

# CONTENTS

Preface xxix

Trade Mark xxxviii

## PART I: Overview 1

### Chapter 1 Introduction 3

#### 1.1 DATA COMMUNICATIONS 4

- 1.1.1 Components 4
- 1.1.2 Data Representation 5
- 1.1.3 Data Flow 6

#### 1.2 NETWORKS 7

- 1.2.1 Network Criteria 7
- 1.2.2 Physical Structures 8

#### 1.3 NETWORK TYPES 13

- 1.3.1 Local Area Network 13
- 1.3.2 Wide Area Network 14
- 1.3.3 Switching 15
- 1.3.4 The Internet 17
- 1.3.5 Accessing the Internet 18

#### 1.4 INTERNET HISTORY 19

- 1.4.1 Early History 19
- 1.4.2 Birth of the Internet 20
- 1.4.3 Internet Today 22

#### 1.5 STANDARDS AND ADMINISTRATION 22

- 1.5.1 Internet Standards 22
- 1.5.2 Internet Administration 24

#### 1.6 END-CHAPTER MATERIALS 25

- 1.6.1 Recommended Reading 25
- 1.6.2 Key Terms 25
- 1.6.3 Summary 26

#### 1.7 PRACTICE SET 27

- 1.7.1 Quizzes 27
- 1.7.2 Questions 27
- 1.7.3 Problems 28

#### 1.8 SIMULATION EXPERIMENTS 28

- 1.8.1 Applets 28
- 1.8.2 Lab Assignments 28

### Chapter 2 Network Models 31

#### 2.1 PROTOCOL LAYERING 32

- 2.1.1 Scenarios 32
- 2.1.2 Principles of Protocol Layering 34
- 2.1.3 Logical Connections 35

2.2	TCP/IP PROTOCOL SUITE	35
2.2.1	Layered Architecture	35
2.2.2	Layers in the TCP/IP Protocol Suite	37
2.2.3	Description of Each Layer	38
2.2.4	Encapsulation and Decapsulation	41
2.2.5	Addressing	42
2.2.6	Multiplexing and Demultiplexing	43
2.3	THE OSI MODEL	44
2.3.1	OSI versus TCP/IP	45
2.3.2	Lack of OSI Model's Success	45
2.4	END-CHAPTER MATERIALS	46
2.4.1	Recommended Reading	46
2.4.2	Key Terms	46
2.4.3	Summary	46
2.5	PRACTICE SET	47
2.5.1	Quizzes	47
2.5.2	Questions	47
2.5.3	Problems	48

## **PART II: Physical Layer 51**

### **Chapter 3 Introduction to Physical Layer 53**

3.1	DATA AND SIGNALS	54
3.1.1	Analog and Digital Data	55
3.1.2	Analog and Digital Signals	55
3.1.3	Periodic and Nonperiodic	56
3.2	PERIODIC ANALOG SIGNALS	56
3.2.1	Sine Wave	56
3.2.2	Phase	59
3.2.3	Wavelength	61
3.2.4	Time and Frequency Domains	61
3.2.5	Composite Signals	63
3.2.6	Bandwidth	65
3.3	DIGITAL SIGNALS	68
3.3.1	Bit Rate	69
3.3.2	Bit Length	69
3.3.3	Digital Signal as a Composite Analog Signal	70
3.3.4	Transmission of Digital Signals	70
3.4	TRANSMISSION IMPAIRMENT	76
3.4.1	Attenuation	77
3.4.2	Distortion	79
3.4.3	Noise	79
3.5	DATA RATE LIMITS	81
3.5.1	Noiseless Channel: Nyquist Bit Rate	81
3.5.2	Noisy Channel: Shannon Capacity	82
3.5.3	Using Both Limits	83

- 3.6 PERFORMANCE 84
  - 3.6.1 Bandwidth 84
  - 3.6.2 Throughput 85
  - 3.6.3 Latency (Delay) 85
  - 3.6.4 Bandwidth-Delay Product 87
  - 3.6.5 Jitter 88
- 3.7 END-CHAPTER MATERIALS 89
  - 3.7.1 Recommended Reading 89
  - 3.7.2 Key Terms 89
  - 3.7.3 Summary 89
- 3.8 PRACTICE SET 90
  - 3.8.1 Quizzes 90
  - 3.8.2 Questions 90
  - 3.8.3 Problems 91
- 3.9 SIMULATION EXPERIMENTS 94
  - 3.9.1 Applets 94

## **Chapter 4** *Digital Transmission* 95

- 4.1 DIGITAL-TO-DIGITAL CONVERSION 96
  - 4.1.1 Line Coding 96
  - 4.1.2 Line Coding Schemes 100
  - 4.1.3 Block Coding 109
  - 4.1.4 Scrambling 113
- 4.2 ANALOG-TO-DIGITAL CONVERSION 115
  - 4.2.1 Pulse Code Modulation (PCM) 115
  - 4.2.2 Delta Modulation (DM) 123
- 4.3 TRANSMISSION MODES 125
  - 4.3.1 Parallel Transmission 125
  - 4.3.2 Serial Transmission 126
- 4.4 END-CHAPTER MATERIALS 129
  - 4.4.1 Recommended Reading 129
  - 4.4.2 Key Terms 130
  - 4.4.3 Summary 130
- 4.5 PRACTICE SET 131
  - 4.5.1 Quizzes 131
  - 4.5.2 Questions 131
  - 4.5.3 Problems 131
- 4.6 SIMULATION EXPERIMENTS 134
  - 4.6.1 Applets 134

## **Chapter 5** *Analog Transmission* 135

- 5.1 DIGITAL-TO-ANALOG CONVERSION 136
  - 5.1.1 Aspects of Digital-to-Analog Conversion 137
  - 5.1.2 Amplitude Shift Keying 138
  - 5.1.3 Frequency Shift Keying 140
  - 5.1.4 Phase Shift Keying 142
  - 5.1.5 Quadrature Amplitude Modulation 146

5.2	<b>ANALOG-TO-ANALOG CONVERSION</b>	147
5.2.1	Amplitude Modulation (AM)	147
5.2.2	Frequency Modulation (FM)	148
5.2.3	Phase Modulation (PM)	149
5.3	<b>END-CHAPTER MATERIALS</b>	151
5.3.1	Recommended Reading	151
5.3.2	Key Terms	151
5.3.3	Summary	151
5.4	<b>PRACTICE SET</b>	152
5.4.1	Quizzes	152
5.4.2	Questions	152
5.4.3	Problems	153
5.5	<b>SIMULATION EXPERIMENTS</b>	154
5.5.1	Applets	154
<b>Chapter 6</b> <i>Bandwidth Utilization: Multiplexing and Spectrum Spreading</i> 155		
6.1	<b>MULTIPLEXING</b>	156
6.1.1	Frequency-Division Multiplexing	157
6.1.2	Wavelength-Division Multiplexing	162
6.1.3	Time-Division Multiplexing	163
6.2	<b>SPREAD SPECTRUM</b>	175
6.2.1	Frequency Hopping Spread Spectrum	176
6.2.2	Direct Sequence Spread Spectrum	178
6.3	<b>END-CHAPTER MATERIALS</b>	180
6.3.1	Recommended Reading	180
6.3.2	Key Terms	180
6.3.3	Summary	180
6.4	<b>PRACTICE SET</b>	181
6.4.1	Quizzes	181
6.4.2	Questions	181
6.4.3	Problems	182
6.5	<b>SIMULATION EXPERIMENTS</b>	184
6.5.1	Applets	184
<b>Chapter 7</b> <i>Transmission Media</i> 185		
7.1	<b>INTRODUCTION</b>	186
7.2	<b>GUIDED MEDIA</b>	187
7.2.1	Twisted-Pair Cable	187
7.2.2	Coaxial Cable	190
7.2.3	Fiber-Optic Cable	192
7.3	<b>UNGUIDED MEDIA: WIRELESS</b>	197
7.3.1	Radio Waves	199
7.3.2	Microwaves	200
7.3.3	Infrared	201

7.4	<b>END-CHAPTER MATERIALS</b>	202
7.4.1	Recommended Reading	202
7.4.2	Key Terms	202
7.4.3	Summary	203
7.5	<b>PRACTICE SET</b>	203
7.5.1	Quizzes	203
7.5.2	Questions	203
7.5.3	Problems	204
<b>Chapter 8</b>	<i>Switching</i>	207
8.1	<b>INTRODUCTION</b>	208
8.1.1	Three Methods of Switching	208
8.1.2	Switching and TCP/IP Layers	209
8.2	<b>CIRCUIT-SWITCHED NETWORKS</b>	209
8.2.1	Three Phases	211
8.2.2	Efficiency	212
8.2.3	Delay	213
8.3	<b>PACKET SWITCHING</b>	213
8.3.1	Datagram Networks	214
8.3.2	Virtual-Circuit Networks	216
8.4	<b>STRUCTURE OF A SWITCH</b>	222
8.4.1	Structure of Circuit Switches	222
8.4.2	Structure of Packet Switches	226
8.5	<b>END-CHAPTER MATERIALS</b>	230
8.5.1	Recommended Reading	230
8.5.2	Key terms	230
8.5.3	Summary	230
8.6	<b>PRACTICE SET</b>	231
8.6.1	Quizzes	231
8.6.2	Questions	231
8.6.3	Problems	231
8.7	<b>SIMULATION EXPERIMENTS</b>	234
8.7.1	Applets	234
<b>PART III: Data-Link Layer</b>		<b>235</b>
<b>Chapter 9</b>	<i>Introduction to Data-Link Layer</i>	237
9.1	<b>INTRODUCTION</b>	238
9.1.1	Nodes and Links	239
9.1.2	Services	239
9.1.3	Two Categories of Links	241
9.1.4	Two Sublayers	242
9.2	<b>LINK-LAYER ADDRESSING</b>	242
9.2.1	Three Types of addresses	244
9.2.2	Address Resolution Protocol (ARP)	245
9.2.3	An Example of Communication	248

9.3	<b>END-CHAPTER MATERIALS</b>	252
9.3.1	Recommended Reading	252
9.3.2	Key Terms	252
9.3.3	Summary	252
9.4	<b>PRACTICE SET</b>	253
9.4.1	Quizzes	253
9.4.2	Questions	253
9.4.3	Problems	254
<b>Chapter 10</b>		<i>Error Detection and Correction</i> 257
10.1	<b>INTRODUCTION</b>	258
10.1.1	Types of Errors	258
10.1.2	Redundancy	258
10.1.3	Detection versus Correction	258
10.1.4	Coding	259
10.2	<b>BLOCK CODING</b>	259
10.2.1	Error Detection	259
10.3	<b>CYCLIC CODES</b>	264
10.3.1	Cyclic Redundancy Check	264
10.3.2	Polynomials	267
10.3.3	Cyclic Code Encoder Using Polynomials	269
10.3.4	Cyclic Code Analysis	270
10.3.5	Advantages of Cyclic Codes	274
10.3.6	Other Cyclic Codes	274
10.3.7	Hardware Implementation	274
10.4	<b>CHECKSUM</b>	277
10.4.1	Concept	278
10.4.2	Other Approaches to the Checksum	281
10.5	<b>FORWARD ERROR CORRECTION</b>	282
10.5.1	Using Hamming Distance	283
10.5.2	Using XOR	283
10.5.3	Chunk Interleaving	283
10.5.4	Combining Hamming Distance and Interleaving	284
10.5.5	Compounding High- and Low-Resolution Packets	284
10.6	<b>END-CHAPTER MATERIALS</b>	285
10.6.1	Recommended Reading	285
10.6.2	Key Terms	286
10.6.3	Summary	286
10.7	<b>PRACTICE SET</b>	287
10.7.1	Quizzes	287
10.7.2	Questions	287
10.7.3	Problems	288
10.8	<b>SIMULATION EXPERIMENTS</b>	292
10.8.1	Applets	292
10.9	<b>PROGRAMMING ASSIGNMENTS</b>	292

<b>Chapter 11</b>	<i>Data Link Control (DLC)</i>	293
11.1	DLC SERVICES	294
11.1.1	Framing	294
11.1.2	Flow and Error Control	297
11.1.3	Connectionless and Connection-Oriented	298
11.2	DATA-LINK LAYER PROTOCOLS	299
11.2.1	Simple Protocol	300
11.2.2	Stop-and-Wait Protocol	301
11.2.3	Piggybacking	304
11.3	HDLC	304
11.3.1	Configurations and Transfer Modes	305
11.3.2	Framing	305
11.4	POINT-TO-POINT PROTOCOL (PPP)	309
11.4.1	Services	309
11.4.2	Framing	310
11.4.3	Transition Phases	311
11.4.4	Multiplexing	312
11.5	END-CHAPTER MATERIALS	319
11.5.1	Recommended Reading	319
11.5.2	Key Terms	319
11.5.3	Summary	319
11.6	PRACTICE SET	320
11.6.1	Quizzes	320
11.6.2	Questions	320
11.6.3	Problems	321
11.7	SIMULATION EXPERIMENTS	323
11.7.1	Applets	323
11.8	PROGRAMMING ASSIGNMENTS	323
<b>Chapter 12</b>	<i>Media Access Control (MAC)</i>	325
12.1	RANDOM ACCESS	326
12.1.1	ALOHA	326
12.1.2	CSMA	331
12.1.3	CSMA/CD	334
12.1.4	CSMA/CA	338
12.2	CONTROLLED ACCESS	341
12.2.1	Reservation	341
12.2.2	Polling	342
12.2.3	Token Passing	343
12.3	CHANNELIZATION	344
12.3.1	FDMA	344
12.3.2	TDMA	346
12.3.3	CDMA	347
12.4	END-CHAPTER MATERIALS	352
12.4.1	Recommended Reading	352
12.4.2	Key Terms	353
12.4.3	Summary	353

12.5	PRACTICE SET	354
12.5.1	Quizzes	354
12.5.2	Questions	354
12.5.3	Problems	356
12.6	SIMULATION EXPERIMENTS	360
12.6.1	Applets	360
12.7	PROGRAMMING ASSIGNMENTS	360
<b>Chapter 13</b> <i>Wired LANs: Ethernet</i> 361		
13.1	ETHERNET PROTOCOL	362
13.1.1	IEEE Project 802	362
13.1.2	Ethernet Evolution	363
13.2	STANDARD ETHERNET	364
13.2.1	Characteristics	364
13.2.2	Addressing	366
13.2.3	Access Method	368
13.2.4	Efficiency of Standard Ethernet	370
13.2.5	Implementation	370
13.2.6	Changes in the Standard	373
13.3	FAST ETHERNET (100 MBPS)	376
13.3.1	Access Method	377
13.3.2	Physical Layer	377
13.4	GIGABIT ETHERNET	379
13.4.1	MAC Sublayer	380
13.4.2	Physical Layer	381
13.5	10 GIGABIT ETHERNET	382
13.5.1	Implementation	382
13.6	END-CHAPTER MATERIALS	383
13.6.1	Recommended Reading	383
13.6.2	Key Terms	383
13.6.3	Summary	383
13.7	PRACTICE SET	384
13.7.1	Quizzes	384
13.7.2	Questions	384
13.7.3	Problems	385
13.8	SIMULATION EXPERIMENTS	385
13.8.1	Applets	385
13.8.2	Lab Assignments	386
<b>Chapter 14</b> <i>Other Wired Networks</i> 387		
14.1	TELEPHONE NETWORKS	388
14.1.1	Major Components	388
14.1.2	LATAs	388
14.1.3	Signaling	390
14.1.4	Services Provided by Telephone Networks	393
14.1.5	Dial-Up Service	394
14.1.6	Digital Subscriber Line (DSL)	396



<b>14.2</b>	<b>CABLE NETWORKS</b>	<b>397</b>
14.2.1	Traditional Cable Networks	397
14.2.2	Hybrid Fiber-Coaxial (HFC) Network	398
14.2.3	Cable TV for Data Transfer	399
<b>14.3</b>	<b>SONET</b>	<b>400</b>
14.3.1	Architecture	401
14.3.2	SONET Layers	403
14.3.3	SONET Frames	404
14.3.4	STS Multiplexing	412
14.3.5	SONET Networks	415
14.3.6	Virtual Tributaries	420
<b>14.4</b>	<b>ATM</b>	<b>421</b>
14.4.1	Design Goals	422
14.4.2	Problems	422
14.4.3	Architecture	425
<b>14.5</b>	<b>END-CHAPTER MATERIALS</b>	<b>429</b>
14.5.1	Recommended Reading	429
14.5.2	Key Terms	430
14.5.3	Summary	431
<b>14.6</b>	<b>PRACTICE SET</b>	<b>432</b>
14.6.1	Quizzes	432
14.6.2	Questions	432
14.6.3	Problems	433
<b>Chapter 15</b>	<b>Wireless LANs</b>	<b>435</b>
<b>15.1</b>	<b>INTRODUCTION</b>	<b>436</b>
15.1.1	Architectural Comparison	436
15.1.2	Characteristics	438
15.1.3	Access Control	438
<b>15.2</b>	<b>IEEE 802.11 PROJECT</b>	<b>439</b>
15.2.1	Architecture	440
15.2.2	MAC Sublayer	441
15.2.3	Addressing Mechanism	446
15.2.4	Physical Layer	448
<b>15.3</b>	<b>BLUETOOTH</b>	<b>451</b>
15.3.1	Architecture	451
15.3.2	Bluetooth Layers	452
<b>15.4</b>	<b>END-CHAPTER MATERIALS</b>	<b>458</b>
15.4.1	Further Reading	458
15.4.2	Key Terms	458
15.4.3	Summary	458
<b>15.5</b>	<b>PRACTICE SET</b>	<b>459</b>
15.5.1	Quizzes	459
15.5.2	Questions	459
15.5.3	Problems	460
<b>15.6</b>	<b>SIMULATION EXPERIMENTS</b>	<b>463</b>
15.6.1	Applets	463
15.6.2	Lab Assignments	463

<b>Chapter 16</b>	<i>Other Wireless Networks</i>	<b>465</b>
16.1	<b>WiMAX</b>	<b>466</b>
16.1.1	Services	466
16.1.2	IEEE Project 802.16	467
16.1.3	Layers in Project 802.16	467
16.2	<b>CELLULAR TELEPHONY</b>	<b>470</b>
16.2.1	Operation	471
16.2.2	First Generation (1G)	473
16.2.3	Second Generation (2G)	474
16.2.4	Third Generation (3G)	480
16.2.5	Fourth Generation (4G)	482
16.3	<b>SATELLITE NETWORKS</b>	<b>483</b>
16.3.1	Operation	483
16.3.2	GEO Satellites	485
16.3.3	MEO Satellites	485
16.3.4	LEO Satellites	488
16.4	<b>END-CHAPTER MATERIALS</b>	<b>489</b>
16.4.1	Recommended Reading	489
16.4.2	Key Terms	490
16.4.3	Summary	490
16.5	<b>PRACTICE SET</b>	<b>491</b>
16.5.1	Quizzes	491
16.5.2	Questions	491
16.5.3	Problems	491
<b>Chapter 17</b>	<i>Connecting Devices and Virtual LANs</i>	<b>493</b>
17.1	<b>CONNECTING DEVICES</b>	<b>494</b>
17.1.1	Hubs	494
17.1.2	Link-Layer Switches	495
17.1.3	Routers	501
17.2	<b>VIRTUAL LANS</b>	<b>502</b>
17.2.1	Membership	504
17.2.2	Configuration	504
17.2.3	Communication between Switches	505
17.2.4	Advantages	506
17.3	<b>END-CHAPTER MATERIALS</b>	<b>506</b>
17.3.1	Recommended Reading	506
17.3.2	Key Terms	506
17.3.3	Summary	506
17.4	<b>PRACTICE SET</b>	<b>507</b>
17.4.1	Quizzes	507
17.4.2	Questions	507
17.4.3	Problems	507

**PART IV: Network Layer 509****Chapter 18** *Introduction to Network Layer* 511

- 18.1 NETWORK-LAYER SERVICES 512
  - 18.1.1 Packetizing 513
  - 18.1.2 Routing and Forwarding 513
  - 18.1.3 Other Services 514
- 18.2 PACKET SWITCHING 516
  - 18.2.1 Datagram Approach: Connectionless Service 516
  - 18.2.2 Virtual-Circuit Approach: Connection-Oriented Service 517
- 18.3 NETWORK-LAYER PERFORMANCE 522
  - 18.3.1 Delay 522
  - 18.3.2 Throughput 523
  - 18.3.3 Packet Loss 525
  - 18.3.4 Congestion Control 525
- 18.4 IPV4 ADDRESSES 528
  - 18.4.1 Address Space 529
  - 18.4.2 Classful Addressing 530
  - 18.4.3 Classless Addressing 532
  - 18.4.4 Dynamic Host Configuration Protocol (DHCP) 539
  - 18.4.5 Network Address Resolution (NAT) 543
- 18.5 FORWARDING OF IP PACKETS 546
  - 18.5.1 Forwarding Based on Destination Address 547
  - 18.5.2 Forwarding Based on Label 553
  - 18.5.3 Routers as Packet Switches 555
- 18.6 END-CHAPTER MATERIALS 556
  - 18.6.1 Recommended Reading 556
  - 18.6.2 Key Terms 556
  - 18.6.3 Summary 556
- 18.7 PRACTICE SET 557
  - 18.7.1 Quizzes 557
  - 18.7.2 Questions 557
  - 18.7.3 Problems 558
- 18.8 SIMULATION EXPERIMENTS 560
  - 18.8.1 Applets 560
- 18.9 PROGRAMMING ASSIGNMENT 560

**Chapter 19** *Network-Layer Protocols* 561

- 19.1 INTERNET PROTOCOL (IP) 562
  - 19.1.1 Datagram Format 563
  - 19.1.2 Fragmentation 567
  - 19.1.3 Options 572
  - 19.1.4 Security of IPv4 Datagrams 573
- 19.2 ICMPv4 574
  - 19.2.1 MESSAGES 575
  - 19.2.2 Debugging Tools 578
  - 19.2.3 ICMP Checksum 580

<b>19.3</b>	<b>MOBILE IP</b>	<b>581</b>
19.3.1	Addressing	581
19.3.2	Agents	583
19.3.3	Three Phases	584
19.3.4	Inefficiency in Mobile IP	589
<b>19.4</b>	<b>END-CHAPTER MATERIALS</b>	<b>591</b>
19.4.1	Recommended Reading	591
19.4.2	Key Terms	591
19.4.3	Summary	591
<b>19.5</b>	<b>PRACTICE SET</b>	<b>592</b>
19.5.1	Quizzes	592
19.5.2	Questions	592
19.5.3	Problems	593
<b>19.6</b>	<b>SIMULATION EXPERIMENTS</b>	<b>594</b>
19.6.1	Applets	594
19.6.2	Lab Assignments	594
<b>Chapter 20</b>	<b>Unicast Routing</b>	<b>595</b>
<b>20.1</b>	<b>INTRODUCTION</b>	<b>596</b>
20.1.1	General Idea	596
20.1.2	Least-Cost Routing	596
<b>20.2</b>	<b>ROUTING ALGORITHMS</b>	<b>598</b>
20.2.1	Distance-Vector Routing	598
20.2.2	Link-State Routing	604
20.2.3	Path-Vector Routing	606
<b>20.3</b>	<b>UNICAST ROUTING PROTOCOLS</b>	<b>611</b>
20.3.1	Internet Structure	611
20.3.2	Routing Information Protocol (RIP)	613
20.3.3	Open Shortest Path First (OSPF)	618
20.3.4	Border Gateway Protocol Version 4 (BGP4)	623
<b>20.4</b>	<b>END-CHAPTER MATERIALS</b>	<b>631</b>
20.4.1	Recommended Reading	631
20.4.2	Key Terms	631
20.4.3	Summary	632
<b>20.5</b>	<b>PRACTICE SET</b>	<b>632</b>
20.5.1	Quizzes	632
20.5.2	Questions	632
20.5.3	Problems	634
<b>20.6</b>	<b>SIMULATION EXPERIMENTS</b>	<b>637</b>
20.6.1	Applets	637
<b>20.7</b>	<b>PROGRAMMING ASSIGNMENT</b>	<b>637</b>
<b>Chapter 21</b>	<b>Multicast Routing</b>	<b>639</b>
<b>21.1</b>	<b>INTRODUCTION</b>	<b>640</b>
21.1.1	Unicasting	640
21.1.2	Multicasting	640
21.1.3	Broadcasting	643

<b>21.2</b>	<b>MULTICASTING BASICS</b>	<b>643</b>	
21.2.1	Multicast Addresses	643	
21.2.2	Delivery at Data-Link Layer	645	
21.2.3	Collecting Information about Groups	647	
21.2.4	Multicast Forwarding	648	
21.2.5	Two Approaches to Multicasting	649	
<b>21.3</b>	<b>INTRADOMAIN MULTICAST PROTOCOLS</b>	<b>650</b>	
21.3.1	Multicast Distance Vector (DVMRP)	651	
21.3.2	Multicast Link State (MOSPF)	653	
21.3.3	Protocol Independent Multicast (PIM)	654	
<b>21.4</b>	<b>INTERDOMAIN MULTICAST PROTOCOLS</b>	<b>657</b>	
<b>21.5</b>	<b>IGMP</b>	<b>658</b>	
21.5.1	Messages	658	
21.5.2	Propagation of Membership Information	659	
21.5.3	Encapsulation	660	
<b>21.6</b>	<b>END-CHAPTER MATERIALS</b>	<b>660</b>	
21.6.1	Recommended Reading	660	
21.6.2	Key Terms	660	
21.6.3	Summary	660	
<b>21.7</b>	<b>PRACTICE SET</b>	<b>661</b>	
21.7.1	Quizzes	661	
21.7.2	Questions	661	
21.7.3	Problems	662	
<b>21.8</b>	<b>SIMULATION EXPERIMENTS</b>	<b>663</b>	
21.8.1	Applets	663	
<b>Chapter 22</b>		<b><i>Next Generation IP</i></b>	<b>665</b>
<b>22.1</b>	<b>IPv6 ADDRESSING</b>	<b>666</b>	
22.1.1	Representation	666	
22.1.2	Address Space	667	
22.1.3	Address Space Allocation	668	
22.1.4	Autoconfiguration	672	
22.1.5	Renumbering	673	
<b>22.2</b>	<b>THE IPv6 PROTOCOL</b>	<b>674</b>	
22.2.1	Packet Format	674	
22.2.2	Extension Header	677	
<b>22.3</b>	<b>THE ICMPv6 PROTOCOL</b>	<b>679</b>	
22.3.1	Error-Reporting Messages	679	
22.3.2	Informational Messages	680	
22.3.3	Neighbor-Discovery Messages	681	
22.3.4	Group Membership Messages	682	
<b>22.4</b>	<b>TRANSITION FROM IPv4 TO IPv6</b>	<b>682</b>	
22.4.1	Strategies	683	
22.4.2	Use of IP Addresses	684	
<b>22.5</b>	<b>END-CHAPTER MATERIALS</b>	<b>684</b>	
22.5.1	Recommended Reading	684	
22.5.2	Key Terms	685	
22.5.3	Summary	685	

22.6	PRACTICE SET	685
22.6.1	Quizzes	685
22.6.2	Questions	685
22.6.3	Problems	686
22.7	SIMULATION EXPERIMENTS	688
22.7.1	Applets	688
<b>PART V: Transport Layer 689</b>		
<b>Chapter 23 Introduction to Transport Layer 691</b>		
23.1	INTRODUCTION	692
23.1.1	Transport-Layer Services	693
23.1.2	Connectionless and Connection-Oriented Protocols	703
23.2	TRANSPORT-LAYER PROTOCOLS	707
23.2.1	Simple Protocol	707
23.2.2	Stop-and-Wait Protocol	708
23.2.3	Go-Back-N Protocol (GBN)	713
23.2.4	Selective-Repeat Protocol	720
23.2.5	Bidirectional Protocols: Piggybacking	726
23.3	END-CHAPTER MATERIALS	727
23.3.1	Recommended Reading	727
23.3.2	Key Terms	727
23.3.3	Summary	728
23.4	PRACTICE SET	728
23.4.1	Quizzes	728
23.4.2	Questions	728
23.4.3	Problems	729
23.5	SIMULATION EXPERIMENTS	733
23.5.1	Applets	733
23.6	PROGRAMMING ASSIGNMENT	733
<b>Chapter 24 Transport-Layer Protocols 735</b>		
24.1	INTRODUCTION	736
24.1.1	Services	736
24.1.2	Port Numbers	736
24.2	USER DATAGRAM PROTOCOL	737
24.2.1	User Datagram	737
24.2.2	UDP Services	738
24.2.3	UDP Applications	741
24.3	TRANSMISSION CONTROL PROTOCOL	743
24.3.1	TCP Services	743
24.3.2	TCP Features	746
24.3.3	Segment	748
24.3.4	A TCP Connection	750
24.3.5	State Transition Diagram	756
24.3.6	Windows in TCP	760
24.3.7	Flow Control	762
24.3.8	Error Control	768
24.3.9	TCP Congestion Control	777

	24.3.10	TCP Timers	786
	24.3.11	Options	790
24.4	<b>SCTP</b>	<b>791</b>	
	24.4.1	SCTP Services	791
	24.4.2	SCTP Features	792
	24.4.3	Packet Format	794
	24.4.4	An SCTP Association	796
	24.4.5	Flow Control	799
	24.4.6	Error Control	801
24.5	<b>END-CHAPTER MATERIALS</b>	<b>805</b>	
	24.5.1	Recommended Reading	805
	24.5.2	Key Terms	805
	24.5.3	Summary	805
24.6	<b>PRACTICE SET</b>	<b>806</b>	
	24.6.1	Quizzes	806
	24.6.2	Questions	806
	24.6.3	Problems	809

## **PART VI: Application Layer 815**

### **Chapter 25 Introduction to Application Layer 817**

25.1	<b>INTRODUCTION</b>	<b>818</b>
	25.1.1	Providing Services 819
	25.1.2	Application-Layer Paradigms 820
25.2	<b>CLIENT-SERVER PROGRAMMING</b>	<b>823</b>
	25.2.1	Application Programming Interface 823
	25.2.2	Using Services of the Transport Layer 827
	25.2.3	Iterative Communication Using UDP 828
	25.2.4	Iterative Communication Using TCP 830
	25.2.5	Concurrent Communication 832
25.3	<b>ITERATIVE PROGRAMMING IN C</b>	<b>833</b>
	25.3.1	General Issues 833
	25.3.2	Iterative Programming Using UDP 834
	25.3.3	Iterative Programming Using TCP 837
25.4	<b>ITERATIVE PROGRAMMING IN JAVA</b>	<b>842</b>
	25.4.1	Addresses and Ports 843
	25.4.2	Iterative Programming Using UDP 846
	25.4.3	Iterative Programming Using TCP 857
25.5	<b>END-CHAPTER MATERIALS</b>	<b>865</b>
	25.5.1	Recommended Reading 865
	25.5.2	Key Terms 866
	25.5.3	Summary 866
25.6	<b>PRACTICE SET</b>	<b>866</b>
	25.6.1	Quizzes 866
	25.6.2	Questions 866
	25.6.3	Problems 869
25.7	<b>SIMULATION EXPERIMENTS</b>	<b>869</b>
	25.7.1	Applets 869
25.8	<b>PROGRAMMING ASSIGNMENT</b>	<b>870</b>

<b>Chapter 26</b>	<i>Standard Client-Server Protocols</i>	871
26.1	<b>WORLD WIDE WEB AND HTTP</b>	872
26.1.1	World Wide Web	872
26.1.2	HyperText Transfer Protocol (HTTP)	876
26.2	<b>FTP</b>	887
26.2.1	Two Connections	888
26.2.2	Control Connection	888
26.2.3	Data Connection	889
26.2.4	Security for FTP	891
26.3	<b>ELECTRONIC MAIL</b>	891
26.3.1	Architecture	892
26.3.2	Web-Based Mail	903
26.3.3	E-Mail Security	904
26.4	<b>TELNET</b>	904
26.4.1	Local versus Remote Logging	905
26.5	<b>SECURE SHELL (SSH)</b>	907
26.5.1	Components	907
26.5.2	Applications	908
26.6	<b>DOMAIN NAME SYSTEM (DNS)</b>	910
26.6.1	Name Space	911
26.6.2	DNS in the Internet	915
26.6.3	Resolution	916
26.6.4	Caching	918
26.6.5	Resource Records	918
26.6.6	DNS Messages	919
26.6.7	Registrars	920
26.6.8	DDNS	920
26.6.9	Security of DNS	921
26.7	<b>END-CHAPTER MATERIALS</b>	921
26.7.1	Recommended Reading	921
26.7.2	Key Terms	922
26.7.3	Summary	922
26.8	<b>PRACTICE SET</b>	923
26.8.1	Quizzes	923
26.8.2	Questions	923
26.8.3	Problems	924
26.9	<b>SIMULATION EXPERIMENTS</b>	927
26.9.1	Applets	927
26.9.2	Lab Assignments	927
<b>Chapter 27</b>	<i>Network Management</i>	929
27.1	<b>INTRODUCTION</b>	930
27.1.1	Configuration Management	930
27.1.2	Fault Management	932
27.1.3	Performance Management	933
27.1.4	Security Management	933
27.1.5	Accounting Management	934
27.2	<b>SNMP</b>	934
27.2.1	Managers and Agents	935



27.2.2	Management Components	935
27.2.3	An Overview	937
27.2.4	SMI	938
27.2.5	MIB	942
27.2.6	SNMP	944
27.3	ASN.1	951
27.3.1	Language Basics	951
27.3.2	Data Types	952
27.3.3	Encoding	955
27.4	END-CHAPTER MATERIALS	955
27.4.1	Recommended Reading	955
27.4.2	Key Terms	956
27.4.3	Summary	956
27.5	PRACTICE SET	956
27.5.1	Quizzes	956
27.5.2	Questions	956
27.5.3	Problems	958
<b>Chapter 28</b>	<i>Multimedia</i>	<b>961</b>
28.1	COMPRESSION	962
28.1.1	Lossless Compression	962
28.1.2	Lossy Compression	972
28.2	MULTIMEDIA DATA	978
28.2.1	Text	978
28.2.2	Image	978
28.2.3	Video	982
28.2.4	Audio	984
28.3	MULTIMEDIA IN THE INTERNET	986
28.3.1	Streaming Stored Audio/Video	986
28.3.2	Streaming Live Audio/Video	989
28.3.3	Real-Time Interactive Audio/Video	990
28.4	REAL-TIME INTERACTIVE PROTOCOLS	995
28.4.1	Rationale for New Protocols	996
28.4.2	RTP	999
28.4.3	RTCP	1001
28.4.4	Session Initialization Protocol (SIP)	1005
28.4.5	H.323	1012
28.5	END-CHAPTER MATERIALS	1014
28.5.1	Recommended Reading	1014
28.5.2	Key Terms	1015
28.5.3	Summary	1015
28.6	PRACTICE SET	1016
28.6.1	Quizzes	1016
28.6.2	Questions	1016
28.6.3	Problems	1018
28.7	SIMULATION EXPERIMENTS	1021
28.7.1	Applets	1021
28.7.2	Lab Assignments	1021
28.8	PROGRAMMING ASSIGNMENTS	1022

**Chapter 29 Peer-to-Peer Paradigm 1023**

- 29.1 INTRODUCTION 1024
  - 29.1.1 P2P Networks 1024
  - 29.1.2 Distributed Hash Table (DHT) 1026
- 29.2 CHORD 1029
  - 29.2.1 Identifier Space 1029
  - 29.2.2 Finger Table 1029
  - 29.2.3 Interface 1030
  - 29.2.4 Applications 1036
- 29.3 PASTRY 1036
  - 29.3.1 Identifier Space 1036
  - 29.3.2 Routing 1037
  - 29.3.3 Application 1041
- 29.4 KADEMLIA 1041
  - 29.4.1 Identifier Space 1041
  - 29.4.2 Routing Table 1041
  - 29.4.3 K-Buckets 1044
- 29.5 BITTORRENT 1045
  - 29.5.1 BitTorrent with a Tracker 1045
  - 29.5.2 Trackerless BitTorrent 1046
- 29.6 END-CHAPTER MATERIALS 1047
  - 29.6.1 Recommended Reading 1047
  - 29.6.2 Key Terms 1047
  - 29.6.3 Summary 1047
- 29.7 PRACTICE SET 1048
  - 29.7.1 Quizzes 1048
  - 29.7.2 Questions 1048
  - 29.7.3 Problems 1048

**PART VII: Topics Related to All Layers 1051****Chapter 30 Quality of Service 1053**

- 30.1 DATA-FLOW CHARACTERISTICS 1054
  - 30.1.1 Definitions 1054
  - 30.1.2 Sensitivity of Applications 1054
  - 30.1.3 Flow Classes 1055
- 30.2 FLOW CONTROL TO IMPROVE QOS 1055
  - 30.2.1 Scheduling 1056
  - 30.2.2 Traffic Shaping or Policing 1058
  - 30.2.3 Resource Reservation 1061
  - 30.2.4 Admission Control 1062
- 30.3 INTEGRATED SERVICES (INTSERV) 1062
  - 30.3.1 Flow Specification 1062
  - 30.3.2 Admission 1063
  - 30.3.3 Service Classes 1063
  - 30.3.4 Resource Reservation Protocol (RSVP) 1063
  - 30.3.5 Problems with Integrated Services 1065
- 30.4 DIFFERENTIATED SERVICES (DIFFSERV) 1066
  - 30.4.1 DS Field 1066

30.4.2	Per-Hop Behavior	1067
30.4.3	Traffic Conditioners	1067
<b>30.5</b>	<b>END-CHAPTER MATERIALS</b>	<b>1068</b>
30.5.1	Recommended Reading	1068
30.5.2	Key Terms	1068
30.5.3	Summary	1068
<b>30.6</b>	<b>PRACTICE SET</b>	<b>1069</b>
30.6.1	Quizzes	1069
30.6.2	Questions	1069
30.6.3	Problems	1070
<b>30.7</b>	<b>SIMULATION EXPERIMENTS</b>	<b>1075</b>
30.7.1	Applets	1075
<b>30.8</b>	<b>PROGRAMMING ASSIGNMENTS</b>	<b>1075</b>
<b>Chapter 31</b>	<i>Cryptography and Network Security</i>	<b>1077</b>
<b>31.1</b>	<b>INTRODUCTION</b>	<b>1078</b>
31.1.1	Security Goals	1078
31.1.2	Attacks	1079
31.1.3	Services and Techniques	1081
<b>31.2</b>	<b>CONFIDENTIALITY</b>	<b>1081</b>
31.2.1	Symmetric-Key Ciphers	1081
31.2.2	Asymmetric-Key Ciphers	1092
<b>31.3</b>	<b>OTHER ASPECTS OF SECURITY</b>	<b>1097</b>
31.3.1	Message Integrity	1097
31.3.2	Message Authentication	1099
31.3.3	Digital Signature	1100
31.3.4	Entity Authentication	1105
31.3.5	Key Management	1108
<b>31.4</b>	<b>END-CHAPTER MATERIALS</b>	<b>1114</b>
31.4.1	Recommended Reading	1114
31.4.2	Key Terms	1114
31.4.3	Summary	1114
<b>31.5</b>	<b>PRACTICE SET</b>	<b>1115</b>
31.5.1	Quizzes	1115
31.5.2	Questions	1115
31.5.3	Problems	1117
<b>31.6</b>	<b>SIMULATION EXPERIMENTS</b>	<b>1121</b>
31.6.1	Applets	1121
<b>31.7</b>	<b>PROGRAMMING ASSIGNMENTS</b>	<b>1122</b>
<b>Chapter 32</b>	<i>Internet Security</i>	<b>1123</b>
<b>32.1</b>	<b>NETWORK-LAYER SECURITY</b>	<b>1124</b>
32.1.1	Two Modes	1124
32.1.2	Two Security Protocols	1126
32.1.3	Services Provided by IPSec	1129
32.1.4	Security Association	1130
32.1.5	Internet Key Exchange (IKE)	1132
32.1.6	Virtual Private Network (VPN)	1133

32.2	TRANSPORT-LAYER SECURITY	1134
32.2.1	SSL Architecture	1135
32.2.2	Four Protocols	1138
32.3	APPLICATION-LAYER SECURITY	1140
32.3.1	E-mail Security	1141
32.3.2	Pretty Good Privacy (PGP)	1142
32.3.3	S/MIME	1147
32.4	FIREWALLS	1151
32.4.1	Packet-Filter Firewall	1152
32.4.2	Proxy Firewall	1152
32.5	END-CHAPTER MATERIALS	1153
32.5.1	Recommended Reading	1153
32.5.2	Key Terms	1154
32.5.3	Summary	1154
32.6	PRACTICE SET	1154
32.6.1	Quizzes	1154
32.6.2	Questions	1155
32.6.3	Problems	1155
32.7	SIMULATION EXPERIMENTS	1156
32.7.1	Applets	1156
32.7.2	Lab Assignments	1156

**Appendices A-H available online at  
<http://www.mhhe.com/forouzan>**

## **Appendices**

- Appendix A** *Unicode*
- Appendix B** *Positional Numbering System*
- Appendix C** *HTML, CSS, XML, and XSL*
- Appendix D** *A Touch of Probability*
- Appendix E** *Mathematical Review*
- Appendix F** *8B/6T Code*
- Appendix G** *Miscellaneous Information*
- Appendix H** *Telephone History*

*Glossary* 1157

*References* 1193

*Index* 1199