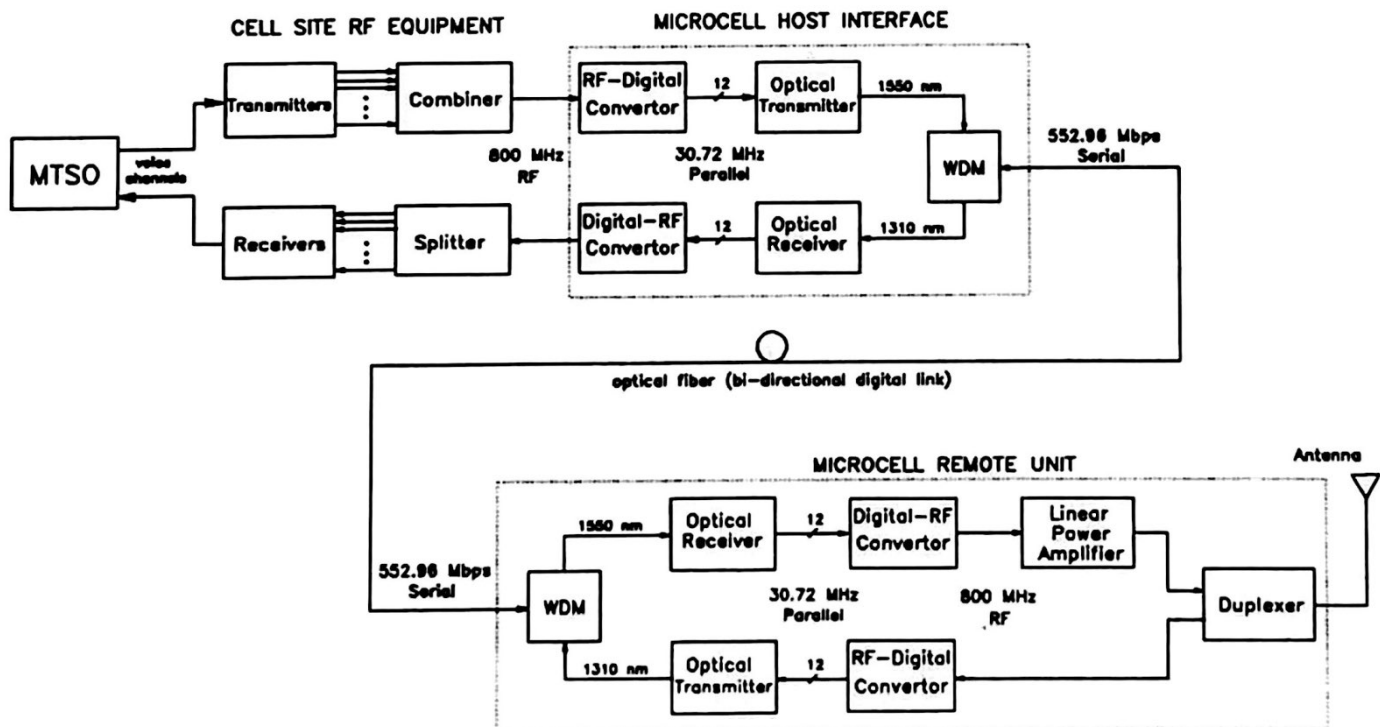


Fig.1. Digital RF transport microcell: system block diagram

The host interface for each microcell is contained in a 17" x 7" x 8.5" rack mountable module. The remote cabinet is 34" x 20" x 11" (including power supply and backup batteries), and can be pole or wall mounted.

IV. DIGITAL RF TRANSPORT: PERFORMANCE EVALUATION

Microcells employing the digital transport architecture have been tested on the bench as well as in actual service, and have demonstrated all the advantages of other centralized radio microcells, including transparency to modulation technique and channel selection, and a small remote unit size that is independent of the number of channels being carried. The absolute group delay due to the filtering and digitization process has been measured at less than 4 μ s across the band, and should not adversely affect TDMA or CDMA signals.

In addition, the digital microcell has proven to have some significant advantages over earlier generation analog versions. Because the forward link carries a relatively narrow dynamic range of signals, with the path performance typically limited by the linearity of the power amplifier (as in analog microcells), much of the following discussion will focus on the transport of the more hostile reverse link (mobile to cell site) spectrum.

Assuming that the digital transport can be accomplished without significant errors, the reverse link dynamic range will be limited by signal-to-noise ratio and linearity of the digitization and reconstruction process. In analog systems, the spurious free dynamic range is a function of the noise level in the signal bandwidth (N_s) and the third-order intercept point (IP_3), both in dBm:

$$SFDR = (2/3) \times (IP_3 - N_s) \quad (1)$$

Neglecting fiber loss, distributed feedback (DFB) lasers with an output power of +3 dBm have achieved a spurious free dynamic range on the order of 82 dB [4], with an absolute theoretical maximum of approximately 88 dB, assuming a 30 kHz signal bandwidth [10].

In the digitized system described here, (1) cannot be applied, because the third-order intermodulation products not only fail to rise faster than the fundamentals, their level may actually drop as the fundamental signals increase or additional signals are added (due, in part, to the "dithering effect", which can add effective bits of resolution to an over-sampled system). Consequently, one must evaluate the

dynamic range by noting the behavior of the noise floor and the third-order products as a function of signal level in order to determine the effect of any anomalies in the curves. In the prototype system, third-order spurious free dynamic range was limited to about 76 dB.

The real advantage of the digital transport method becomes apparent when one examines the optical budgets of the digital and analog systems. First of all, although the digital system third-order dynamic range is less than the theoretical maximum attributed to analog systems, it should be noted that this is achieved with a -4 dBm output laser, rather than the +3 dBm assumed earlier. An analog system with an equivalent laser power would be limited to a maximum dynamic range of about 74 dB.

Secondly, the nature of digital transport is such that, up until the point where the optical level approaches the sharp threshold where synchronization is lost, there is no degradation of the signal being transported whereas analog systems suffer 2 dB of degradation for every dB of optical attenuation [5]. The digital transport can maintain the RF path at its full dynamic range for optical levels as low as -31 dBm (more than a 20 dB improvement over analog transport). The dramatic nature of the improvement can be seen in Fig. 2, with an arbitrary 65 dB dynamic range performance requirement marked to show the effect on the usable fiber distance.

V. DIGITAL RF TRANSPORT: FUTURE APPLICATIONS

The dynamic range and optical budget advantages already demonstrated constitute only a portion of the potential benefits of digital RF transport.

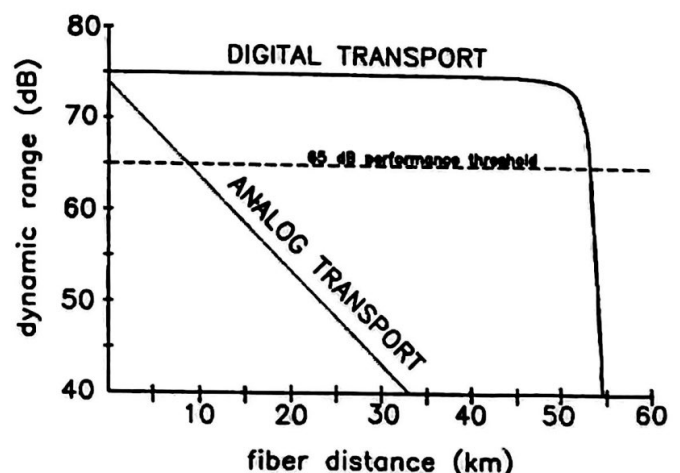


Fig. 2. Dynamic range vs. fiber distance (-4 dBm lasers)

Further potential advantages stem from the fact that digital signals are well suited to being time-division multiplexed with other digital signals. Although the current system uses time-division multiplexing to carry secondary digital channels with alarm and control information, secondary channels could serve a multitude of other purposes, including an uplink diversity path, an alternate RF service (such as paging), or digitized cable TV signals.

Ultimately, the establishment of a standard for the digital transport of RF could lead to a digital RF distribution system, carrying cellular or personal communications services, paging, trunking, or even broadcast signals, with drop and add capability, to a widespread network of microcells situated to provide seamless coverage of a service area.

Perhaps the biggest potential for the future of digital transport can be anticipated by another look at Fig.1. Because the voice channels between the mobile telephone switching office (MTSO) and the cell site are often already in digitized form, and the interface to the host microcell interface optical transceiver is a parallel digital word, one might legitimately wonder why one should even bother to make the intermediate conversion to RF. Conceivably, the cell site transceivers, combiners, splitters, and RF-digital converters could all be replaced by a digital signal processing unit, which would take the digitized voice signals and synthesize a digitized RF spectrum, reversing the process on the uplink path. In this configuration, RF would appear only at the remote microcell cabinet, and all cell site RF transceivers, combiners, splitters and filters would be replaced by an all-digital base station.

VI. CONCLUSIONS

The application of new digital RF transport technology to a fiber-fed microcell application has been described, and its performance compared with that of analog microcells. Digital microcells have demonstrated dynamic range as good as or better than their analog counterparts, with no discernible degradation for fiber distances in excess of 50 km. Digital RF transport also has the potential for revolutionizing the way we think about distributing RF by making possible a digital RF transport infrastructure, in which a network of remote antenna locations are served, without degradation, from a centrally located all-digital base station.

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