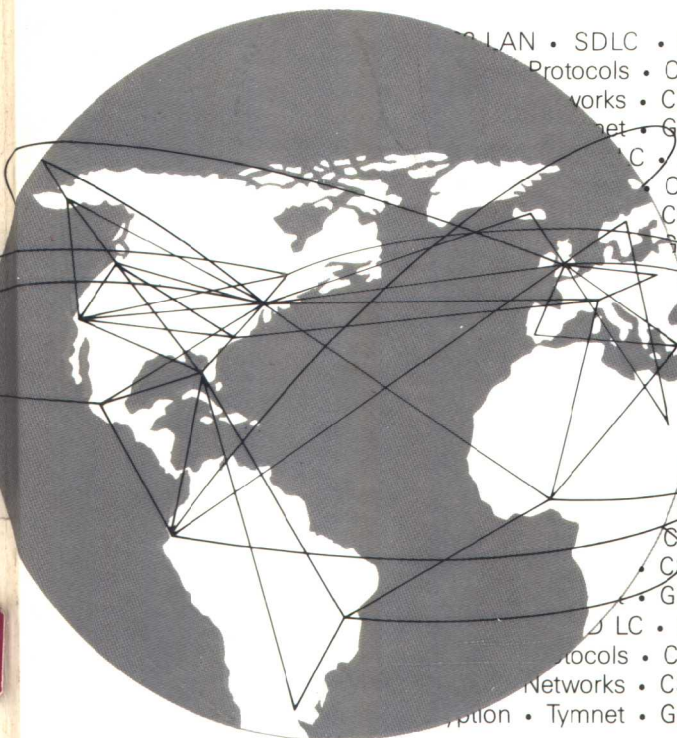


COMPUTER NETWORKS

Protocols, Standards, and Interfaces

UYLESS BLACK



• LAN • SDLC • Ethernet • HDLC • LAPB • X.75 • Bis
• Protocols • CCITT • Aloha • V series Modems • S
• Networks • CSMA/CD • X.3 • LAPD • Public Netw
• T • Gateways • Bridges • RS232C.
• C • Ethernet • HDLC • LAPB • X.75 • Bis
• CCITT • Aloha • V series Modems • S
• CSMA/CD • X.3 • LAPD • Public Netw
• Gateways • Bridges • RS232C.
• Ethernet • HDLC • LAPB • X.75 • Bis
• CCITT • Aloha • V series Modems • S
• MA/CD • X.3 • LAPD • Public Netw
• Gateways • Bridges • RS232C.
• Ethernet • HDLC • LAPB • X.75 • Bis
• CCITT • Aloha • V series Modems • S
• CSMA/CD • X.3 • LAPD • Public Netw
• Gateways • Bridges • RS232C.
• Ethernet • HDLC • LAPB • X.75 • Bis
• Protocols • CCITT • Aloha • V series Modems • S
• Networks • CSMA/CD • X.3 • LAPD • Public Netw
• T • Tymnet • Gateways • Bridges • RS232C.

Computer Networks

Protocols, Standards, and Interfaces

Uyless Black
Center for Advanced
Professional Education

Prentice-Hall, Inc.
Englewood Cliffs, New Jersey 07632

Library of Congress Cataloging-in-Publication Data

Black, Uyles D.

Computer networks.

Includes index.

1. Computer networks. I. Title.
TK5105.5.B56 1987 004.6 87-2228
ISBN 0-13-165754-2

Editorial/production supervision
and interior design: Evalyn Schoppet
Cover design: 20/20 Services, Inc.
Manufacturing buyer: Gordon Osbourne

© 1987 by Prentice-Hall, Inc.
A division of Simon & Schuster
Englewood Cliffs, New Jersey 07632

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.

Printed in the United States of America

10 9 8 7 6 5 4 3 2

ISBN 0-13-165754-2 025

Prentice-Hall Computer Communications Series
Wushow Chou, Advisor

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

Acknowledgments

It has been said that writing a book is an act of intellectual masochism. This statement has more than an element of truth to it. The author suffers, but derives gratification from the process as well. This is also true of the author's friends and colleagues; in my case, their support and encouragement has been essential during this lengthy project.

My Prentice-Hall editors, Karl Karlstrom and John Wait have been instrumental in seeing this book come to print. Dan Joraanstad from Prentice-Hall has also been very helpful and supportive of my ideas and efforts.

My friend, Phil Dietz, deserves special mention. He provided invaluable support in clarifying and simplifying some highly technical descriptions of electronics in this book, as he did for my previous book.

My four colleagues at the Center for Advanced Professional Education, Ed Sawicki, Ken Sherman, Herb Stern, and Rick Watkins, have played an important role in the production of this book, since they helped keep the bread on my table while I worked on the manuscript.

I also wish to thank the many individuals who have attended my lectures and seminars. I have benefitted enormously from their input to my lectures and to this book. My seminar attendees, not only in the United States but in Europe, Canada, and Asia, have given me immeasurably valuable insights into the data communications industry. I hope this book addresses some of their needs.

The reviews from Prentice-Hall were also very valuable to me. In several instances, they helped smooth out some technical detail, and I owe the reviewers my gratitude.

Holly Velez, Terece Crawford, and Jo Ann Schreiner have displayed uncommon intelligence and patience in dealing with my indecipherable notes and dictation, and with the constant changes. Jean Stum provided very valuable assistance as well.

Finally, the Black family has been the basic foundation supporting my efforts in the past, and they continue to offer this support today. My parents, my brothers, and my son, Tom, have my love and gratitude for their support.

Contents

Acknowledgments ix

Chapter One. Introduction to Computer Networks 1

The Use of Networks, 1 Advantages of Networks, 1 Structure of the Communications Network, 2 *Point-to-Point and Multidrop Circuits*, 4 *Data Flow and Physical Circuits*, 5 Network Topologies, 6 *Topologies and Design Goals*, 6 *Hierarchical Topology*, 8 *Horizontal Topology (Bus)*, 10 *Star Topology*, 10 *Ring Topology*, 10 *Mesh Topology*, 11 The Telephone Network, 11 *Switched and Nonswitched Options*, 13 Fundamentals of Communications Theory, 14 *Channel Speed and Bit Rate*, 14 *Voice Communications and Analog Waveforms*, 15 *Bandwidth and the Frequency Spectrum*, 16 Connecting the Analog and Digital Worlds, 19 *Digital Signals*, 19 *The Modem*, 20 Synchronizing Network Components, 21 *Synchronization Codes*, 22 *Asynchronous and Synchronous Transmission*, 25 Message Formats, 26 The Communications Port, 27 Additional Network Components, 28 Conclusion, 30 *Notes*, 30 *Suggested Readings*, 30

Chapter Two. Communications Between and Among Computers and Terminals 32

Introduction, 32 Traffic Control and Accountability, 32 *Checking for Errors*, 34 Wide Area and Local Networks, 35 Connection-Oriented and Connectionless Networks, 38 Classification of Communications Protocols, 41 Polling/Selection Systems, 43 *Selective and Group Polling*, 46 *Stop-and-Wait Polling/Selection*, 47 *Continuous ARQ (Sliding Windows)*, 48 Nonpolling Systems, 52 *Request to Send/Clear to Send*, 53 *Xon/Xoff*, 53 *Time Division Multiple Access (TDMA)*, 55 Nonpriority Systems, 56 *Time Division Multiplexing (TDM) or Slot*, 56 *Register Insertion*,

iii

56 *Carrier-Sense (Collision) Systems*, 56 *Token Passing*, 59 *Priority Systems*, 61 *Priority Slot*, 61 *Carrier-Sense (Collision-free) Systems*, 61 *Token Passing (Priority) Systems*, 62 *Conclusion*, 63 *Notes*, 63 *Suggested Readings*, 63

Chapter Three. Layered Protocols, Networks, and the OSI Model 64

Introduction, 64 *Rationale for Layered Protocols*, 64 *Goals of Layered Protocols*, 65 *Network Design Problems*, 65 *Communications Between Layers*, 66 *A Pragmatic Illustration*, 69 *Introduction to Standards Organizations and the OSI Standard*, 72 *Standards Organizations*, 72 *The Layers of OSI*, 74 *Conclusion*, 76 *Suggested Readings*, 77

Chapter Four. Polling/Selection Networks 78

Introduction, 78 *Binary Synchronous Control (BSC)*, 78 *BSC Formats and Control Codes*, 79 *Line Modes*, 80 *Line Control*, 81 *Other BSC Systems*, 83 *The 3270 Family*, 83 *Problems with BSC*, 85 *HDLC*, 86 *HDLC Options*, 86 *HDLC Frame Format*, 89 *Code Transparency and Synchronization*, 91 *HDLC Control Field*, 92 *Commands and Responses*, 95 *The HDLC Transmission Process*, 100 *HDLC Subsets*, 105 *SDLC*, 107 *Protocol Conversion*, 108 *Conclusion*, 111 *Notes*, 111 *Suggested Readings*, 111

Chapter Five. Satellite Networks 113

Introduction, 113 *Pros and Cons of Satellite Networks*, 114 *Brief History*, 116 *Using Satellites to Communicate*, 117 *Conventional Multiplexing*, 117 *Polling/Selection*, 117 *Nonpolling Peer/Peer Systems*, 119 *Nonpolling Primary Secondary Systems*, 124 *Satellite Delay Units (SDUs)*, 127 *The Teleport*, 129 *Conclusion*, 129 *Notes*, 130 *Suggested Readings*, 130

Chapter Six. Local Area Networks 131

Introduction, 131 *Primary Attributes of a LAN*, 132 *Broadband and Baseband LANs*, 133 *IEEE LAN Standards*, 133 *Relationship of the 802 Standards to the ISO/CCITT Model*, 134 *Connection Options with LANs*, 135 *LLC and MAC Protocol Data Units*, 137 *LAN Topologies and Protocols*, 138 *CSMA/CD and IEEE 802.3*, 139 *Token Ring (Priority)*, 144 *Token Bus and IEEE 802.4*, 149 *Summary of the 802 Specifications*, 151 *Other Systems*, 152 *AT&T Information System Network (ISN)*, 152 *IBM Token Ring*, 153 *ANSI Fiber Distributed Data Interface (FDDI)*, 159 *General Motors' Manufacturing Automation Protocol*

(MAP), 163 *The Technical and Office Products System (TOP)*, 163 Conclusion, 163 *Notes*, 165 *Suggested Readings*, 165

Chapter Seven. Switching and Routing in Networks 166

Introduction, 166 Telephone Switching Systems, 166 *Electromechanical Systems*, 169 *Stored Program Control Systems*, 171 Message Switching, 173 Packet Switching, 175 *When and When Not To Use Packet Switching*, 177 *Packet Routing*, 179 Packet-Switching Support to Circuit-Switching Networks, 189 Conclusion, 191 *Notes*, 191 *Suggested Readings*, 192

Chapter Eight. The X.25 Network 193

Introduction, 193 Layers of X.25, 195 *X.25 and the Physical Layer*, 195 *X.25 and the Data Link Layer*, 196 *Companion Standards to X.25*, 198 Features of X.25, 198 *X.25 Channel Options*, 198 Flow-control Principles, 203 Other Packet Types, 203 X.25 Logical Channel States, 207 Timeouts and Time Limits, 208 Packet Formats, 208 *The D Bit*, 213 *The M Bit*, 213 *A and B Packets*, 214 *The Q Bit*, 215 Flow Control and Windows, 216 X.25 Facilities, 216 Other Standards and Layers, 219 *The PAD*, 219 *PAD: Packet Formats and Packet Flow*, 226 *The Transport Layer*, 227 Internetworking, 232 Connectionless-mode Networks, 234 X.75, 234 Communications Between Layers, 238 Conclusion, 248 *Notes*, 250 *Suggested Readings*, 250

Chapter Nine. Digital Networks 252

Introduction, 252 Advantages of Digital Systems, 252 Signal Conversion, 254 Digital Carrier Systems, 257 Channel and Data Service Units, 260 Analog-to-Digital Techniques, 260 *Waveform Analysis*, 260 *Parameter Coding (Vocoders)*, 262 Future Digital Systems, 263 Integrated Digital Networks, 264 *Satellite Business Systems' Integrated Network*, 264 *The Integrated Services Digital Network*, 266 *Europe, the Far East, and the ISDN Recommendations*, 281 *United States and the ISDN Recommendations*, 282 Digital Switching, 283 Voice Transmission by Packet, 285 Bell Labs' Packet-Switched Voice-Data Patent, 287 Conclusion, 288 *Notes*, 289 *Suggested Readings*, 289

Chapter Ten. Public Networks and Carrier Offerings 290

Introduction, 290 Public Networks, 290 *Telenet*, 290 *TYMNET*, 292 *AUTONET*, 293 *Graphnet*, 294 *PACNET*, 294 Carrier Offerings,

295 *ISACOMM*, 295 *Interexchange Carrier Channels*, 295 AT&T's Major Offerings, 296 *ACCUNET T1.5*, 297 *SKYNET 1.5*, 297 *ACCUNET Reserved 1.5*, 297 *Circuit-Switched Digital Capability (CSDC)*, 298 Local Area Data Transport (LADT), 299 ACCUNET Packet Service, 301 Satellite Channel Offerings, 302 Offerings in Europe, 303 Offerings in Canada, 305 *Telephone Networks*, 305 *Telecom Canada*, 306 *CNCP Telecommunications*, 307 *TELEGLOBE Canada*, 308 *Telesat Canada*, 309 Conclusion, 309 *Notes*, 310 *Suggested Readings*, 310

Chapter Eleven. Personal Computer Networks 311

Introduction, 311 Personal Computer Communications Characteristics, 313 *Error Handling*, 315 Using the Personal Computer as a Server, 316 Linking the Personal Computer to Mainframe Computers, 317 Samples of Vendor Offerings, 320 File Transfer on Personal Computers, 321 Personal Computers and Local Area Networks, 323 *Examples of LANs and PCs*, 325 Personal Computer Networks and the OSI Model, 328 Conclusion, 329 *Notes*, 330 *Suggested Readings*, 330

Chapter Twelve. The PBX and Data Communications Networks 332

Introduction, 332 Evolution of the PBX, 333 Issue of Voice/Data Integration, 336 Issue of Using a PBX in a LAN, 337 *Wiring Costs*, 339 The Fourth-Generation PBX, 339 The Digital Multiplexed Interface (DMI) and Computer-to-PBX Interface (CPI) Proposals, 346 Conclusion, 348 *Notes*, 348 *Suggested Readings*, 348

Chapter Thirteen. Upper-Level Protocols 350

Introduction, 350 Network Security, 350 *Encryption with Private Keys*, 352 *The Data Encryption Standard (DES)*, 354 *Encryption with Public Keys*, 358 *ISO Security Recommendations*, 359 Terminal Systems and Protocols, 359 *Telematics*, 360 *Teletex*, 362 Electronic Mail, 370 Protocols for File Management, 373 Conclusion, 375 Final Thoughts, 375 *Notes*, 376 *Suggested Readings*, 377

Appendix A: A Data Communications Tutorial 379

Appendix B: Translation Tables 393

Appendix C: Physical Level Interfaces 396

Appendix D: Commonly Used Standards 414

Appendix E: Supporting Standards to X.25/X.75 Networks 427

Index 441

CHAPTER ONE

Introduction to Computer Networks

The Use of Networks

Due to the tremendous impact of computers and computer networks on society during the past decade, this period in history has come to be called the "information age." The productivity and profitability of both organizations and individuals have been enhanced significantly by these revolutionary tools. Hardly a day goes by without an individual using a computer network to conduct personal and professional business. This trend is accelerating as more businesses and homes discover the power of computers and communications networks. The day-to-day transactions at department stores, banks, reservation counters, and other businesses are all dependent upon computer networks. The information age is equally dependent on the computer *and* the computer network.

What is a computer network? Several definitions are accepted in the industry. Perhaps the simplest is: A number of computers (and usually terminals) interconnected by one or more transmission paths. The transmission path is often the telephone line, due to its convenience and universal presence. The network exists to meet one goal: the transfer and exchange of data between the computers and terminals. This data exchange provides for the many computer-based services we often take for granted in our daily lives, such as bank teller machines, point-of-sale terminals, check-verification devices, and even the guidance of the space shuttle.

Advantages of Networks

Computer networks provide several important advantages to businesses and individuals.

1. Modern organizations today are widely dispersed, with offices located in diverse parts of a country and the world. Many of the computers and

terminals located at the sites need to exchange information and data, often on a daily basis. A network provides the means to exchange data among these computers and to make programs and data available to the people of the organization.

2. The networking of computers permits the sharing of resources of the machines. For instance, if a computer becomes saturated with too much work at one site, the work can be loaded through the network path onto another computer in the network. Such load sharing permits a more even and better utilization of resources.
3. Networking also provides the critical function of back-up. In the event that one computer fails, its counterpart can assume its functions and workload. Back-up capability is especially important in systems such as air traffic control. In the event a computer malfunctions, back-up computers rapidly take over and assume control of operations without endangering air travelers.
4. The use of networking allows a very flexible working environment. Employees can work at home by using terminals tied through networks into the computer at the office. Many employees now carry terminals or portable personal computers on trips and tie into their networks through hotel room telephones. Other employees travel to remote offices and use telephones and networks to transmit and receive critical sales, administrative, and research data from computers at company headquarters.

The information age is aptly named, for our society now relies on information to reduce the costs to produce our goods as well as to improve the overall quality of our lives. Communications systems and computer networks provide for rapid exchange of information residing on computers throughout a country.

Structure of the Communications Network

Before proceeding further, it will be helpful to define some terms. Figure 1-1 illustrates a simple data communications system. The *application process* (AP) is the end-user application. It usually consists of software such as a computer program, or it could be an end-user terminal. Typical examples are an accounts receivable program, a payroll program, an airline reservation system, an inventory control package, or a personnel system.

In Figure 1-1, site A could execute an application process (AP_{A1}) in the form of a software program to access an application process at site B (which is in this case a program [AP_{B1}] and a data base). Figure 1-1 also shows a site B program (AP_{B2}) accessing a file at site A through an application program

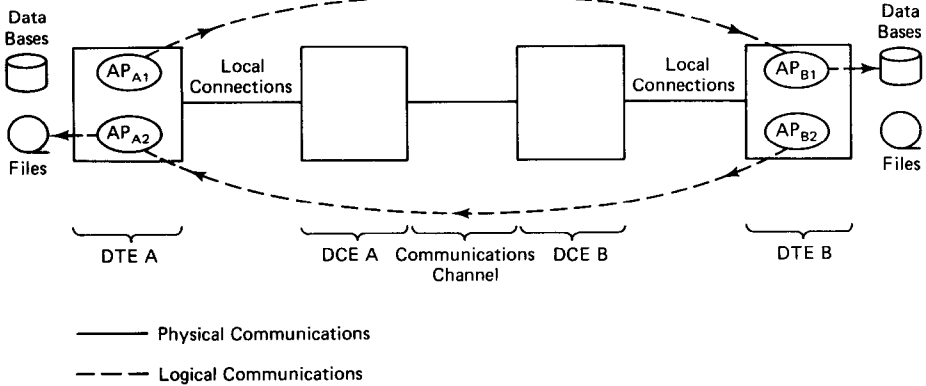


Figure 1-1. A Communications System

(AP_{A2}). (This book uses the term *application process* to describe end-user applications, unless otherwise noted.)

The application resides in the *data terminal equipment*, or DTE. DTE is a generic term used to describe the end-user machine, which is usually a computer or terminal. The DTE could be a large mainframe computer, such as a large IBM or ICL machine, or it could be a smaller machine, such as a terminal or a personal computer. The DTE takes many forms in the industry. Here are several examples:

- a work station for an air traffic controller
- an automated teller machine in a bank
- a point-of-sale terminal in a department store
- a sampling device to measure the quality of air
- a computer used to automate the manufacturing process in a factory
- an electronic mail computer or terminal
- a personal computer in the home or office.

The function of a communications network is to interconnect DTEs together so that they can share resources, exchange data, provide back-up for each other, and allow employees and individuals to perform their work from any location.

Figure 1-1 shows that a network provides *logical* and *physical* communications for the computers and terminals to be connected. The applications and files use the physical channel to effect logical communications. Logical, in this context, means the DTEs are not concerned with the physical aspects of the communications process. Application A1 need only issue a logical *Read* request with an identification of the data. In turn, the

communications system is responsible for sending the *Read* request across the physical channels to application B1.

Figure 1-1 also shows the *data circuit-terminating equipment*, or DCE (also called data communications equipment). Its function is to connect the DTEs into the communication line or channel.¹ The DCEs designed in the 1960s and 1970s were strictly communications devices. However, in the last few years the DCEs have incorporated more user functions, and today some DCEs contain a portion of an application process. Notwithstanding, the primary function of the DCE remains to provide an *interface* of the DTE into the communications network. The familiar modem is an example of a DCE.

The interfaces are specified and established through *protocols*. Protocols are agreements on how communications components and DTEs are to communicate with each other. They may include actual regulations which stipulate a required or recommended convention or technique. Typically, several levels of interfaces and protocols are required to support an end-user application.

Today, many organizations are adapting common interfaces and protocols as a result of worldwide efforts to publish recommended *standards* that are vendor and product independent. Our goal is to gain an understanding of these valuable protocols, standards, and interfaces.

Point-to-point and Multidrop Circuits

DCEs and DTEs are connected in one of two ways. As illustrated in Figure 1-1, they are connected in a point-to-point configuration in which only two DTE devices are on the line or channel. Illustrated in Figure 1-2 is another approach called a multidrop configuration. In this configuration, more than two devices are connected to the same channel.

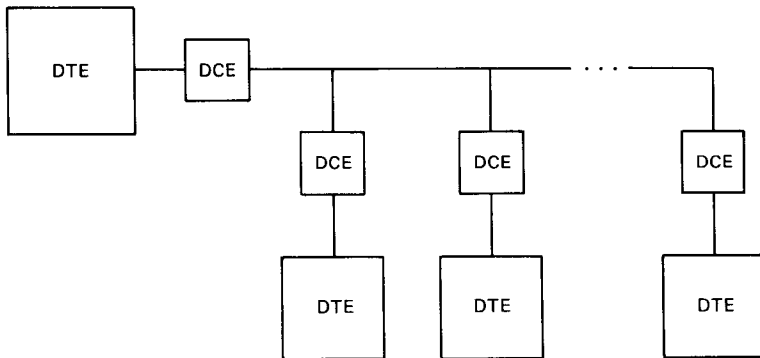


Figure 1-2. Multidrop Circuits

Data Flow and Physical Circuits

The DTEs and DCEs send communications traffic to each other in one of three methods:

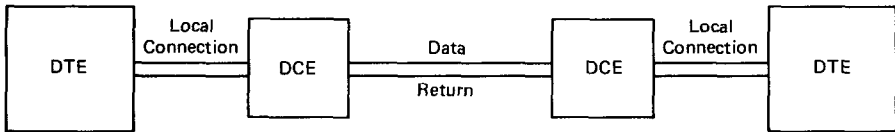
Simplex: Transmission in one direction only

Half-Duplex: Transmission in both directions, but only one direction at a time (also called two-way alternate [TWA])

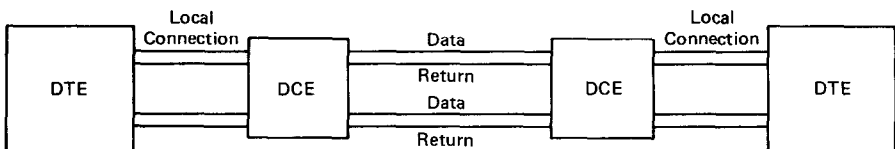
Full-Duplex (or Duplex): Transmission simultaneously in both directions (also called two-way simultaneous [TWS]).

Simplex transmission is common in television and commercial radio. It is not as common in data communications because of the one-way nature of the process, but simplex systems are found in some applications, such as telemetry. Half-duplex transmission is found in many systems, such as inquiry/response applications wherein a DTE sends a query to another DTE and waits for the applications process to access and/or compute the answer and transmit the response back. Terminal-based systems (keyboard terminals and terminals with CRT screens) often use half-duplex techniques. Full-duplex (or simply duplex) provides for simultaneous two-way transmission, without the intervening stop-and-wait aspect of half-duplex. Full-duplex is widely used in applications requiring continuous channel usage, high throughput, and fast response time.

Thus far, the terms half-duplex and full-duplex (duplex) have been used to describe how data moves across the circuit. We have focused on these terms as they are used in the data communications industry. Figure 1-3 shows the physical circuit itself, without regard to how data moves. Some



(a) Two-wire Circuit



(b) Four-wire Circuit

Figure 1-3. Two-Wire and Four-Wire Circuits

people in the industry use *half-duplex* and *full-duplex* to describe data flow *and* the physical circuit itself. The following discussion explains the physical circuit.

In telephone communications, the terms *two-wire* and *four-wire* circuits are often used to describe the channel. A two-wire circuit is sometimes called a half-duplex circuit. One wire is for the transmission data and the other is for the return circuit. (See Appendix A for a discussion of return circuits.) A four-wire circuit is sometimes called a full-duplex circuit. Two pairs of two wires exist, two for the data and two for the return circuits. The telephone company usually describes a two-wire circuit as a switched dial-up circuit, and a four-wire circuit as a leased, nonswitched circuit. However, exceptions exist and the reader is encouraged to check with the specific telephone company. The tradeoffs of switched and nonswitched circuits are discussed later in the chapter.

The advantages cited earlier of communications networks cannot be realized without the addition of an important component to the system. This component is the *data switching equipment*, or DSE. Figure 1-4 illustrates the use of the DSE in conjunction with the DTE and DCE. As the name implies, the major function of the DSE is to switch or route traffic (user data) through the network to the final destination. The DSE provides the vital functions of network routing around failed or busy devices and channels. The DSE may also route the data to the final destination through intermediate components, perhaps other switches.

Figure 1-4 illustrates a simple arrangement of the DCE, DTE, and DSE in the network. Later discussions will reveal that the configurations can be considerably more complex.

Network Topologies

Topologies and Design Goals

A network configuration is also called a *network topology*. A network topology is the shape (or the physical connectivity) of the network. The term topology is borrowed from geometry to describe the form of something. The network designer has three major goals when establishing the topology of a network.

- provide maximum possible reliability to assure proper receipt of all traffic (alternate routing)
- route the traffic across the least-cost path within the network between the sending and receiving DTEs (although the least-cost route may not be chosen if other factors, such as reliability, are more important)
- give the end user the best possible response time and throughput.

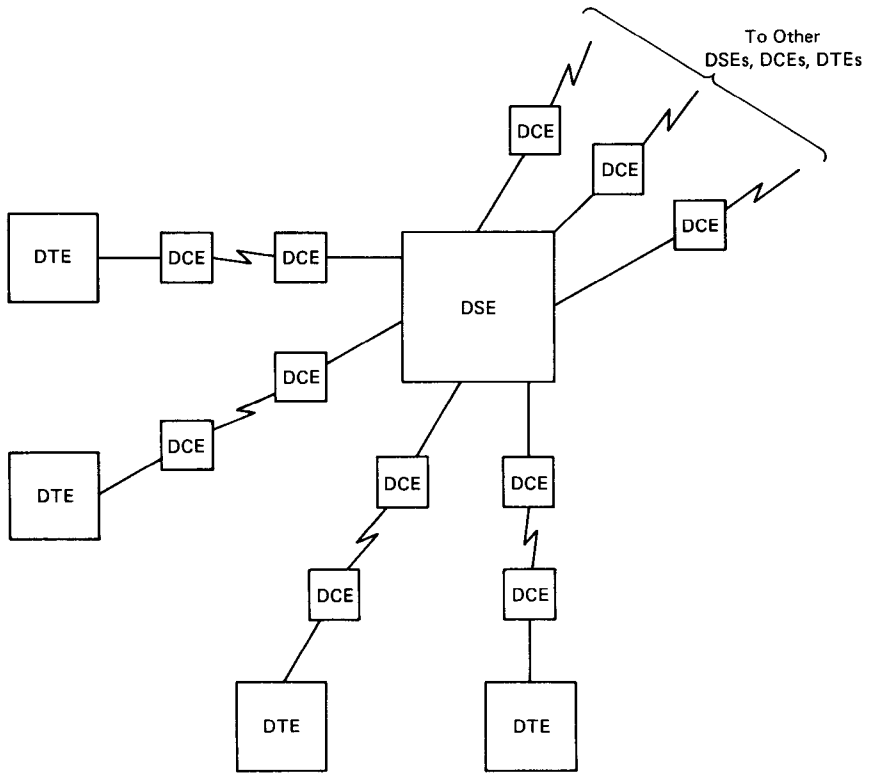


Figure 1-4. Data Switching Equipment (DSE)

Network reliability refers to the ability to deliver user data correctly (without errors) from one DTE to another DTE. It entails the ability to recover from errors or lost data in the network, including channel, DTE, DCE, or DSE failure. Reliability also refers to the maintenance of the system, which includes day-to-day testing; preventive maintenance, such as relieving faulty or failing components of their tasks; and fault isolation in the event of problems. When a component creates problems, the network diagnostic system can pinpoint the error readily, isolate the fault, and perhaps isolate the component from the network.

The second major goal in establishing a topology for the network is to provide the least-cost path between the application processes residing on the DTEs. This involves:

1. minimizing the actual length of the channel between the components, which usually entails routing the traffic through the fewest number of intermediate components;

2. providing the least expensive channel option for a particular application; for instance, transmitting low-priority data over a relatively inexpensive dial-up, low-speed telephone line, in contrast to transmitting the same data over an expensive high-speed satellite channel.

The third major goal is to provide the best possible response time and throughput. Short response time entails minimizing delay between the transmission and the receipt of the data between the DTEs, and is especially important for interactive sessions between user applications. Throughput entails the transmission of the maximum amount of end-user data in a given period.

The more common network topologies are depicted in Figure 1-5:

- the hierarchical topology (tree)
- the horizontal topology (bus)
- the star topology
- the ring topology (hub)
- the mesh topology.

Hierarchical Topology

The hierarchical topology is one of the most common networks found today. The software to control the network is relatively simple and the topology provides a concentration point for control and error resolution. In most cases, the DTE at the highest order of the hierarchy is in control of the network. In Figure 1-5(a), traffic flow among and between the DTEs is initiated by DTE A. Many vendors implement a distributed aspect to the hierarchical network by providing methods for the subordinate DTEs to directly control these DTEs below them in the hierarchy. This reduces the workload of the central host at site A.

While the hierarchical topology is attractive from the standpoint of simplicity of control, it presents significant potential bottleneck problems. In some instances, the uppermost DTE, typically a large-scale mainframe computer, controls all traffic between DTEs. Not only can this create bottlenecks, but it also presents reliability problems. In the event the upper-level DTE fails, the network capabilities are lost completely if the DTE is not fully backed up by another computer. Nonetheless, hierarchical topologies have been used widely in the past and will continue to be used for many years. They permit a graceful evolution toward a more complex network, because subordinate DTEs can be added relatively easy.

The hierarchical topology is also called a vertical network or a tree network. The word "tree" is derived from the fact that a hierarchical network often resembles a tree with branches stemming from the top of the

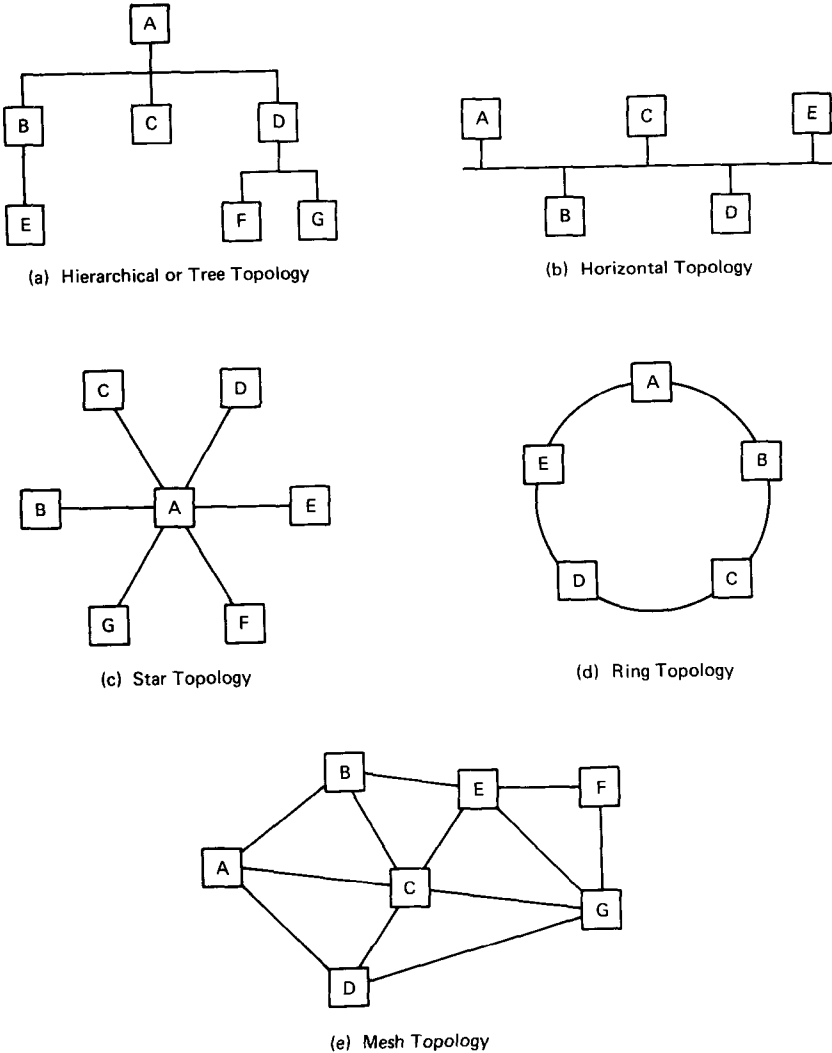


Figure 1-5. Network Topologies

tree down to the lower level. You might pause at this point and determine if you could draw a tree-type network topology relating to one of your daily activities. One common example is the organizational chart hanging in your office. Indeed, the advantages and disadvantages of a vertical data communications network are much the same of those of a hierarchically structured business—clear lines of authority with frequent bottlenecks at the upper levels and often insufficient delegation of responsibility.