

Computer Networks

Third Edition

Andrew S. Tanenbaum

*Vrije Universiteit
Amsterdam, The Netherlands*

For book and bookstore information



<http://www.prenhall.com>



*Prentice Hall PTR
Upper Saddle River, New Jersey 07458*

EXHIBIT

11

WITNESS
Michael Goodrich, Ph.D.
DATE: 2-24-17
Nancy A. Morrow
CSR No. 11977

Handwritten notes and scribbles in the top left corner, including the letters 'TK' and some illegible markings.

Library of Congress Cataloging in Publication Data

Tanenbaum, Andrew S. 1944-
Computer networks / Andrew S. Tanenbaum. -- 3rd ed.
p. cm.
Includes bibliographical references and index.
ISBN 0-13-349945-6
I. Computer networks. I. Title.
TK5105.5.T36 1996
004.6--dc20

96-4121
CIP

Editorial/production manager: *Caville Trentacoste*
Interior design and composition: *Andrew S. Tanenbaum*
Cover design director: *Jerry Votta*
Cover designer: *Don Martinetti, DM Graphics, Inc.*
Cover concept: *Andrew S. Tanenbaum, from an idea by Marilyn Tremaine*
Interior graphics: *Hadel Studio*
Manufacturing manager: *Alexis R. Heydt*
Acquisitions editor: *Mary Franz*
Editorial Assistant: *Noreen Regino*



© 1996 by Prentice Hall PTR
Prentice-Hall, Inc.
A Simon & Schuster Company
Upper Saddle River, New Jersey 07458

The publisher offers discounts on this book when ordered in bulk quantities. For more information, contact:

Corporate Sales Department, Prentice Hall PTR, One Lake Street, Upper Saddle River, NJ 07458.
Phone: (800) 382-3419; Fax: (201) 236-7141. E-mail: corpsales@prehall.com

All rights reserved. No part of this book may be reproduced, in any form or by any means, without permission in writing from the publisher.

All product names mentioned herein are the trademarks of their respective owners.

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

ISBN 0-13-349945-6

Prentice-Hall International (UK) Limited, *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Prentice-Hall Canada Inc., *Toronto*
Prentice-Hall Hispanoamericana, S.A., *Mexico*
Prentice-Hall of India Private Limited, *New Delhi*
Prentice-Hall of Japan, Inc., *Tokyo*
Simon & Schuster Asia Pte. Ltd., *Singapore*
Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*

10/1/16
10/1/16
10/1/16
10/1/16
10/1/16
10/1/16

To Suzanne, Barbara, Marvin, and Little Bram

been cleaned up. Finally, the monitor detects orphan frames by setting the *monitor* bit in the *Access control* byte whenever it passes through. If an incoming frame has this bit set, something is wrong since the same frame has passed the monitor twice without having been drained, so the monitor drains it.

One last monitor function concerns the length of the ring. The token is 24 bits long, which means that the ring must be big enough to hold 24 bits. If the 1-bit delays in the stations plus the cable length add up to less than 24 bits, the monitor inserts extra delay bits so that a token can circulate.

One maintenance function that cannot be handled by the monitor is locating breaks in the ring. When a station notices that either of its neighbors appears to be dead, it transmits a BEACON frame giving the address of the presumably dead station. When the beacon has propagated around as far as it can, it is then possible to see how many stations are down and delete them from the ring using the bypass relays in the wire center, all without human intervention.

It is instructive to compare the approaches taken to controlling the token bus and the token ring. The 802.4 committee was scared to death of having any centralized component that could fail in some unexpected way and take the system down with it. Therefore they designed a system in which the current token holder had special powers (e.g., soliciting bids to join the ring), but no station was otherwise different from the others (e.g., currently assigned administrative responsibility for maintenance).

The 802.5 committee, on the other hand, felt that having a centralized monitor made handling lost tokens, orphan frames and so on much easier. Furthermore, in a normal system, stations hardly ever crash, so occasionally having to put up with contention for a new monitor is not a great hardship. The price paid is that if the monitor ever really goes berserk but continues to issue ACTIVE MONITOR PRESENT control frames periodically, no station will ever challenge it. Monitors cannot be impeached.

This difference in approach comes from the different application areas the two committees had in mind. The 802.4 committee was thinking in terms of factories with large masses of metal moving around under computer control. Network failures could result in severe damage and had to be prevented at all costs. The 802.5 committee was interested in office automation, where a failure once in a rare while could be tolerated as the price for a simpler system. Whether 802.4 is, in fact, more reliable than 802.5 is a matter of some controversy.

4.3.4. Comparison of 802.3, 802.4, and 802.5

With three different and incompatible LANs available, each with different properties, many organizations are faced with the question: Which one should we install? In this section we will look at all three of the 802 LAN standards, pointing out their strengths and weaknesses, comparing and contrasting them.

To start with, it is worth noting that the three LAN standards use roughly similar technology and get roughly similar performance. While computer scientists and engineers can discuss the merits of coax versus twisted pair for hours on end if given half a chance, the people in the marketing, personnel, or accounting departments probably do not really care that much one way or the other.

Let us start with the advantages of 802.3. It is far and away the most widely used type at present, with a huge installed base and considerable operational experience. The protocol is simple. Stations can be installed on the fly, without taking the network down. A passive cable is used and modems are not required. Furthermore, the delay at low load is practically zero (stations do not have to wait for a token; they just transmit immediately).

On the other hand, 802.3 has a substantial analog component. Each station has to be able to detect the signal of the weakest other station, even when it itself is transmitting, and all of the collision detect circuitry in the transceiver is analog. Due to the possibility of having frames aborted by collisions, the minimum valid frame is 64 bytes, which represents substantial overhead when the data consist of just a single character from a terminal.

Furthermore, 802.3 is nondeterministic, which is often inappropriate for real-time work [although some real-time work is possible by simulating a token ring in software (Venkatramani and Chiueh, 1995)]. It also has no priorities. The cable length is limited to 2.5 km (at 10 Mbps) because the round-trip cable length determines the slot time, hence the performance. As the speed increases, the efficiency drops because the frame transmission times drop but the contention interval does not (the slot width is 2τ no matter what the data rate is). Alternatively, the cable has to be made shorter. Also, at high load, the presence of collisions becomes a major problem and can seriously affect the throughput.

Now let us consider 802.4, the token bus. It uses highly reliable cable television equipment, which is available off-the-shelf from numerous vendors. It is more deterministic than 802.3, although repeated losses of the token at critical moments can introduce more uncertainty than its supporters like to admit. It can handle short minimum frames.

Token bus also supports priorities and can be configured to provide a guaranteed fraction of the bandwidth to high-priority traffic, such as digitized voice. It also has excellent throughput and efficiency at high load, effectively becoming TDM. Finally, broadband cable can support multiple channels, not only for data, but also for voice and television.

On the down side, broadband systems use a lot of analog engineering and include modems and wideband amplifiers. The protocol is extremely complex and has substantial delay at low load (stations must always wait for the token, even in an otherwise idle system). Finally, it is poorly suited for fiber optic implementations and has a small installed base of users.

Now consider the token ring. It uses point-to-point connections, meaning that the engineering is easy and can be fully digital. Rings can be built using virtually

any transmission medium from carrier pigeon to fiber optics. The standard twisted pair is cheap and simple to install. The use of wire centers make the token ring the only LAN that can detect and eliminate cable failures automatically.

Like the token bus, priorities are possible, although the scheme is not as fair. Also like the token bus, short frames are possible, but unlike the token bus, so are arbitrarily large ones, limited only by the token-holding time. Finally, the throughput and efficiency at high load are excellent, like the token bus and unlike 802.3.

The major minus is the presence of a centralized monitor function, which introduces a critical component. Even though a dead monitor can be replaced, a sick one can cause headaches. Furthermore, like all token passing schemes, there is always delay at low load because the sender must wait for the token.

It is also worth pointing out that there have been numerous studies of all three LANs. The principal conclusion we can draw from these studies is that we can draw no conclusions from them. One can always find a set of parameters that makes one of the LANs look better than the others. Under most circumstances, all three perform well, so that factors other than the performance are probably more important when making a choice.

6
(sounded
cob!)

4.3.5. IEEE Standard 802.6: Distributed Queue Dual Bus

None of the 802 LANs we have studied so far are suitable for use as a MAN. Cable length limitations and performance problems when thousands of stations are connected limits them to campus-sized areas. For networks covering an entire city, IEEE defined one MAN, called **DQDB (Distributed Queue Dual Bus)**, as standard 802.6. In this section we will examine how it works. For additional information, see (Kessler and Train, 1992). A bibliography listing 171 papers about DQDB is given in (Sadiku and Arvind, 1994).

The basic geometry of 802.6 is illustrated in Fig. 1-4. Two parallel, unidirectional buses snake through the city, with stations attached to both buses in parallel. Each bus has a head-end, which generates a steady stream of 53-byte cells. Each cell travels downstream from the head-end. When it reaches the end, it falls off the bus.

Each cell carries a 44-byte payload field, making it compatible with some AAL modes. Each cell also holds two protocol bits, *Busy*, set to indicate that a cell is occupied, and *Request*, which can be set when a station wants to make a request.

To transmit a cell, a station has to know whether the destination is to the left of it or to the right of it. If the destination is to the right, the sender uses bus *A*. Otherwise, it uses bus *B*. Data are inserted onto either bus using a wired-OR circuit, so failure of a station does not take down the network.

Unlike all the other 802 LAN protocols, 802.6 is not greedy. In all the others, if a station gets the chance to send, it will. Here, stations queue up in the order