

The background of the book cover is a photograph of a vast, snow-covered mountain range under a clear blue sky. A bright sun is positioned in the upper right corner, creating a starburst effect. In the foreground and middle ground, several hikers are seen ascending a steep, snow-covered slope. The hiker in the immediate foreground is wearing a large orange and black backpack and is using trekking poles. The overall scene conveys a sense of adventure and challenge.

Behrouz A. Forouzan

**Data
Communications
and Networking**

Fourth Edition

Don't forget to check out the Online Learning Center, www.mhhe.com/forouzan for additional resources!

Instructors and students using *Data Communications and Networking*, Fourth Edition by Behrouz A. Forouzan will find a wide variety of resources available at the Online Learning Center, www.mhhe.com/forouzan

Instructor Resources

Instructors can access the following resources by contacting their McGraw-Hill Representative for a secure password.

- a** PowerPoint Slides. Contain figures, tables, highlighted points, and brief descriptions of each section.
- O** Complete Solutions Manual. Password-protected solutions to all end-of-chapter problems are provided.
- a** Pageout. A free tool that helps you create your own course website.
- D** Instructor Message Board. Allows you to share ideas with other instructors using the text.

Student Resources

The student resources are available to those students using the book. Once you have accessed the Online Learning Center, click on "Student Resources," then select a chapter from the drop down menu that appears. Each chapter has a wealth of materials to help you review communications and networking concepts. Included are:

- a** Chapter Summaries. Bulleted summary points provide an essential review of major ideas and concepts covered in each chapter.
- a** Student Solutions Manual. Contains answers for odd-numbered problems.
- O** Glossary. Defines key terms presented in the book.
- O** Flashcards. Facilitate learning through practice and review.
- a** Animated Figures. Visual representations model key networking concepts, bringing them to life.
- D** Automated Quizzes. Easy-to-use quizzes strengthen learning and emphasize important ideas from the book.
- a** Web links. Connect students to additional resources available online.

DATA
COMMUNICATIONS
AND
NETWORKING

McGraw-Hill Forouzan Networking Series

Titles by Behrouz A. Forouzan:

Data Communications and Networking

TCP/IP Protocol Suite

Local Area Networks

Business Data Communications

DATA COMMUNICATIONS AND NETWORKING

Fourth Edition

Behrouz A. Forouzan

DeAnza College

with

Sophia Chung Fegan



Higher Education

Boston Burr Ridge, IL Dubuque, IA Madison, WI New York San Francisco St. Louis
Bangkok Bogota Caracas Kuala Lumpur Lisbon London Madrid Mexico City
Milan Montreal New Delhi Santiago Seoul Singapore Sydney Taipei Toronto



DATA COMMUNICATIONS AND NETWORKING, FOURTH EDITION

Published by McGraw-Hill, a business unit of The McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020. Copyright © 2007 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.

Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

This book is printed on acid-free paper.

1234567890DOC/DOC09876

ISBN-13 978-0-07-296775-3

ISBN-to 0-07-296775-7

Publisher: *Alan R. Apt*

Developmental Editor: *Rebecca Olson*

Executive Marketing Manager: *Michael Weitz*

Senior Project Manager: *Sheila M. Frank*

Senior Production Supervisor: *Kara Kudronowicz*

Senior Media Project Manager: *Jodi K. Banowetz*

Associate Media Producer: *Christina Nelson*

Senior Designer: *David W. Hash*

Cover Designer: *Rokusek Design*

(USE) Cover Image: Women ascending Mount McKinley, Alaska. Mount McKinley (Denali) 12,000 feet, ©Allan Kearney/Getty Images

Compositor: *Interactive Composition Corporation*

Typeface: *10/12 Times Roman*

Printer: *R. R. Donnelley Crawfordsville, IN*

Library of Congress **Cataloging-in-Publication** Data

Forouzan, Behrouz A.

Data communications and networking / Behrouz A Forouzan. — 4th ed.

p. em. — (McGraw-Hill Forouzan networking series)

Includes index.

ISBN 978-0-07-296775-3 - ISBN 0-07-296775-7 (hard copy : alk. paper)

1. Data transmission systems. 2. Computer networks. I. Title. II. Series.

TK5105.F6617 2007

004.6--dc22

2006000013

CIP

To my wife, Faezeh, with love
Behrouz Forouzan

BRIEF CONTENTS

Preface xxix

PART 1 Overview 1

Chapter 1 *Introduction* 3

Chapter 2 *Network Models* 27

PART 2 Physical Layer and Media 55

Chapter 3 *Data and Signals* 57

Chapter 4 *Digital Transmission* 101

Chapter 5 *Analog Transmission* 141

Chapter 6 *Bandwidth Utilization: Multiplexing and Spreading* 161

Chapter 7 *Transmission Media* 191

Chapter 8 *Switching* 213

Chapter 9 *Using Telephone and Cable Networks for Data Transmission* 241

PART 3 Data Link Layer 265

Chapter 10 *Error Detection and Correction* 267

Chapter 11 *Data Link Control* 307

Chapter 12 *Multiple Access* 363

Chapter 13 *Wired LANs: Ethernet* 395

Chapter 14 *Wireless LANs* 421

Chapter 15 *Connecting LANs, Backbone Networks, and Virtual LANs* 445

Chapter 16 *Wireless WANs: Cellular Telephone and Satellite Networks* 467

Chapter 17 *SONET/SDH* 491

Chapter 18 *Virtual-Circuit Networks: Frame Relay and ATM* 517

PART 4	Network Layer	547
Chapter 19	<i>Network Layer: Logical Addressing</i>	549
Chapter 20	<i>Network Layer: Internet Protocol</i>	579
Chapter 21	<i>Network Layer: Address Mapping, Error Reporting, and Multicasting</i>	611
Chapter 22	<i>Network Layer: Delivery, Forwarding, and Routing</i>	647
PARTS	Transport Layer	701
Chapter 23	<i>Process-to-Process Delivery: UDP, TCP, and SCTP</i>	703
Chapter 24	<i>Congestion Control and Quality of Service</i>	761
PART 6	Application Layer	795
Chapter 25	<i>Domain Name System</i>	797
Chapter 26	<i>Remote Logging, Electronic Mail, and File Transfer</i>	817
Chapter 27	<i>WWW and HTTP</i>	851
Chapter 28	<i>Network Management: SNMP</i>	873
Chapter 29	<i>Multimedia</i>	901
PART 7	Security	929
Chapter 30	<i>Cryptography</i>	931
Chapter 31	<i>Network Security</i>	961
Chapter 32	<i>Security in the Internet: IPSec, SSL/TLS, PGP, VPN, and Firewalls</i>	995
Appendix A	<i>Unicode</i>	1029
Appendix B	<i>Numbering Systems</i>	1037
Appendix C	<i>Mathematical Review</i>	1043
Appendix D	<i>8B/6T Code</i>	1055
Appendix E	<i>Telephone History</i>	1059
Appendix F	<i>Co!llect Addresses</i>	1061
Appendix G	<i>RFCs</i>	1063
Appendix H	<i>UDP and TCP Ports</i>	1065
	<i>Acronyms</i>	1067
	<i>Glossary</i>	1071
	<i>References</i>	1107
	<i>Index</i>	IIII

CONTENTS

Preface xxix

PART 1 Overview 1

Chapter 1 Introduction 3

- 1.1 DATA COMMUNICATIONS 3
 - Components 4
 - Data Representation 5
 - DataFlow 6
- 1.2 NETWORKS 7
 - Distributed Processing 7
 - Network Criteria 7
 - Physical Structures 8
 - Network Models 13
 - Categories of Networks 13
 - Interconnection of Networks: Internetwork IS
- 1.3 THE INTERNET 16
 - A Brief History 17
 - The Internet Today 17
- 1.4 PROTOCOLS AND STANDARDS 19
 - Protocols 19
 - Standards 19
 - Standards Organizations 20
 - Internet Standards 21
- 1.5 RECOMMENDED READING 21
 - Books 21
 - Sites 22
 - RFCs 22
- 1.6 KEY TERMS 22
- 1.7 SUMMARY 23
- 1.8 PRACTICE SET 24
 - Review Questions 24
 - Exercises 24
 - Research Activities 25

Chapter 2 Network Models 27

- 2.1 LAYERED TASKS 27
 - Sender, Receiver, and Carrier 28
 - Hierarchy 29

2.2	THE OSI MODEL	29
	Layered Architecture	30
	Peer-to-Peer Processes	30
	Encapsulation	33
2.3	LAYERS IN THE OSI MODEL	33
	Physical Layer	33
	Data Link Layer	34
	Network Layer	36
	Transport Layer	37
	Session Layer	39
	Presentation Layer	39
	Application Layer	41
	Summary of Layers	42
2.4	TCP/IP PROTOCOL SUITE	42
	Physical and Data Link Layers	43
	Network Layer	43
	Transport Layer	44
	Application Layer	45
2.5	ADDRESSING	45
	Physical Addresses	46
	Logical Addresses	47
	Port Addresses	49
	Specific Addresses	50
2.6	RECOMMENDED READING	50
	Books	51
	Sites	51
	RFCs	51
2.7	KEY TERMS	51
2.8	SUMMARY	52
2.9	PRACTICE SET	52
	Review Questions	52
	Exercises	53
	Research Activities	54
PART 2 Physical Layer and Media		55
Chapter 3 Data and Signals		57
3.1	ANALOG AND DIGITAL	57
	Analog and Digital Data	57
	Analog and Digital Signals	58
	Periodic and Nonperiodic Signals	58
3.2	PERIODIC ANALOG SIGNALS	59
	Sine Wave	59
	Phase	63
	Wavelength	64
	Time and Frequency Domains	65
	Composite Signals	66
	Bandwidth	69
3.3	DIGITAL SIGNALS	71
	Bit Rate	73
	Bit Length	73
	Digital Signal as a Composite Analog Signal	74
	Transmission of Digital Signals	74

3.4	TRANSMISSION IMPAIRMENT	80
	Attenuation	81
	Distortion	83
	Noise	84
3.5	DATA RATE LIMITS	85
	Noiseless Channel: Nyquist Bit Rate	86
	Noisy Channel: Shannon Capacity	87
	Using Both Limits	88
3.6	PERFORMANCE	89
	Bandwidth	89
	Throughput	90
	Latency (Delay)	90
	Bandwidth-Delay Product	92
	Jitter	94
3.7	RECOMMENDED READING	94
	Books	94
3.8	KEYTERMS	94
3.9	SUMMARY	95
3.10	PRACTICE SET	96
	Review Questions	96
	Exercises	96

Chapter 4 *Digital Transmission* 101

4.1	DIGITAL-TO-DIGITAL CONVERSION	101
	Line Coding	101
	Line Coding Schemes	106
	Block Coding	115
	Scrambling	118
4.2	ANALOG-TO-DIGITAL CONVERSION	120
	Pulse Code Modulation (PCM)	121
	Delta Modulation (DM)	129
4.3	TRANSMISSION MODES	131
	Parallel Transmission	131
	Serial Transmission	132
4.4	RECOMMENDED READING	135
	Books	135
4.5	KEYTERMS	135
4.6	SUMMARY	136
4.7	PRACTICE SET	137
	Review Questions	137
	Exercises	137

Chapter 5 *Analog Transmission* 141

5.1	DIGITAL-TO-ANALOG CONVERSION	141
	Aspects of Digital-to-Analog Conversion	142
	Amplitude Shift Keying	143
	Frequency Shift Keying	146
	Phase Shift Keying	148
	Quadrature Amplitude Modulation	152
5.2	ANALOG-TO-ANALOG CONVERSION	152
	Amplitude Modulation	153
	Frequency Modulation	154
	Phase Modulation	155

5.3	RECOMMENDED READING	156
	Books	156
5.4	KEY TERMS	157
5.5	SUMMARY	157
5.6	PRACTICE SET	158
	Review Questions	158
	Exercises	158
	Chapter 6	<i>Bandwidth Utilization: Multiplexing and Spreading</i>
		161
6.1	MULTIPLEXING	161
	Frequency-Division Multiplexing	162
	Wavelength-Division Multiplexing	167
	Synchronous Time-Division Multiplexing	169
	Statistical Time-Division Multiplexing	179
6.2	SPREAD SPECTRUM	180
	Frequency Hopping Spread Spectrum (FHSS)	181
	Direct Sequence Spread Spectrum	184
6.3	RECOMMENDED READING	185
	Books	185
6.4	KEY TERMS	185
6.5	SUMMARY	186
6.6	PRACTICE SET	187
	Review Questions	187
	Exercises	187
	Chapter 7	<i>Transmission Media</i>
		191
7.1	GUIDED MEDIA	192
	Twisted-Pair Cable	193
	Coaxial Cable	195
	Fiber-Optic Cable	198
7.2	UNGUIDED MEDIA: WIRELESS	203
	Radio Waves	205
	Microwaves	206
	Infrared	207
7.3	RECOMMENDED READING	208
	Books	208
7.4	KEY TERMS	208
7.5	SUMMARY	209
7.6	PRACTICE SET	209
	Review Questions	209
	Exercises	210
	Chapter 8	<i>Switching</i>
		213
8.1	CIRCUIT-SWITCHED NETWORKS	214
	Three Phases	217
	Efficiency	217
	Delay	217
	Circuit-Switched Technology in Telephone Networks	218
8.2	DATAGRAM NETWORKS	218
	Routing Table	220

	Efficiency	220
	Delay	221
	Datagram Networks in the Internet	221
8.3	VIRTUAL-CIRCUIT NETWORKS	221
	Addressing	222
	Three Phases	223
	Efficiency	226
	Delay in Virtual-Circuit Networks	226
	Circuit-Switched Technology in WANs	227
8.4	STRUCTURE OF A SWITCH	227
	Structure of Circuit Switches	227
	Structure of Packet Switches	232
8.5	RECOMMENDED READING	235
	Books	235
8.6	KEY TERMS	235
8.7	SUMMARY	236
8.8	PRACTICE SET	236
	Review Questions	236
	Exercises	237

Chapter 9 *Using Telephone and Cable Networks for Data Transmission* 241

9.1	TELEPHONE NETWORK	241
	Major Components	241
	LATAs	242
	Signaling	244
	Services Provided by Telephone Networks	247
9.2	DIAL-UP MODEMS	248
	Modem Standards	249
9.3	DIGITAL SUBSCRIBER LINE	251
	ADSL	252
	ADSL Lite	254
	HDSL	255
	SDSL	255
	VDSL	255
	Summary	255
9.4	CABLE TV NETWORKS	256
	Traditional Cable Networks	256
	Hybrid Fiber-Coaxial (HFC) Network	256
9.5	CABLE TV FOR DATA TRANSFER	257
	Bandwidth	257
	Sharing	259
	CM and CMTS	259
	Data Transmission Schemes: DOCSIS	260
9.6	RECOMMENDED READING	261
	Books	261
9.7	KEY TERMS	261
9.8	SUMMARY	262
9.9	PRACTICE SET	263
	Review Questions	263
	Exercises	264

PART 3 Data Link Layer 265**Chapter 10 Error Detection and Correction 267**

- 10.1 INTRODUCTION 267
 - Types of Errors 267
 - Redundancy 269
 - Detection Versus Correction 269
 - Forward Error Correction Versus Retransmission 269
 - Coding 269
 - Modular Arithmetic 270
- 10.2 BLOCK CODING 271
 - Error Detection 272
 - Error Correction 273
 - Hamming Distance 274
 - Minimum Hamming Distance 274
- 10.3 LINEAR BLOCK CODES 277
 - Minimum Distance for Linear Block Codes 278
 - Some Linear Block Codes 278
- 10.4 CYCLIC CODES 284
 - Cyclic Redundancy Check 284
 - Hardware Implementation 287
 - Polynomials 291
 - Cyclic Code Analysis 293
 - Advantages of Cyclic Codes 297
 - Other Cyclic Codes 297
- 10.5 CHECKSUM 298
 - Idea 298
 - One's Complement 298
 - Internet Checksum 299
- 10.6 RECOMMENDED READING 301
 - Books 301
 - RFCs 301
- 10.7 KEY TERMS 301
- 10.8 SUMMARY 302
- 10.9 PRACTICE SET 303
 - Review Questions 303
 - Exercises 303

Chapter 11 Data Link Control 307

- 11.1 FRAMING 307
 - Fixed-Size Framing 308
 - Variable-Size Framing 308
- 11.2 FLOW AND ERROR CONTROL 311
 - Flow Control 311
 - Error Control 311
- 11.3 PROTOCOLS 311
- 11.4 NOISELESS CHANNELS 312
 - Simplest Protocol 312
 - Stop-and-Wait Protocol 315
- 11.5 NOISY CHANNELS 318
 - Stop-and-Wait Automatic Repeat Request 318
 - Go-Back-N Automatic Repeat Request 324

	Selective Repeat Automatic Repeat Request	332
	Piggybacking	339
11.6	HDLC	340
	Configurations and Transfer Modes	340
	Frames	341
	Control Field	343
11.7	POINT-TO-POINT PROTOCOL	346
	Framing	348
	Transition Phases	349
	Multiplexing	350
	Multilink PPP	355
11.8	RECOMMENDED READING	357
	Books	357
11.9	KEY TERMS	357
11.10	SUMMARY	358
11.11	PRACTICE SET	359
	Review Questions	359
	Exercises	359
	Chapter 12	<i>Multiple Access</i>
		363
12.1	RANDOMACCESS	364
	ALOHA	365
	Carrier Sense Multiple Access (CSMA)	370
	Carrier Sense Multiple Access with Collision Detection (CSMA/CD)	373
	Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)	377
12.2	CONTROLLED ACCESS	379
	Reservation	379
	Polling	380
	Token Passing	381
12.3	CHANNELIZATION	383
	Frequency-Division Multiple Access (FDMA)	383
	Time-Division Multiple Access (TDMA)	384
	Code-Division Multiple Access (CDMA)	385
12.4	RECOMMENDED READING	390
	Books	391
12.5	KEY TERMS	391
12.6	SUMMARY	391
12.7	PRACTICE SET	392
	Review Questions	392
	Exercises	393
	Research Activities	394
	Chapter 13	<i>Wired LANs: Ethernet</i>
		395
13.1	IEEE STANDARDS	395
	Data Link Layer	396
	Physical Layer	397
13.2	STANDARD ETHERNET	397
	MAC Sublayer	398
	Physical Layer	402
13.3	CHANGES IN THE STANDARD	406
	Bridged Ethernet	406
	Switched Ethernet	407
	Full-Duplex Ethernet	408

- 13.4 FAST ETHERNET 409
 - MAC Sublayer 409
 - Physical Layer 410
- 13.5 GIGABIT ETHERNET 412
 - MAC Sublayer 412
 - Physical Layer 414
 - Ten-Gigabit Ethernet 416
- 13.6 RECOMMENDED READING 417
 - Books 417
- 13.7 KEY TERMS 417
- 13.8 SUMMARY 417
- 13.9 PRACTICE SET 418
 - Review Questions 418
 - Exercises 419

Chapter 14 *Wireless LANs* 421

- 14.1 IEEE 802.11 421
 - Architecture 421
 - MAC Sublayer 423
 - Addressing Mechanism 428
 - Physical Layer 432
- 14.2 BLUETOOTH 434
 - Architecture 435
 - Bluetooth Layers 436
 - Radio Layer 436
 - Baseband Layer 437
 - L2CAP 440
 - Other Upper Layers 441
- 14.3 RECOMMENDED READING 441
 - Books 442
- 14.4 KEYTERMS 442
- 14.5 SUMMARY 442
- 14.6 PRACTICE SET 443
 - Review Questions 443
 - Exercises 443

Chapter 15 *Connecting LANs, Backbone Networks, and Virtual LANs* 445

- 15.1 CONNECTING DEVICES 445
 - Passive Hubs 446
 - Repeaters 446
 - Active Hubs 447
 - Bridges 447
 - Two-Layer Switches 454
 - Routers 455
 - Three-Layer Switches 455
 - Gateway 455
- 15.2 BACKBONE NETWORKS 456
 - Bus Backbone 456
 - Star Backbone 457
 - Connecting Remote LANs 457

- 15.3 VIRTUAL LANs 458
 - Membership 461
 - Configuration 461
 - Communication Between Switches 462
 - IEEE Standard 462
 - Advantages 463
- 15.4 RECOMMENDED READING 463
 - Books 463
 - Site 463
- 15.5 KEY TERMS 463
- 15.6 SUMMARY 464
- 15.7 PRACTICE SET 464
 - Review Questions 464
 - Exercises 465

Chapter 16 *Wireless WANs: Cellular Telephone and Satellite Networks* 467

- 16.1 CELLULAR TELEPHONY 467
 - Frequency-Reuse Principle 467
 - Transmitting 468
 - Receiving 469
 - Roaming 469
 - First Generation 469
 - Second Generation 470
 - Third Generation 477
- 16.2 SATELLITE NETWORKS 478
 - Orbits 479
 - Footprint 480
 - Three Categories of Satellites 480
 - GEO Satellites 481
 - MEO Satellites 481
 - LEO Satellites 484
- 16.3 RECOMMENDED READING 487
 - Books 487
- 16.4 KEY TERMS 487
- 16.5 SUMMARY 487
- 16.6 PRACTICE SET 488
 - Review Questions 488
 - Exercises 488

Chapter 17 *SONET/SDH* 491

- 17.1 ARCHITECTURE 491
 - Signals 491
 - SONET Devices 492
 - Connections 493
- 17.2 SONET LAYERS 494
 - Path Layer 494
 - Line Layer 495
 - Section Layer 495
 - Photonic Layer 495
 - Device-Layer Relationships 495

17.3	SONET FRAMES	496
	Frame, Byte, and Bit Transmission	496
	STS-1 Frame Format	497
	Overhead Summary	501
	Encapsulation	501
17.4	STS MULTIPLEXING	503
	Byte Interleaving	504
	Concatenated Signal	505
	Add/Drop Multiplexer	506
17.5	SONET NETWORKS	507
	Linear Networks	507
	Ring Networks	509
	Mesh Networks	510
17.6	VIRTUAL TRIBUTARIES	512
	Types of VTs	512
17.7	RECOMMENDED READING	513
	Books	513
17.8	KEY TERMS	513
17.9	SUMMARY	514
17.10	PRACTICE SET	514
	Review Questions	514
	Exercises	515
	Chapter 18	<i>Virtual-Circuit Networks: Frame Relay and ATM</i>
		517
18.1	FRAME RELAY	517
	Architecture	518
	Frame Relay Layers	519
	Extended Address	521
	FRADs	522
	VOFR	522
	LMI	522
	Congestion Control and Quality of Service	522
18.2	ATM	523
	Design Goals	523
	Problems	523
	Architecture	526
	Switching	529
	ATM Layers	529
	Congestion Control and Quality of Service	535
18.3	ATM LANs	536
	ATM LAN Architecture	536
	LAN Emulation (LANE)	538
	Client/Server Model	539
	Mixed Architecture with Client/Server	540
18.4	RECOMMENDED READING	540
	Books	541
18.5	KEY TERMS	541
18.6	SUMMARY	541
18.7	PRACTICE SET	543
	Review Questions	543
	Exercises	543

PART 4 Network Layer 547**Chapter 19** *Netw/ark Layer: Logical Addressing* 549

- 19.1 IPv4ADDRESSES 549
 - Address Space 550
 - Notations 550
 - Classful Addressing 552
 - Classless Addressing 555
 - Network Address Translation (NAT) 563
- 19.2 IPv6 ADDRESSES 566
 - Structure 567
 - Address Space 568
- 19.3 RECOMMENDED READING 572
 - Books 572
 - Sites 572
 - RFCs 572
- 19.4 KEY TERMS 572
- 19.5 SUMMARY 573
- 19.6 PRACTICE SET 574
 - Review Questions 574
 - Exercises 574
 - Research Activities 577

Chapter 20 *Network Layer: Internet Protocol* 579

- 20.1 INTERNETWORKING 579
 - Need for Network Layer 579
 - Internet as a Datagram Network 581
 - Internet as a Connectionless Network 582
- 20.2 IPv4 582
 - Datagram 583
 - Fragmentation 589
 - Checksum 594
 - Options 594
- 20.3 IPv6 596
 - Advantages 597
 - Packet Format 597
 - Extension Headers 602
- 20.4 TRANSITION FROM IPv4 TO IPv6 603
 - Dual Stack 604
 - Tunneling 604
 - Header Translation 605
- 20.5 RECOMMENDED READING 605
 - Books 606
 - Sites 606
 - RFCs 606
- 20.6 KEY TERMS 606
- 20.7 SUMMARY 607
- 20.8 PRACTICE SET 607
 - Review Questions 607
 - Exercises 608
 - Research Activities 609

Chapter 21 *Network Layer: Address Mapping, Error Reporting, and Multicasting* 611

- 21.1 ADDRESS MAPPING 611
 - Mapping Logical to Physical Address: ARP 612
 - Mapping Physical to Logical Address: RARp, BOOTP, and DHCP 618
- 21.2 ICMP 621
 - Types of Messages 621
 - Message Format 621
 - Error Reporting 622
 - Query 625
 - Debugging Tools 627
- 21.3 IGMP 630
 - Group Management 630
 - IGMP Messages 631
 - Message Format 631
 - IGMP Operation 632
 - Encapsulation 635
 - Netstat Utility 637
- 21.4 ICMPv6 638
 - Error Reporting 638
 - Query 639
- 21.5 RECOMMENDED READING 640
 - Books 641
 - Site 641
 - RFCs 641
- 21.6 KEYTERMS 641
- 21.7 SUMMARY 642
- 21.8 PRACTICE SET 643
 - Review Questions 643
 - Exercises 644
 - Research Activities 645

Chapter 22 *Network Layer: Delivery, Forwarding, and Routing* 647

- 22.1 DELIVERY 647
 - Direct Versus Indirect Delivery 647
- 22.2 FORWARDING 648
 - Forwarding Techniques 648
 - Forwarding Process 650
 - Routing Table 655
- 22.3 UNICAST ROUTING PROTOCOLS 658
 - Optimization 658
 - Intra- and Interdomain Routing 659
 - Distance Vector Routing 660
 - Link State Routing 666
 - Path Vector Routing 674
- 22.4 MULTICAST ROUTING PROTOCOLS 678
 - Unicast, Multicast, and Broadcast 678
 - Applications 681
 - Multicast Routing 682
 - Routing Protocols 684

- 22.5 RECOMMENDED READING 694
 - Books 694
 - Sites 694
 - RFCs 694
- 22.6 KEY TERMS 694
- 22.7 SUMMARY 695
- 22.8 PRACTICE SET 697
 - Review Questions 697
 - Exercises 697
 - Research Activities 699

PART 5 Transport Layer 701

Chapter 23 *Process-to-Process Delivery: UDP, TCP, and SCTP 703*

- 23.1 PROCESS-TO-PROCESS DELIVERY 703
 - Client/Server Paradigm 704
 - Multiplexing and Demultiplexing 707
 - Connectionless Versus Connection-Oriented Service 707
 - Reliable Versus Unreliable 708
 - Three Protocols 708
- 23.2 USER DATAGRAM PROTOCOL (UDP) 709
 - Well-Known Ports for UDP 709
 - User Datagram 710
 - Checksum 711
 - UDP Operation 713
 - Use of UDP 715
- 23.3 TCP 715
 - TCP Services 715
 - TCP Features 719
 - Segment 721
 - A TCP Connection 723
 - Flow Control 728
 - Error Control 731
 - Congestion Control 735
- 23.4 SCTP 736
 - SCTP Services 736
 - SCTP Features 738
 - Packet Format 742
 - An SCTP Association 743
 - Flow Control 748
 - Error Control 751
 - Congestion Control 753
- 23.5 RECOMMENDED READING 753
 - Books 753
 - Sites 753
 - RFCs 753
- 23.6 KEY TERMS 754
- 23.7 SUMMARY 754
- 23.8 PRACTICE SET 756
 - Review Questions 756
 - Exercises 757
 - Research Activities 759

Chapter 24 *Congestion Control and Quality of Service* 767

- 24.1 DATA TRAFFIC 761
 - Traffic Descriptor 761
 - Traffic Profiles 762
- 24.2 CONGESTION 763
 - Network Performance 764
- 24.3 CONGESTION CONTROL 765
 - Open-Loop Congestion Control 766
 - Closed-Loop Congestion Control 767
- 24.4 TWO EXAMPLES 768
 - Congestion Control in TCP 769
 - Congestion Control in Frame Relay 773
- 24.5 QUALITY OF SERVICE 775
 - Flow Characteristics 775
 - Flow Classes 776
- 24.6 TECHNIQUES TO IMPROVE QoS 776
 - Scheduling 776
 - Traffic Shaping 777
 - Resource Reservation 780
 - Admission Control 780
- 24.7 INTEGRATED SERVICES 780
 - Signaling 781
 - Flow Specification 781
 - Admission 781
 - Service Classes 781
 - RSVP 782
 - Problems with Integrated Services 784
- 24.8 DIFFERENTIATED SERVICES 785
 - DS Field 785
- 24.9 QoS IN SWITCHED NETWORKS 786
 - QoS in Frame Relay 787
 - QoS in ATM 789
- 24.10 RECOMMENDED READING 790
 - Books 791
- 24.11 KEY TERMS 791
- 24.12 SUMMARY 791
- 24.13 PRACTICE SET 792
 - Review Questions 792
 - Exercises 793

PART 6 *Application Layer* 795**Chapter 25** *Domain Name System* 797

- 25.1 NAME SPACE 798
 - Flat Name Space 798
 - Hierarchical Name Space 798
- 25.2 DOMAIN NAME SPACE 799
 - Label 799
 - Domain Name 799
 - Domain 801

25.3	DISTRIBUTION OF NAME SPACE	801
	Hierarchy of Name Servers	802
	Zone	802
	Root Server	803
	Primary and Secondary Servers	803
25.4	DNS IN THE INTERNET	803
	Generic Domains	804
	Country Domains	805
	Inverse Domain	805
25.5	RESOLUTION	806
	Resolver	806
	Mapping Names to Addresses	807
	Mapping Address to Names	807
	Recursive Resolution	808
	Iterative Resolution	808
	Caching	808
25.6	DNS MESSAGES	809
	Header	809
25.7	TYPES OF RECORDS	811
	Question Record	811
	Resource Record	811
25.8	REGISTRARS	811
25.9	DYNAMIC DOMAIN NAME SYSTEM (DDNS)	812
25.10	ENCAPSULATION	812
25.11	RECOMMENDED READING	812
	Books	813
	Sites	813
	RFCs	813
25.12	KEY TERMS	813
25.13	SUMMARY	813
25.14	PRACTICE SET	814
	Review Questions	814
	Exercises	815

Chapter 26 *Remote Logging, Electronic Mail, and File Transfer* 817

26.1	REMOTE LOGGING	817
	TELNET	817
26.2	ELECTRONIC MAIL	824
	Architecture	824
	User Agent	828
	Message Transfer Agent: SMTP	834
	Message Access Agent: POP and IMAP	837
	Web-Based Mail	839
26.3	FILE TRANSFER	840
	File Transfer Protocol (FTP)	840
	Anonymous FTP	844
26.4	RECOMMENDED READING	845
	Books	845
	Sites	845
	RFCs	845
26.5	KEY TERMS	845
26.6	SUMMARY	846

- 26.7 PRACTICE SET 847
 - Review Questions 847
 - Exercises 848
 - Research Activities 848

Chapter 27 *WWW and HTTP* 851

- 27.1 ARCHITECTURE 851
 - Client (Browser) 852
 - Server 852
 - Uniform Resource Locator 853
 - Cookies 853
- 27.2 WEB DOCUMENTS 854
 - Static Documents 855
 - Dynamic Documents 857
 - Active Documents 860
- 27.3 HTTP 861
 - HTTP Transaction 861
 - Persistent Versus Nonpersistent Connection 868
 - Proxy Server 868
- 27.4 RECOMMENDED READING 869
 - Books 869
 - Sites 869
 - RFCs 869
- 27.5 KEY TERMS 869
- 27.6 SUMMARY 870
- 27.7 PRACTICE SET 871
 - Review Questions 871
 - Exercises 871

Chapter 28 *Network Management: SNMP* 873

- 28.1 NETWORK MANAGEMENT SYSTEM 873
 - Configuration Management 874
 - Fault Management 875
 - Performance Management 876
 - Security Management 876
 - Accounting Management 877
- 28.2 SIMPLE NETWORK MANAGEMENT PROTOCOL (SNMP) 877
 - Concept 877
 - Management Components 878
 - Structure of Management Information 881
 - Management Information Base (MIB) 886
 - Lexicographic Ordering 889
 - SNMP 891
 - Messages 893
 - UDP Ports 895
 - Security 897
- 28.3 RECOMMENDED READING 897
 - Books 897
 - Sites 897
 - RFCs 897
- 28.4 KEY TERMS 897
- 28.5 SUMMARY 898

28.6	PRACTICE SET	899
	Review Questions	899
	Exercises	899
Chapter 29 <i>Multimedia</i> 901		
29.1	DIGITIZING AUDIO AND VIDEO	902
	Digitizing Audio	902
	Digitizing Video	902
29.2	AUDIO AND VIDEO COMPRESSION	903
	Audio Compression	903
	Video Compression	904
29.3	STREAMING STORED AUDIO/VIDEO	908
	First Approach: Using a Web Server	909
	Second Approach: Using a Web Server with Metafile	909
	Third Approach: Using a Media Server	910
	Fourth Approach: Using a Media Server and RTSP	911
29.4	STREAMING LIVE AUDIO/VIDEO	912
29.5	REAL-TIME INTERACTIVE AUDIO/VIDEO	912
	Characteristics	912
29.6	RTP	916
	RTP Packet Format	917
	UDP Port	919
29.7	RTCP	919
	Sender Report	919
	Receiver Report	920
	Source Description Message	920
	Bye Message	920
	Application-Specific Message	920
	UDP Port	920
29.8	VOICE OVER IP	920
	SIP	920
	H.323	923
29.9	RECOMMENDED READING	925
	Books	925
	Sites	925
29.10	KEY TERMS	925
29.11	SUMMARY	926
29.12	PRACTICE SET	927
	Review Questions	927
	Exercises	927
	Research Activities	928

PART 7 Security 929

Chapter 30 *Cryptography* 931

30.1	INTRODUCTION	931
	Definitions	931
	Two Categories	932
30.2	SYMMETRIC-KEY CRYPTOGRAPHY	935
	Traditional Ciphers	935
	Simple Modem Ciphers	938

	Modern Round Ciphers	940
	Mode of Operation	945
30.3	ASYMMETRIC-KEY CRYPTOGRAPHY	949
	RSA	949
	Diffie-Hellman	952
30.4	RECOMMENDED READING	956
	Books	956
30.5	KEY TERMS	956
30.6	SUMMARY	957
30.7	PRACTICE SET	958
	Review Questions	958
	Exercises	959
	Research Activities	960
	Chapter 31	<i>Network Security</i>
		961
31.1	SECURITY SERVICES	961
	Message Confidentiality	962
	Message Integrity	962
	Message Authentication	962
	Message Nonrepudiation	962
	Entity Authentication	962
31.2	MESSAGE CONFIDENTIALITY	962
	Confidentiality with Symmetric-Key Cryptography	963
	Confidentiality with Asymmetric-Key Cryptography	963
31.3	MESSAGE INTEGRITY	964
	Document and Fingerprint	965
	Message and Message Digest	965
	Difference	965
	Creating and Checking the Digest	966
	Hash Function Criteria	966
	Hash Algorithms: SHA-1	967
31.4	MESSAGE AUTHENTICATION	969
	MAC	969
31.5	DIGITAL SIGNATURE	971
	Comparison	971
	Need for Keys	972
	Process	973
	Services	974
	Signature Schemes	976
31.6	ENTITY AUTHENTICATION	976
	Passwords	976
	Challenge-Response	978
31.7	KEY MANAGEMENT	981
	Symmetric-Key Distribution	981
	Public-Key Distribution	986
31.8	RECOMMENDED READING	990
	Books	990
31.9	KEY TERMS	990
31.10	SUMMARY	991
31.11	PRACTICE SET	992
	Review Questions	992
	Exercises	993
	Research Activities	994

Chapter 32 *Security in the Internet: IPSec, SSUFLS, PGP, VPN, and Firewalls* 995

- 32.1 IPSecurity (IPSec) 996
 - Two Modes 996
 - Two Security Protocols 998
 - Security Association 1002
 - Internet Key Exchange (IKE) 1004
 - Virtual Private Network 1004
- 32.2 SSLffLS 1008
 - SSL Services 1008
 - Security Parameters 1009
 - Sessions and Connections 1011
 - Four Protocols 1012
 - Transport Layer Security 1013
- 32.3 PGP 1014
 - Security Parameters 1015
 - Services 1015
 - A Scenario 1016
 - PGP Algorithms 1017
 - Key Rings 1018
 - PGP Certificates 1019
- 32.4 FIREWALLS 1021
 - Packet-Filter Firewall 1022
 - Proxy Firewall 1023
- 32.5 RECOMMENDED READING 1024
 - Books 1024
- 32.6 KEY IERMS 1024
- 32.7 SUMMARY 1025
- 32.8 PRACTICE SET 1026
 - Review Questions 1026
 - Exercises 1026

Appendix A *Unicode* 1029

- A.1 UNICODE 1029
 - Planes 1030
 - Basic Multilingual Plane (BMP) 1030
 - Supplementary Multilingual Plane (SMP) 1032
 - Supplementary Ideographic Plane (SIP) 1032
 - Supplementary Special Plane (SSP) 1032
 - Private Use Planes (PUPs) 1032
- A.2 ASCII 1032
 - Some Properties of ASCII 1036

Appendix B *Numbering Systems* 1037

- B.1 BASE 10: DECIMAL 1037
 - Weights 1038
- B.2 BASE 2: BINARY 1038
 - Weights 1038
 - Conversion 1038

B.3	BASE 16: HEXADECIMAL	1039	
	Weights	1039	
	Conversion	1039	
	A Comparison	1040	
BA	BASE 256: IP ADDRESSES	1040	
	Weights	1040	
	Conversion	1040	
B.5	OTHER CONVERSIONS	1041	
	Binary and Hexadecimal	1041	
	Base 256 and Binary	1042	
	Appendix C	<i>Mathenwtical Review</i>	1043
C.1	TRIGONOMETRIC FUNCTIONS	1043	
	Sine Wave	1043	
	Cosine Wave	1045	
	Other Trigonometric Functions	1046	
	Trigonometric Identities	1046	
C.2	FOURIER ANALYSIS	1046	
	Fourier Series	1046	
	Fourier Transform	1048	
C.3	EXPONENT AND LOGARITHM	1050	
	Exponential Function	1050	
	Logarithmic Function	1051	
	Appendix O	<i>8B/6T Code</i>	1055
	Appendix E	<i>Telephone History</i>	1059
	Before 1984	1059	
	Between 1984 and 1996	1059	
	After 1996	1059	
	Appendix F	<i>Contact Addresses</i>	1061
	Appendix G	<i>RFCs</i>	1063
	Appendix H	<i>UDP and TCP Ports</i>	1065
	Acronyms	1067	
	Glossary	1071	
	References	1107	
	Index	1111	

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.

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 five-layer Internet 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 Internet model was chosen because it is a protocol that is fully implemented.

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

Visual Approach

The book presents highly technical subject matter without complex formulas by using a balance of text and figures. More than 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. Both of these ideas are easy to grasp visually.

Highlighted Points

We emphasize important concepts in highlighted boxes for quick reference and immediate attention.

Examples and Applications

When appropriate, we have selected examples to reflect true-to-life situations. For example, in Chapter 6 we have shown several cases of telecommunications in current telephone networks.

Recommended Reading

Each chapter includes a list of books and sites that can be used for further reading.

Key Terms

Each chapter includes a list of key terms for the student.

Summary

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

Practice Set

Each chapter includes a practice set designed to reinforce and apply salient concepts. It consists of three parts: review questions, exercises, and research activities (only for appropriate chapters). Review questions are intended to test the student's first-level understanding of the material presented in the chapter. Exercises require deeper understanding of the material. Research activities are designed to create motivation for further study.

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 Fourth Edition

The Fourth Edition has major changes from the Third Edition, both in the organization and in the contents.

Organization

The following lists the changes in the organization of the book:

1. Chapter 6 now contains multiplexing as well as spreading.
2. Chapter 8 is now totally devoted to switching.
3. The contents of Chapter 12 are moved to Chapter 11.
4. Chapter 17 covers SONET technology.
5. Chapter 19 discusses IP addressing.
6. Chapter 20 is devoted to the Internet Protocol.
7. Chapter 21 discusses three protocols: ARP, ICMP, and IGMP.
8. Chapter 28 is new and devoted to network management in the Internet.
9. The previous Chapters 29 to 31 are now Chapters 30 to 32.

Contents

We have revised the contents of many chapters including the following:

1. The contents of Chapters 1 to 5 are revised and augmented. Examples are added to clarify the contents.
2. The contents of Chapter 10 are revised and augmented to include methods of error detection and correction.
3. Chapter 11 is revised to include a full discussion of several control link protocols.
4. Delivery, forwarding, and routing of datagrams are added to Chapter 22.
5. The new transport protocol, SCTP, is added to Chapter 23.
6. The contents of Chapters 30, 31, and 32 are revised and augmented to include additional discussion about security issues and the Internet.
7. New examples are added to clarify the understanding of concepts.

End Materials

1. A section is added to the end of each chapter listing additional sources for study.
2. The review questions are changed and updated.
3. The multiple-choice questions are moved to the book site to allow students to self-test their knowledge about the contents of the chapter and receive immediate feedback.
4. Exercises are revised and new ones are added to the appropriate chapters.
5. Some chapters contain research activities.

Instructional Materials

Instructional materials for both the student and the teacher are revised and augmented. The solutions to exercises contain both the explanation and answer including full colored figures or tables when needed. The Powerpoint presentations are more comprehensive and include text and figures.

Contents

The book is divided into seven parts. The first part is an overview; the last part concerns network security. The middle five parts are designed to represent the five layers of the Internet model. The following summarizes the contents of each part.

Part One: Overview

The first part gives a general overview of data communications and networking. Chapter 1 covers introductory concepts needed for the rest of the book. Chapter 2 introduces the Internet model.

Part Two: Physical Layer

The second part is a discussion of the physical layer of the Internet model. Chapters 3 to 6 discuss telecommunication aspects of the physical layer. Chapter 7 introduces the transmission media, which, although not part of the physical layer, is controlled by it. Chapter 8 is devoted to switching, which can be used in several layers. Chapter 9 shows how two public networks, telephone and cable TV, can be used for data transfer.

Part Three: Data Link Layer

The third part is devoted to the discussion of the data link layer of the Internet model. Chapter 10 covers error detection and correction. Chapters 11, 12 discuss issues related to data link control. Chapters 13 through 16 deal with LANs. Chapters 17 and 18 are about WANs. LANs and WANs are examples of networks operating in the first two layers of the Internet model.

Part Four: Network Layer

The fourth part is devoted to the discussion of the network layer of the Internet model. Chapter 19 covers IP addresses. Chapters 20 and 21 are devoted to the network layer protocols such as IP, ARP, ICMP, and IGMP. Chapter 22 discusses delivery, forwarding, and routing of packets in the Internet.

Part Five: Transport Layer

The fifth part is devoted to the discussion of the transport layer of the Internet model. Chapter 23 gives an overview of the transport layer and discusses the services and duties of this layer. It also introduces three transport-layer protocols: UDP, TCP, and SCTP. Chapter 24 discusses congestion control and quality of service, two issues related to the transport layer and the previous two layers.

Part Six: Application Layer

The sixth part is devoted to the discussion of the application layer of the Internet model. Chapter 25 is about DNS, the application program that is used by other application programs to map application layer addresses to network layer addresses. Chapter 26 to 29 discuss some common applications protocols in the Internet.

Part Seven: Security

The seventh part is a discussion of security. It serves as a prelude to further study in this subject. Chapter 30 briefly discusses cryptography. Chapter 31 introduces security aspects. Chapter 32 shows how different security aspects can be applied to three layers of the Internet model.

Online Learning Center

The McGraw-Hill Online Learning Center contains much additional material. Available at www.mhhe.com/forouzan. As students read through *Data Communications and Networking*, they can go online to take self-grading quizzes. They can also access lecture materials such as PowerPoint slides, and get additional review from animated figures from the book. Selected solutions are also available over the Web. The solutions to odd-numbered problems are provided to students, and instructors can use a password to access the complete set of solutions.

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 provides 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 following are some guidelines.

- Parts one to three are strongly recommended.
- Parts four to six can be covered if there is no following course in *TCP/IP* protocol.
- Part seven is recommended if there is no following course in network security.

Acknowledgments

It is obvious that the development of a book of this scope needs the support of many people.

Peer Review

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 third and fourth editions of this book.

Farid Ahmed, *Catholic University*
 Kaveh Ashenayi, *University ofTulsa*
 Yoris Au, *University ofTexas, San Antonio*
 Essie Bakhtiar, *Clayton College & State University*
 Anthony Barnard, *University ofAlabama, Brimingham*
 A.T. Burrell, *Oklahoma State University*
 Scott Campbell, *Miami University*
 Teresa Carrigan, *Blackburn College*
 Hwa Chang, *Tufts University*
 Edward Chlebus, *Illinois Institute ofTechnology*
 Peter Cooper, *Sam Houston State University*
 Richard Coppins, *Virginia Commonwealth University*
 Harpal Dhillon, *Southwestern Oklahoma State University*
 Hans-Peter Dommel, *Santa Clara University*
 M. Barry Dumas, *Baruch College, CUNY*
 William Figg, *Dakota State University*
 Dale Fox, *Quinnipiac University*
 Terrence Fries, *Coastal Carolina University*
 Errin Fulp, *Wake Forest University*

Sandeep Gupta, *Arizona State University*
 George Hamer, *South Dakota State University*
 James Henson, *California State University, Fresno*
 Tom Hilton, *Utah State University*
 Allen Holliday, *California State University, Fullerton*
 Seyed Hossein Hosseini, *University of Wisconsin, Milwaukee*
 Gerald Isaacs, *Carroll College, Waukesha*
 Hrishikesh Joshi, *DeVry University*
 E.S. Khosravi, *Southern University*
 Bob Kinicki, *Worcester Polytechnic University*
 Kevin Kwiat, *Hamilton College*
 Ten-Hwang Lai, *Ohio State University*
 Chung-Wei Lee, *Auburn University*
 Ka-Cheong Leung, *Texas Tech University*
 Gertrude Levine, *Fairleigh Dickinson University*
 Alvin Sek See Lim, *Auburn University*
 Charles Liu, *California State University, Los Angeles*
 Wenhong Liu, *California State University, Los Angeles*
 Mark Llewellyn, *University of Central Florida*
 Sanchita Mal-Sarkar, *Cleveland State University*
 Louis Marseille, *Harford Community College*
 Kevin McNeill, *University of Arizona*
 Arnold C. Meltzer, *George Washington University*
 Rayman Meservy, *Brigham Young University*
 Prasant Mohapatra, *University of California, Davis*
 Hung Z Ngo, *SUNY, Buffalo*
 Larry Owens, *California State University, Fresno*
 Arnold Patton, *Bradley University*
 Dolly Samson, *Hawaii Pacific University*
 Joseph Sherif, *California State University, Fullerton*
 Robert Simon, *George Mason University*
 Ronald I. Srodawa, *Oakland University*
 Daniel Tian, *California State University, Monterey Bay*
 Richard Tibbs, *Radford University*
 Christophe Veltsos, *Minnesota State University, Mankato*
 Yang Wang, *University of Maryland, College Park*
 Sherali Zeadally, *Wayne State University*

McGraw-Hill Staff

Special thanks go to the staff of McGraw-Hill. Alan Apt, our publisher, proved how a proficient publisher can make the impossible possible. Rebecca Olson, the developmental editor, gave us help whenever we needed it. Sheila Frank, our project manager, guided us through the production process with enormous enthusiasm. We also thank David Hash in design, Kara Kudronowicz in production, and Patti Scott, the copy editor.

Overview

Objectives

Part 1 provides a general idea of what we will see in the rest of the book. Four major concepts are discussed: data communications, networking, protocols and standards, and networking models.

Networks exist so that data may be sent from one place to another—the basic concept of *data communications*. To fully grasp this subject, we must understand the data communication components, how different types of data can be represented, and how to create a data flow.

Data communications between remote parties can be achieved through a process called *networking*, involving the connection of computers, media, and networking devices. Networks are divided into two main categories: local area networks (LANs) and wide area networks (WANs). These two types of networks have different characteristics and different functionalities. The Internet, the main focus of the book, is a collection of LANs and WANs held together by internetworking devices.

Protocols and standards are vital to the implementation of data communications and networking. Protocols refer to the rules; a standard is a protocol that has been adopted by vendors and manufacturers.

Network models serve to organize, unify, and control the hardware and software components of data communications and networking. Although the term "network model" suggests a relationship to networking, the model also encompasses data communications.

Chapters

This part consists of two chapters: Chapter 1 and Chapter 2.

Chapter 1

In Chapter 1, we introduce the concepts of data communications and networking. We discuss data communications components, data representation, and data flow. We then move to the structure of networks that carry data. We discuss network topologies, categories of networks, and the general idea behind the Internet. The section on protocols and standards gives a quick overview of the organizations that set standards in data communications and networking.

Chapter 2

The two dominant networking models are the Open Systems Interconnection (OSI) and the Internet model (TCP/IP). The first is a theoretical framework; the second is the actual model used in today's data communications. **In** Chapter 2, we first discuss the OSI model to give a general background. We then concentrate on the Internet model, which is the foundation for the rest of the book.