



DATA COMMUNICATIONS AND NETWORKING

Second Edition







DATA COMMUNICATIONS AND NETWORKING

Second Edition

Behrouz A. Forouzan

DeAnza College

with

Catherine Coombs and Sophia Chung Fegan



Boston Burr Ridge, IL Dubuque, IA Madison, WI San Francisco St
Bangkok Bogotá Caracas Lisbon London Madrid
Mexico City Milan New Delhi Seoul Singapore Toronto





McGraw-Hill Higher Education

A Division of The McGraw-Hill Companies

DATA COMMUNICATIONS AND NETWORKING

Published by McGraw-Hill, an imprint of the McGraw-Hill Companies, Inc. 1221 Avenue of the Americas, New York, NY, 10020. Copyright © 2001, 1998 by The McGraw-Hill Companies, Inc. All rights reserved. No part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written consent of The McGraw-Hill Companies, Inc., including, but not limited to, in any network or other electronic storage or transmission, or broadcast for distance learning.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 0 DOC/DOC 0 9 8 7 6 5 4 3 2 1 0

ISBN 0-07-232204-7

Publisher: *Thomas Casson*
Executive editor: *Elizabeth A. Jones*
Developmental editor: *Emily J. Gray*
Senior marketing manager: *John T. Wannemacher*
Senior project manager: *Amy Hill*
Senior production supervisor: *Heather D. Burbridge*
Freelance design coordinator: *Gino Cieslik*
Supplement coordinator: *Susan Lombardi*
New media: *Christopher Styles*
Cover design: *Joanne Schopler*
Cover illustration: *Tony Stone*
Compositor: *Interactive Composition Corporation*
Typeface: *10/12 Times Roman*
Printer: *R. R. Donnelley & Sons Company*

[CIP to come]

<http://www.mhhe.com>





To Faezeh with love.





BRIEF CONTENTS

Contents ix

Preface xxvii

Chapter 1 *Introduction 1*

Chapter 2 *Basic Concepts 21*

Chapter 3 *The OSI Model 43*

Chapter 4 *Signals 65*

Chapter 5 *Encoding and Modulating 91*

Chapter 6 *Transmission of Digital Data: Interfaces and Modems 139*

Chapter 7 *Transmission Media 187*

Chapter 8 *Multiplexing 231*

Chapter 9 *Error Detection and Correction 273*

Chapter 10 *Data Link Control 301*

Chapter 11 *Data Link Protocols 329*

Chapter 12 *Local Area Networks 369*

Chapter 13 *Metropolitan Area Networks 413*

Chapter 14 *Switching 431*



Chapter 15	<i>Point-to-Point Protocol (PPP)</i>	455
Chapter 16	<i>Integrated Services Digital Network (ISDN)</i>	471
Chapter 17	<i>X.25</i>	505
Chapter 18	<i>Frame Relay</i>	525
Chapter 19	<i>ATM</i>	553
Chapter 20	<i>SONET/SDH</i>	593
Chapter 21	<i>Networking and Internetworking Devices</i>	613
Chapter 22	<i>Transport Layer</i>	657
Chapter 23	<i>Upper OSI Layers</i>	677
Chapter 24	<i>TCP/IP Protocol Suite: Part 1</i>	705
Chapter 25	<i>TCP/IP Protocol Suite: Part 2, Application Layer</i>	737
Appendix A	<i>ASCII Code</i>	777
Appendix B	<i>Numbering Systems and Transformation</i>	783
Appendix C	<i>Representation of Binary Numbers</i>	791
Appendix D	<i>Fourier Analysis</i>	799
Appendix E	<i>Hardware Equipment for Error Detection</i>	803
Appendix F	<i>Huffman Coding</i>	811
Appendix G	<i>LZW (Lempel-Ziv-Welch) Compression Method</i>	817
Appendix H	<i>Next Generation of TCP/IP Protocol Suite: IPv6 and ICMPv6</i>	825
Appendix I	<i>Spanning Tree</i>	839
	<i>Glossary</i>	845
	<i>Acronyms</i>	877
	<i>Index</i>	000



TABLE OF CONTENTS

Preface xxvii

Chapter 1 *Introduction 1*

- 1.1 WHY STUDY DATA COMMUNICATIONS 1
- 1.2 DATA COMMUNICATION 2
 - Components 3
- 1.3 NETWORKS 4
 - Distributed Processing 4
 - Network Criteria 5
 - Applications 6
- 1.4 PROTOCOLS AND STANDARDS 7
 - Protocols 7
 - Standards 8
- 1.5 STANDARDS ORGANIZATIONS 9
 - Standards Creation Committees 9
 - Forums 12
 - Regulatory Agencies 13
- 1.6 STRUCTURE OF THE BOOK 13
- 1.7 KEY TERMS AND CONCEPTS 13
- 1.8 SUMMARY 14
- 1.9 PRACTICE SET 15
 - Review Questions 15
 - Multiple Choice 16
 - Exercises 18

Chapter 2 *Basic Concepts 21*

- 2.1 LINE CONFIGURATION 21
 - Point-to-Point 21
 - Multipoint 22
- 2.2 TOPOLOGY 22
 - Mesh 23
 - Star 25
 - Tree 25



	Bus	26	
	Ring	27	
	Hybrid Topologies	28	
2.3	TRANSMISSION MODE	28	
	Simplex	29	
	Half-Duplex	29	
	Full-Duplex	29	
2.4	CATEGORIES OF NETWORKS	30	
	Local Area Network (LAN)	30	
	Metropolitan Area Network (MAN)	32	
	Wide Area Network (WAN)	32	
2.5	INTERNETWORKS	33	
2.6	KEY TERMS AND CONCEPTS	33	
2.7	SUMMARY	34	
2.8	PRACTICE SET	35	
	Review Questions	35	
	Multiple Choice	36	
	Exercises	38	
	Chapter 3	<i>The OSI Model</i>	43
3.1	THE MODEL	43	
	Layered Architecture	43	
3.2	FUNCTIONS OF THE LAYERS	47	
	Physical Layer	47	
	Data Link Layer	48	
	Network Layer	49	
	Transport Layer	51	
	Session Layer	53	
	Presentation Layer	54	
	Application Layer	55	
	Summary of Layer Functions	56	
3.3	TCP/IP PROTOCOL SUITE	56	
3.4	KEY TERMS AND CONCEPTS	57	
3.5	SUMMARY	58	
3.6	PRACTICE SET	59	
	Review Questions	59	
	Multiple Choice	60	
	Exercises	63	
	Chapter 4	<i>Signals</i>	65
4.1	ANALOG AND DIGITAL	65	
	Analog and Digital Data	66	
	Analog and Digital Signals	66	
4.2	APERIODIC AND PERIODIC SIGNALS	66	
	Periodic Signals	67	
	Aperiodic Signals	67	
4.3	ANALOG SIGNALS	68	
	Simple Analog Signals	68	





4.4 TIME AND FREQUENCY DOMAIN 74
4.5 COMPOSITE SIGNALS 75
 Frequency Spectrum and Bandwidth 76
4.6 DIGITAL SIGNALS 79
 Decomposition of a Digital Signal 80
4.7 KEY TERMS AND CONCEPTS 81
4.8 SUMMARY 82
4.9 PRACTICE SET 83
 Review Questions 83
 Multiple Choice 84
 Exercises 86

Chapter 5 *Encoding and Modulating* 91

5.1 DIGITAL-TO-DIGITAL CONVERSION 92
 Unipolar 92
 Polar 94
 Bipolar 97
5.2 ANALOG-TO-DIGITAL CONVERSION 102
 Pulse Amplitude Modulation (PAM) 102
 Pulse Code Modulation (PCM) 103
 Sampling Rate 104
 How Many Bits Per Sample 106
 Bit Rate 107
5.3 DIGITAL-TO-ANALOG CONVERSION 107
 Aspects of Digital-to-Analog Conversion 108
 Amplitude Shift Keying (ASK) 109
 Frequency Shift Keying (FSK) 111
 Phase Shift Keying (PSK) 113
 Quadrature Amplitude Modulation (QAM) 116
 Bit/Baud Comparison 118
5.4 ANALOG-TO-ANALOG CONVERSION 120
 Amplitude Modulation (AM) 121
 Frequency Modulation (FM) 122
 Phase Modulation (PM) 125
5.5 KEY TERMS AND CONCEPTS 125
5.6 SUMMARY 126
5.7 PRACTICE SET 127
 Review Questions 127
 Multiple Choice 128
 Exercises 133

Chapter 6 *Transmission of Digital Data: Interfaces and Modems* 139

6.1 DIGITAL DATA TRANSMISSION 139
 Parallel Transmission 140
 Serial Transmission 141
6.2 DTE-DCE INTERFACE 143
 Data Terminal Equipment (DTE) 144





xii *TABLE OF CONTENTS*

- Data Circuit–Terminating Equipment (DCE) 144
 - Standards 145
 - EIA-232 Interface 145
- 6.3 OTHER INTERFACE STANDARDS 152
 - EIA-449 153
 - EIA-530 157
 - X.21 158
- 6.4 MODEMS 159
 - Transmission Rate 160
 - Modem Standards 164
- 6.5 56K MODEMS 171
 - Traditional Modems 171
 - 56K Modems 172
 - Why Only 56 Kbps? 174
- 6.6 CABLE MODEM 174
 - Downloading 174
 - Uploading 175
- 6.7 KEY TERMS AND CONCEPTS 175
- 6.8 SUMMARY 176
- 6.9 PRACTICE SET 177
 - Review Questions 177
 - Multiple Choice 179
 - Exercises 185

Chapter 7 *Transmission Media* 187

- 7.1 GUIDED MEDIA 188
 - Twisted-Pair Cable 188
 - Coaxial Cable 192
 - Optical Fiber 193
- 7.2 UNGUIDED MEDIA 200
 - Radio Frequency Allocation 200
 - Propagation of Radio Waves 200
 - Terrestrial Microwave 205
 - Satellite Communication 206
 - Cellular Telephony 208
- 7.3 TRANSMISSION IMPAIRMENT 211
 - Attenuation 211
 - Distortion 213
 - Noise 213
- 7.4 PERFORMANCE 214
 - Throughput 214
 - Propagation Speed 215
 - Propagation Time 215
- 7.5 WAVELENGTH 215
- 7.6 SHANNON CAPACITY 216
- 7.7 MEDIA COMPARISON 217
- 7.8 KEY TERMS AND CONCEPTS 218
- 7.9 SUMMARY 220





7.10	PRACTICE SET	222	
	Review Questions	222	
	Multiple Choice	223	
	Exercises	230	
	Chapter 8	<i>Multiplexing</i>	231
8.1	MANY TO ONE/ONE TO MANY	231	
8.2	FREQUENCY-DIVISION MULTIPLEXING (FDM)	232	
8.3	WAVE-DIVISION MULTIPLEXING (WDM)	235	
8.4	TIME-DIVISION MULTIPLEXING (TDM)	236	
	Inverse Multiplexing	244	
8.5	MULTIPLEXING APPLICATION: THE TELEPHONE SYSTEM	245	
	Common Carrier Services and Hierarchies	245	
	Analog Services	246	
	Digital Services	248	
8.6	DIGITAL SUBSCRIBER LINE (DSL)	254	
	ADSL	254	
	RADSL	255	
	HDSL	256	
	SDSL	256	
	VDSL	256	
8.7	FTTC	257	
	FTTC in the Telephone Network	257	
	FTTC in the Cable TV Network	257	
8.8	KEY TERMS AND CONCEPTS	258	
8.9	SUMMARY	259	
8.10	PRACTICE SET	261	
	Review Questions	261	
	Multiple Choice	262	
	Exercises	266	
	Chapter 9	<i>Error Detection and Correction</i>	273
9.1	TYPES OF ERRORS	273	
	Single-Bit Error	273	
	Burst Error	274	
9.2	DETECTION	275	
	Redundancy	275	
9.3	VERTICAL REDUNDANCY CHECK (VRC)	277	
9.4	LONGITUDINAL REDUNDANCY CHECK (LRC)	279	
9.5	CYCLIC REDUNDANCY CHECK (CRC)	280	
	Performance	284	
9.6	CHECKSUM	284	
9.7	ERROR CORRECTION	287	
	Single-Bit Error Correction	287	
	Hamming Code	289	
	Burst Error Correction	291	





- 9.8 KEY TERMS AND CONCEPTS 292
- 9.9 SUMMARY 293
- 9.10 PRACTICE SET 294
 - Review Questions 294
 - Multiple Choice 294
 - Exercises 298

Chapter 10 *Data Link Control* 301

- 10.1 LINE DISCIPLINE 302
 - ENQ/ACK 302
 - Poll/Select 304
- 10.2 FLOW CONTROL 306
 - Stop-and-Wait 308
 - Sliding Window 308
- 10.3 ERROR CONTROL 312
 - Automatic Repeat Request (ARQ) 312
 - Stop-and-Wait ARQ 312
 - Sliding Window ARQ 315
- 10.4 KEY TERMS AND CONCEPTS 321
- 10.5 SUMMARY 321
- 10.6 PRACTICE SET 322
 - Review Questions 322
 - Multiple Choice 323
 - Exercises 326

Chapter 11 *Data Link Protocols* 329

- 11.1 ASYNCHRONOUS PROTOCOLS 330
 - XMODEM 330
 - YMODEM 331
 - ZMODEM 331
 - BLAST 331
 - Kermit 331
- 11.2 SYNCHRONOUS PROTOCOLS 332
- 11.3 CHARACTER-ORIENTED PROTOCOLS 332
 - Binary Synchronous Communication (BSC) 333
 - BSC Frames 334
 - Data Transparency 337
- 11.4 BIT-ORIENTED PROTOCOLS 339
 - HDLC 340
 - Frames 342
 - More about Frames 348
 - Examples 353
- 11.5 LINK ACCESS PROCEDURES 357
 - LAPB 357
 - LAPD 358
 - LAPM 358
- 11.6 KEY TERMS AND CONCEPTS 358





11.7	SUMMARY	359
11.8	PRACTICE SET	360
	Review Questions	360
	Multiple Choice	361
	Exercises	364
	Chapter 12	<i>Local Area Networks</i> 369
12.1	PROJECT 802	369
	IEEE 802.1	370
	LLC	371
	MAC	371
	Protocol Data Unit (PDU)	371
12.2	ETHERNET	372
	Access Method: CSMA/CD	373
	Addressing	374
	Electrical Specification	374
	Frame Format	374
	Implementation	376
12.3	OTHER ETHERNET NETWORKS	380
	Switched Ethernet	380
	Fast Ethernet	382
	Gigabit Ethernet	384
12.4	TOKEN BUS	385
12.5	TOKEN RING	386
	Access Method: Token Passing	386
	Addressing	388
	Electrical Specification	388
	Frame Formats	388
	Implementation	391
12.6	FDDI	393
	Access Method: Token Passing	393
	Addressing	395
	Electrical Specification	396
	Frame Format	397
	Implementation: Physical Medium Dependent (PMD) Layer	399
12.7	COMPARISON	401
12.8	KEY TERMS AND CONCEPTS	401
12.9	SUMMARY	402
12.10	PRACTICE SET	404
	Review Questions	404
	Multiple Choice	405
	Exercises	410
	Chapter 13	<i>Metropolitan Area Networks</i> 413
13.1	IEEE 802.6 (DQDB)	413
	Access Method: Dual Bus	413
	Distributed Queues	416





	Ring Configuration	418
	Operation: DQDB Layers	419
	Implementation	420
13.2	SMDS	421
	SMDS Architecture	421
	Features	423
13.3	KEY TERMS AND CONCEPTS	424
13.4	SUMMARY	424
13.5	PRACTICE SET	425
	Review Questions	425
	Multiple Choice	425
	Exercises	427
	Chapter 14	<i>Switching</i>
		431
14.1	CIRCUIT SWITCHING	432
	Space-Division Switches	434
	Time-Division Switches	436
	TDM Bus	438
	Space- and Time-Division Switching Combinations	439
	Public Switched Telephone Network (PSTN)	440
14.2	PACKET SWITCHING	441
	Datagram Approach	442
	Virtual Circuit Approach	443
	Circuit-Switched Connection versus Virtual-Circuit Connection	444
14.3	MESSAGE SWITCHING	446
14.4	KEY TERMS AND CONCEPTS	447
14.5	SUMMARY	448
14.6	PRACTICE SET	449
	Review Questions	449
	Multiple Choice	450
	Exercises	452
	Chapter 15	<i>Point-to-Point Protocol (PPP)</i>
		455
15.1	TRANSITION STATES	455
15.2	PPP LAYERS	456
	Physical Layer	456
	Data Link Layer	457
15.3	LINK CONTROL PROTOCOL (LCP)	458
	LCP Packets	458
	Options	460
15.4	AUTHENTICATION	460
	PAP	460
	CHAP	461
15.5	NETWORK CONTROL PROTOCOL (NCP)	462
	IPCP	463
	Other Protocols	464





15.6	AN EXAMPLE	464	
15.7	KEY TERMS AND CONCEPTS	465	
15.8	SUMMARY	466	
15.9	PRACTICE SET	466	
	Review Questions	466	
	Multiple Choice	467	
	Exercises	469	
	Chapter 16	<i>Integrated Services Digital Network (ISDN)</i>	471
16.1	SERVICES	471	
	Bearer Services	471	
	Teleservices	471	
	Supplementary Services	472	
16.2	HISTORY	472	
	Voice Communication over Analog Networks	472	
	Voice and Data Communication over Analog Networks	472	
	Analog and Digital Services to Subscribers	473	
	Integrated Digital Network (IDN)	473	
	Integrated Services Digital Network (ISDN)	474	
16.3	SUBSCRIBER ACCESS TO THE ISDN	475	
	B Channels	476	
	D Channels	476	
	H Channels	476	
	User Interfaces	476	
	Functional Grouping	478	
	Reference Points	480	
16.4	THE ISDN LAYERS	481	
	Physical Layer	482	
	Data Link Layer	487	
	Network Layer	488	
16.5	BROADBAND ISDN	492	
	Services	493	
	Physical Specifications	494	
16.6	FUTURE OF ISDN	495	
16.7	KEY TERMS AND CONCEPTS	496	
16.8	SUMMARY	497	
16.9	PRACTICE SET	498	
	Review Questions	498	
	Multiple Choice	499	
	Exercises	503	
	Chapter 17	<i>X.25</i>	505
17.1	X.25 LAYERS	506	
	Physical Layer	506	
	Frame Layer	506	





	Packet Layer	508	
	PLP Packets	510	
17.2	OTHER PROTOCOLS RELATED TO X.25	516	
	X.121 Protocol	516	
	Triple-X Protocols	516	
17.3	KEY TERMS AND CONCEPTS	517	
17.4	SUMMARY	518	
17.5	PRACTICE SET	518	
	Review Questions	518	
	Multiple Choice	519	
	Exercises	522	
	Chapter 18	<i>Frame Relay</i>	525
18.1	INTRODUCTION	525	
	Advantages	528	
	Disadvantages	528	
	Role of Frame Relay	529	
18.2	FRAME RELAY OPERATION	529	
	Virtual Circuits	530	
	DLCIs Inside the Network	532	
	Switches	532	
18.3	FRAME RELAY LAYERS	533	
	Physical Layer	534	
	Data Link Layer	534	
18.4	CONGESTION CONTROL	535	
	Congestion Avoidance	536	
	Discarding	537	
18.5	LEAKY BUCKET ALGORITHM	537	
18.6	TRAFFIC CONTROL	540	
	Access Rate	541	
	Committed Burst Size	541	
	Committed Information Rate	541	
	Excess Burst Size	542	
	User Rate	542	
18.7	OTHER FEATURES	543	
	Extended Address	543	
	FRADs	543	
	VOFR	544	
	LMI	544	
18.8	KEY TERMS AND CONCEPTS	544	
18.9	SUMMARY	545	
18.10	PRACTICE SET	545	
	Review Questions	545	
	Multiple Choice	546	
	Exercises	555	





Chapter 19 *ATM* **553**

- 19.1 DESIGN GOALS 553
 - Packet Networks 554
 - Mixed Network Traffic 554
 - Cell Networks 555
 - Asynchronous TDM 556
- 19.2 ATM ARCHITECTURE 557
 - Virtual Connection 557
 - Identifiers 558
 - Cells 559
 - Connection Establishment and Release 559
- 19.3 SWITCHING 561
 - VP Switch 561
 - VPC Switch 562
- 19.4 SWITCH FABRICS 563
 - Crossbar Switch 563
 - Knockout Switch 563
 - Banyan Switch 563
 - Batcher-Banyan Switch 565
- 19.5 ATM LAYERS 566
 - Application Adaptation Layer (AAL) 566
 - ATM Layer 573
 - Physical Layer 575
 - Service Classes 576
 - Quality of Service (QoS) 576
 - Traffic Descriptors 578
- 19.6 ATM APPLICATIONS 578
 - ATM WANs 578
 - ATM LANs 578
- 19.7 KEY TERMS AND CONCEPTS 581
- 19.8 SUMMARY 582
- 19.9 PRACTICE SET 583
 - Review Questions 583
 - Multiple Choice 584
 - Exercises 589

Chapter 20 *SONET/SDH* **593**

- 20.1 SYNCHRONOUS TRANSPORT SIGNALS 594
- 20.2 PHYSICAL CONFIGURATION 595
 - SONET Devices 595
 - Sections, Lines, and Paths 596
- 20.3 SONET LAYERS 597
 - Photonic Layer 597
 - Section Layer 597
 - Line Layer 597





xx *TABLE OF CONTENTS*

	Path Layer	598
	Device-Layer Relationships	598
20.4	SONET FRAME	598
	Frame Format	599
	Section Overhead	600
	Line Overhead	601
	Path Overhead	602
	Virtual Tributaries	603
	Types of VTs	603
20.5	MULTIPLEXING STS FRAMES	604
	ATM Convergence to SONET/SDH	605
20.6	APPLICATIONS	606
20.7	KEY TERMS AND CONCEPTS	606
20.8	SUMMARY	607
20.9	PRACTICE SET	607
	Review Questions	607
	Multiple Choice	608
	Exercises	611
	Chapter 21	<i>Networking and Internetworking Devices</i> 613
21.1	REPEATERS	614
	Not an Amplifier	615
21.2	BRIDGES	616
	Types of Bridges	618
	Bridges Connecting Different LANs	620
21.3	ROUTERS	620
	Routing Concepts	622
21.4	GATEWAYS	624
21.5	OTHER DEVICES	625
	Multiprotocol Routers	625
	Brouters	625
	Switches	627
	Routing Switches	627
21.6	ROUTING ALGORITHMS	628
21.7	DISTANCE VECTOR ROUTING	628
	Sharing Information	628
	Routing Table	630
21.8	LINK STATE ROUTING	633
	Information Sharing	633
	The Dijkstra Algorithm	637
21.9	KEY TERMS AND CONCEPTS	640
21.10	SUMMARY	640
21.11	PRACTICE SET	641
	Review Questions	641
	Multiple Choice	642
	Exercises	645





Chapter 22 *Transport Layer* 649

- 22.1 DUTIES OF THE TRANSPORT LAYER 650
 - End-to-End Delivery 650
 - Addressing 651
 - Reliable Delivery 652
 - Flow Control 655
 - Multiplexing 657
- 22.2 CONNECTION 658
 - Connection Establishment 658
 - Connection Termination 659
- 22.3 THE OSI TRANSPORT PROTOCOL 659
 - Transport Classes 659
 - Transport Protocol Data Unit (TPDU) 660
 - Connection-Oriented and Connectionless Services 661
- 22.4 KEY TERMS AND CONCEPTS 662
- 22.5 SUMMARY 663
- 22.6 PRACTICE SET 664
 - Review Questions 664
 - Multiple Choice 664
 - Exercises 666

Chapter 23 *Upper OSI Layers* 669

- 23.1 SESSION LAYER 669
 - Session and Transport Interaction 670
 - Synchronization Points 671
 - Session Protocol Data Unit 672
- 23.2 PRESENTATION LAYER 673
 - Translation 673
 - Encryption/Decryption 675
 - Authentication 685
 - Data Compression 686
- 23.3 APPLICATION LAYER 688
 - Message Handling System (MHS) 688
 - File Transfer, Access, and Management (FTAM) 690
 - Virtual Terminal (VT) 691
 - Directory Services (DS) 692
 - Common Management Information Protocol (CMIP) 693
- 23.4 KEY TERMS AND CONCEPTS 695
- 23.5 SUMMARY 696
- 23.6 PRACTICE SET 697
 - Review Questions 697
 - Multiple Choice 698
 - Exercises 702





Chapter 24 *TCP/IP Protocol Suite: Part 1* 703

- 24.1 OVERVIEW OF TCP/IP 705
 - TCP/IP and the Internet 705
 - TCP/IP and OSI 706
 - Encapsulation 706
- 24.2 NETWORK LAYER 707
 - Internetwork Protocol (IP) 707
- 24.3 ADDRESSING 710
 - Classes 710
 - Dotted-Decimal Notation 711
 - Nodes with More Than One Address 713
 - A Sample Internet 714
- 24.4 SUBNETTING 714
 - Three Levels of Hierarchy 716
 - Masking 716
 - Finding the Subnetwork Address 717
- 24.5 OTHER PROTOCOLS IN THE NETWORK LAYER 719
 - Address Resolution Protocol (ARP) 719
 - Reverse Address Resolution Protocol (RARP) 720
 - Internet Control Message Protocol (ICMP) 721
 - Internet Group Message Protocol (IGMP) 721
- 24.6 TRANSPORT LAYER 721
 - User Datagram Protocol (UDP) 722
 - Transmission Control Protocol (TCP) 723
- 24.7 KEY TERMS AND CONCEPTS 725
- 24.8 SUMMARY 726
- 24.9 PRACTICE SET 727
 - Review Questions 727
 - Multiple Choice 728
 - Exercises 732

Chapter 25 *TCP/IP Protocol Suite: Part 2, Application Layer* 737

- 25.1 CLIENT-SERVER MODEL 737
 - Client 738
 - Server 738
- 25.2 BOOTSTRAP PROTOCOL (BOOTP) AND DYNAMIC HOST CONFIGURATION PROTOCOL (DHCP) 739
 - BOOTP 739
 - DHCP 739
- 25.3 DOMAIN NAME SYSTEM (DNS) 740
 - DNS in the Internet 740
- 25.4 TELNET 742
 - Network Virtual Terminal (NVT) 745
- 25.5 FILE TRANSFER PROTOCOL (FTP) 745
- 25.6 TRIVIAL FILE TRANSFER PROTOCOL (TFTP) 746





25.7	SIMPLE MAIL TRANSFER PROTOCOL (SMTP)	747	
	User Agent (UA)	749	
	Addresses	749	
	Mail Transfer Agent (MTA)	749	
	Multipurpose Internet Mail Extensions (MIME)	750	
	Post Office Protocol (POP)	750	
25.8	SIMPLE NETWORK MANAGEMENT PROTOCOL (SNMP)	752	
	Concept	752	
	SMI	753	
	MIB	753	
	SNMP	754	
25.9	HYPERTEXT TRANSFER PROTOCOL (HTTP)	755	
	HTTP Transaction	755	
	Messages	756	
	Request Messages	756	
	Response Message	756	
	Uniform Resource Locator (URL)	756	
25.10	WORLD WIDE WEB (WWW)	758	
	Hypertext And Hypermedia	758	
	Browser Architecture	758	
	Static Documents	760	
	HTML	760	
	Dynamic Documents	762	
	Common Gateway Interface (CGI)	763	
	Active Documents	764	
	Java	765	
25.11	KEY TERMS AND CONCEPTS	765	
25.12	SUMMARY	766	
25.13	PRACTICE SET	768	
	Review Questions	768	
	Multiple Choice	769	
	Exercises	775	
	Appendix A	<i>ASCII Code</i>	777
	Appendix B	<i>Numbering Systems and Transformation</i>	783
B.1	NUMBERING SYSTEMS	783	
	Decimal Numbers	784	
	Binary Numbers	784	
	Octal Numbers	785	
	Hexadecimal Numbers	786	
B.2	TRANSFORMATION	787	
	From Other Systems to Decimal	788	
	From Decimal to Other Systems	789	
	From Binary to Octal or Hexadecimal	789	
	From Octal or Hexadecimal to Binary	790	





Appendix C *Representation of Binary Numbers* 791

- C.1 UNSIGNED NUMBERS 791
- C.2 SIGNED NUMBERS 792
 - Sign-and-Magnitude 792
 - One's Complement 794
 - Two's Complement 795
- C.3 MORE ABOUT ONE'S COMPLEMENT 796
 - Finding the Complement 796
 - Adding Two Numbers 797

Appendix D *Fourier Analysis* 799

- D.1 FOURIER SERIES 800
- D.2 FOURIER TRANSFORM 802

Appendix E *Hardware Equipment for Error Detection* 803

- E.1 ELECTRONIC DEVICES 803
 - XOR Gate 803
 - NOT Gate 804
 - Shift Register 804
- E.2 VERTICAL REDUNDANCY CHECK (VRC) 805
 - VRC Generator 805
 - VRC Checker 805
- E.3 LONGITUDINAL REDUNDANCY CHECK (LRC) 806
 - LRC Generator 806
 - LRC Checker 806
- E.4 CYCLIC REDUNDANCY CHECK (CRC) 807
 - The CRC Generator 807
 - The CRC Checker 807

Appendix F *Huffman Coding* 811

- F.1 CHARACTER TREE 812
- F.2 ASSIGNING THE CODES 815
- F.3 DECODING 816

Appendix G *LZW (Lempel-Ziv-Welch) Compression Method* 817

- G.1 COMPRESSION 817
 - Dictionary 817
 - Buffer 818
 - Compression Algorithm 818
 - Example of Compression 819
- G.2 DECOMPRESSION 820
 - Dictionary 820
 - Buffers 821
 - Decompression Algorithm 821
 - Decompression Example 821





Appendix H *Next Generation of TCP/IP Protocol Suite: IPv6 and ICMPv6* 825

- H.1 IPv6 826
 - IPv6 Addresses 826
 - IPv6 Packet Format 831
- H.2 ICMPv6 836

Appendix I *Spanning Tree* 839

- I.1 SPANNING TREES AND BRIDGES 839
 - Algorithm 841
 - Forming the Spanning Tree 842
 - Example 842
- I.2 SPANNING TREES AND MULTICAST ROUTING 844

Glossary 845

Acronyms 877

Index 000





Preface

Data communications and networking may be the fastest growing technologies in our culture today. One of the ramifications of that growth is a dramatic increase in the number of professions where an understanding of these technologies is essential for success—and a proportionate increase in the number and types of students taking courses to learn about them. Today, students wanting to understand the concepts and mechanisms underlying telecommunications and networking come from a variety of academic and professional backgrounds. To be useful, a textbook on data communications and networking must be accessible to students without technical backgrounds while still providing substance comprehensive enough to challenge more experienced readers. This text is written with this new mix of students in mind.

Features of the Book

Several features of this text are designed to make it particularly easy for students to understand data communications and networking.

Structure

We have used the seven-layer OSI model as the framework for the text not only because a thorough understanding of the model is essential to understanding most current networking theory but also because it is based on a structure of interdependencies: Each layer builds upon the layer beneath it and supports the layer above it. In the same way, each concept introduced in our text builds upon the concepts examined in the previous sections.

The OSI model was chosen because it is a model, not a protocol. The model is independent of any protocol such as TCP/IP, IPX/SPX (Novell), or AppleTalk. We believe that in an introductory course, the model should be understood before the actual protocols are discussed. The OSI model shows the layered architecture necessary for the design of network systems.

This text is designed for students with little or no background in telecommunication or data communication. For this reason, we use a bottom-up approach. In this approach, students can learn first about telecommunications (lower layers) before learning about data communications (upper layers). For example, students can learn



about signalling, encoding, modulating, and error detection before learning about data transfer across the Internet. This eliminates the need for two courses: One for telecommunications and one for data communications.

The first nine chapters emphasize the physical layer, which is essential for understanding the rest of the layers. These chapters are particularly needed for students with no background in networking and telecommunications.

Chapters 10 through 12 describe all issues related to local area networks. Chapter 13 discusses metropolitan area networks. Chapter 14 describes switching techniques as background preparation for wide area networks.

Chapters 15 to 20 discuss topics associated with wide area networks. Chapter 21 discusses the network layer function and the topic of internetworking local and wide area networks together. Chapters 22 and 23 focus on upper layer protocols (transport, session, presentation, and application layers).

Chapters 24 and 25 are dedicated to the TCP/IP protocol suite. These two chapters give a brief introduction and prepare the students for a course on the TCP/IP protocol suite.

Visual Approach

The book presents highly technical subject matter without complex formulas by using a balance of text and figures. The approximately 700 figures accompanying the text provide a visual and intuitive opportunity for understanding the material. Figures are particularly important in explaining networking concepts, which are based on connections and transmission. These are both often more easily grasped visually than verbally.

For example, Figure 3.8 shows the encapsulation of a network-layer packet in a data-link-layer frame. The figure also shows how network-layer addresses are unchanged compared to the data-link-layer addresses that change from station to station. Another figure, Figure 5.36, shows how an 8-QAM signal can carry three bits in each baud. Figure 8.4 clearly shows how FDM combines three modulated signals into one composite signal. Figures 25.3, 25.4, 25.5, and 25.6 show how the domain name system is divided into three domains: country, generic, and inverse domains.

Highlighted Points

We have repeated important concepts in boxes for quick reference and immediate attention.

Examples and Applications

Whenever appropriate, we have included examples that illustrate the concept introduced in the text. They also help students do the exercises at the end of each chapter.

Also, we have added real-life applications throughout each chapter. For example, in Chapter 8, after a discussion of FDM, we give an application, the analog hierarchy of the telephone system. Similarly, after discussion of TDM, we give an application, the DS hierarchy of the telephone system.

Summary

Each chapter ends with a summary of the material covered in that chapter. The summary is a brief overview of all the important points in the chapter.





Key Terms

Each chapter includes a list of key terms used throughout the chapter for a quick reference.

Practice Set

Each chapter includes a practice set designed to reinforce salient concepts and encourage students to apply them. It consists of three parts: review questions, multiple-choice questions, and exercises. Review questions are intended to test students for their first-level understanding of the material presented in the chapter. Multiple-choice questions test students' grasp of basic concepts and terminology. Exercises require deeper understanding of the material.

Appendixes

The appendixes are intended to provide quick reference material or a review of materials needed to understand the concepts discussed in the book.

Glossary and Acronyms

The book contains an extensive glossary and a list of acronyms.

Changes in the Second Edition

In this edition, material on the newer technologies has been added, the contents of the chapters have been revised, and the end materials have been augmented and improved.

New Material

We have added the following new material:

- 56K modems and cable modems (Chapter 6).
- Transmission impairment and transmission media performance (Chapter 7).
- Digital subscriber line (DSL) technology and fiber to the curb (FTTC) (Chapter 8).
- Switched and Gigabit Ethernet (Chapter 12).
- Point-to-Point Protocol (PPP) (Chapter 15).
- Traffic control (Chapter 18).
- Switching fabrics and ATM LANs (Chapter 19).
- Additional encryption methods (Chapter 23).
- Lempel-Ziv-Welch compression method (Appendix G).
- Spanning Tree algorithm (Appendix I).

Revision

All chapters have been revised, particularly Chapters 4, 9, 18, and 19 and Appendix H.

End Material Augmentation and Improvement

- Several examples are added to many chapters to clarify the materials.
- Key terms are added at the end of each chapter.





- Review questions are added at the end of each chapter.
- The quality and quantity of the multiple-choice questions have been improved.
- The quality and quantity of the exercises have been improved. Most of the old exercises have been revised and many exercises have been added.

Online Supplementary Material

Online Learning Center

The McGraw-Hill Online Learning Center is a “digital cartridge” that contains the book’s pedagogy and supplements. As students read through *Data Communications and Networking*, they can go online to take self-grading quizzes. They also get appropriate access to lecture materials such as PowerPoint slides and animated figures from the book. Solutions are also available to instructors through this site.

Additionally, McGraw-Hill makes it easy to create a website for your networking course with an exclusive McGraw-Hill product called Pageout. It requires no prior knowledge of HTML, no long hours, and no design skills on your part. Instead, Pageout offers a series of templates. Simply fill them with your course information and click on one of 16 designs. The process takes under an hour and leaves you with a professionally designed website.

Although PageOut offers “instant” development, the finished website offers powerful features. An interactive course syllabus allows you to post content to coincide with your lectures, so when students visit your PageOut website, your syllabus will direct them to components of Forouzan’s Online Learning Center, or specific material of your own.

How to Use the Book

This book is written for both an academic and a professional audience. The book can be used as a self-study guide for interested professionals. As a textbook, it can be used for a one-semester or one-quarter course. The chapters are organized to provide a great deal of flexibility. The following are some guidelines:

- Chapters 1 through 12 are fundamental.
- Chapter 13 is optional.
- Chapters 14 through 18 can be covered in detail for a semester course or briefly for a quarter course.
- Chapters 19 through 25 are fundamental.

Acknowledgments

It is obvious that the development of a book of this scope needs the support of many people. We must thank the De Anza students and staff; their encouragement and support enabled the project to materialize and contributed to its success. We especially thank Claudia Gohler and Anastasia Mazharina for their tremendous assistance in preparing solutions to the end materials.





The most important contribution to the development of a book such as this comes from peer reviews. We cannot express our gratitude in words to the many reviewers who spent numerous hours reading the manuscript and providing us with helpful comments and ideas. We would especially like to acknowledge the contributions of the following reviewers for the second edition of this book.

List of Reviewers:

Jay Benson, *Anne Arundel Community College*
John Besci, *Clayton College and State University*
Russell J. Clark, *University of Dayton*
Charles K. Davis, *University of Houston*
David L. Doss, *Illinois State University*
James M. Frazier, *University of North Carolina at Charlotte*
John W. Gray, *University of Massachusetts at Dartmouth*
Thomas F. Hain, *University of South Alabama*
Paul N. Higbee, *University of North Florida*
Seung Bae Im, *California State University at Chico*
Rose M. Laird, *Northern Virginia Community College*
Jorg Liebeherr, *University of Virginia*
Wallace C. Liu, *California State University at Fresno*
Peter Maggiacomo, *Sinclair Community College*
Larry D. Owens, *California State University at Fresno*
Michael Peterson, *Iowa Western Community College*
Satya Prakash Saraswat, *Bentley College*
Timothy W. Price, *Indiana University–Purdue University Indianapolis*
T. Radhakrishnan, *Concordia University*
Heidi Schmidt, *San Francisco State University*
Xiaojun Shen, *University of Missouri, Kansas City*
Gordon Springer, *University of Missouri at Columbia*
Zixiang (Alex) Tan, *Syracuse University*

Special thanks go to the staff of McGraw-Hill. Betsy Jones, our senior editor, proved how a proficient editor can make the impossible possible. Emily Gray, the developmental editor, gave us help whenever we needed it. Amy Hill, our project manager, guided us through the production process with enormous enthusiasm. We also thank Heather Burbridge in production, Gino Cieslik in design, and Betsy Blumenthal, the copy editor.

Trademark Notices

Throughout the text we have used several trademarks. Rather than insert a trademark symbol with each mention of the trademarked name, we acknowledge the trademarks here and state that they are used with no intention of infringing upon them. Other product names, trademarks, and registered trademarks are the property of their respective owners.

- Apple, AppleTalk, EtherTalk, LocalTalk, TokenTalk, and Macintosh are registered trademarks of Apple Computer, Inc.
- Bell and StarLan are registered trademarks of AT&T.





xxxii *PREFACE*

- DEC, DECnet, VAX, and DNA are trademarks of Digital Equipment Corp.
- IBM, SDLC, SNA, and IBM PC are registered trademarks of International Business Machines Corp.
- Novell, Netware, IPX, and SPX are registered trademarks of Novell, Inc.
- Network File System and NFS are registered trademarks of Sun Microsystems, Inc.
- PostScript is a registered trademark of Adobe Systems, Inc.
- UNIX is a registered trademark of UNIX System Laboratories, Inc., a wholly owned subsidiary of Novell, Inc.
- Xerox is a trademark and Ethernet is a registered trademark of Xerox Corp.

