

Brief Contents

Preface xxxi

Trademarks xxxv

Part 1 *Introduction and Underlying Technologies* **1**

Chapter 1 *Introduction* 2

Chapter 2 *The OSI Model and the TCP/IP Protocol Suite* 18

Chapter 3 *Underlying Technologies* 46

Part 2 *Network Layer* **93**

Chapter 4 *Introduction to Network Layer* 94

Chapter 5 *IPv4 Addresses* 114

Chapter 6 *Delivery and Forwarding of IP Packets* 160

Chapter 7 *Internet Protocol Version 4 (IPv4)* 186

Chapter 8 *Address Resolution Protocol (ARP)* 220

Chapter 9 *Internet Control Message Protocol Version 4 (ICMPv4)* 244

Chapter 10 *Mobile IP* 268

Chapter 11 *Unicast Routing Protocols (RIP, OSPF, and BGP)* 282

Chapter 12 *Multicasting and Multicast Routing Protocols* 334

Part 3 *Transport Layer* **373**

Chapter 13 *Introduction to the Transport Layer* 374

Chapter 14 *User Datagram Protocol (UDP)* 414

Chapter 15 *Transmission Control Protocol (TCP)* 432

Chapter 16 *Stream Control Transmission Protocol (SCTP)* 502

Part 4	<i>Application Layer</i>	541
Chapter 17	<i>Introduction to the Application Layer</i>	542
Chapter 18	<i>Host Configuration: DHCP</i>	568
Chapter 19	<i>Domain Name System (DNS)</i>	582
Chapter 20	<i>Remote Login: TELNET and SSH</i>	610
Chapter 21	<i>File Transfer: FTP and TFTP</i>	630
Chapter 22	<i>World Wide Web and HTTP</i>	656
Chapter 23	<i>Electronic Mail: SMTP, POP, IMAP, and MIME</i>	680
Chapter 24	<i>Network Management: SNMP</i>	706
Chapter 25	<i>Multimedia</i>	728
Part 5	<i>Next Generation</i>	767
Chapter 26	<i>IPv6 Addressing</i>	768
Chapter 27	<i>IPv6 Protocol</i>	786
Chapter 28	<i>ICMPv6</i>	800
Part 6	<i>Security</i>	815
Chapter 29	<i>Cryptography and Network Security</i>	816
Chapter 30	<i>Internet Security</i>	858
Part 7	<i>Appendices</i>	891
Appendix A	<i>Unicode</i>	892
Appendix B	<i>Positional Numbering Systems</i>	896
Appendix C	<i>Error Detection Codes</i>	904
Appendix D	<i>Checksum</i>	914
Appendix E	<i>HTML, XHTML, XML, and XSL</i>	920
Appendix F	<i>Client-Server Programming in Java</i>	926
Appendix G	<i>Miscellaneous Information</i>	932
	<i>Glossary</i>	935
	<i>References</i>	955
	<i>Index</i>	957

Contents

Preface xxxi

Trademarks xxxv

Part 1 Introduction and Underlying Technologies 1

Chapter 1 Introduction 2

- 1.1 **A BRIEF HISTORY 3**
 - ARPANET 3
 - Birth of the Internet 3
 - Transmission Control Protocol/Internetworking Protocol (TCP/IP) 4
 - MILNET 4
 - CSNET 4
 - NSFNET 4
 - ANSNET 5
 - The Internet Today 5
 - World Wide Web 6
 - Time Line 6
 - Growth of the Internet 7
- 1.2 **PROTOCOLS AND STANDARDS 7**
 - Protocols 7
 - Standards 8
- 1.3 **STANDARDS ORGANIZATIONS 8**
 - Standards Creation Committees 8
 - Forums 10
 - Regulatory Agencies 10
- 1.4 **INTERNET STANDARDS 10**
 - Maturity Levels 11
 - Requirement Levels 12
- 1.5 **INTERNET ADMINISTRATION 13**
 - Internet Society (ISOC) 13
 - Internet Architecture Board (IAB) 13
 - Internet Engineering Task Force (IETF) 13
 - Internet Research Task Force (IRTF) 14
 - Internet Assigned Numbers Authority (IANA) and Internet Corporation for Assigned Names and Numbers (ICANN) 14
 - Network Information Center (NIC) 14

- 1.6 FURTHER READING 14
 - Books and Papers 15
 - Websites 15
- 1.7 KEY TERMS 15
- 1.8 SUMMARY 15
- 1.9 PRACTICE SET 16
 - Exercises 16
 - Research Activities 17

Chapter 2 The OSI Model and the TCP/IP Protocol Suite 18

- 2.1 PROTOCOL LAYERS 19
 - Hierarchy 20
 - Services 20
- 2.2 THE OSI MODEL 20
 - Layered Architecture 21
 - Layer-to-Layer Communication 22
 - Encapsulation 23
 - Layers in the OSI Model 24
 - Summary of OSI Layers 28
- 2.3 TCP/IP PROTOCOL SUITE 28
 - Comparison between OSI and TCP/IP Protocol Suite 28
 - Layers in the TCP/IP Protocol Suite 30
- 2.4 ADDRESSING 35
 - Physical Addresses 35
 - Logical Addresses 37
 - Port Addresses 39
 - Application-Specific Addresses 40
- 2.5 FURTHER READING 40
 - Books 40
 - RFCs 40
- 2.6 KEY TERMS 41
- 2.7 SUMMARY 41
- 2.8 PRACTICE SET 42
 - Exercises 42
 - Research Activities 44

Chapter 3 Underlying Technologies 46

- 3.1 WIRED LOCAL AREA NETWORKS 47
 - IEEE Standards 47
 - Frame Format 48
 - Addressing 49
 - Ethernet Evolution 51
 - Standard Ethernet 51
 - Fast Ethernet 55
 - Gigabit Ethernet 56
 - Ten-Gigabit Ethernet 59

- 3.2 WIRELESS LANS 59
 - IEEE 802.11 59
 - MAC Sublayer 61
 - Addressing Mechanism 64
 - Bluetooth 67
- 3.3 POINT-TO-POINT WANS 70
 - 56K Modems 70
 - DSL Technology 71
 - Cable Modem 72
 - T Lines 75
 - SONET 75
 - PPP 76
- 3.4 SWITCHED WANS 77
 - X.25 77
 - Frame Relay 78
 - ATM 78
- 3.5 CONNECTING DEVICES 83
 - Repeaters 83
 - Bridges 84
 - Routers 86
- 3.6 FURTHER READING 88
- 3.7 KEY TERMS 88
- 3.8 SUMMARY 89
- 3.9 PRACTICE SET 89
 - Exercises 89
 - Research Activities 90

Part 2 Network Layer 93

Chapter 4 Introduction to Network Layer 94

- 4.1 INTRODUCTION 95
- 4.2 SWITCHING 96
 - Circuit Switching 96
 - Packet Switching 96
- 4.3 PACKET SWITCHING AT NETWORK LAYER 97
 - Connectionless Service 97
 - Connection-Oriented Service 99
- 4.4 NETWORK LAYER SERVICES 103
 - An Example 103
 - Logical Addressing 104
 - Services Provided at the Source Computer 105
 - Services Provided at Each Router 106
 - Services Provided at the Destination Computer 107
- 4.5 OTHER NETWORK LAYER ISSUES 108
 - Error Control 108
 - Flow Control 109
 - Congestion Control 110

Quality of Service 111
 Routing 111
 Security 111
 4.6 FURTHER READING 111
 4.7 KEY TERMS 112
 4.8 SUMMARY 112
 4.9 PRACTICE SET 112
 Exercises 112

Chapter 5 IPv4 Addresses 114

5.1 INTRODUCTION 115
 Address Space 115
 Notation 115
 Range of Addresses 117
 Operations 118
 5.2 CLASSFUL ADDRESSING 121
 Classes 121
 Classes and Blocks 123
 Two-Level Addressing 126
 An Example 129
 Three-Level Addressing: Subnetting 131
 Supernetting 134
 5.3 CLASSLESS ADDRESSING 135
 Variable-Length Blocks 136
 Two-Level Addressing 136
 Block Allocation 141
 Subnetting 142
 5.4 SPECIAL ADDRESSES 147
 Special Blocks 147
 Special Addresses in Each block 148
 5.5 NAT 149
 Address Translation 150
 Translation Table 150
 5.6 FURTHER READING 152
 Books 152
 RFCs 152
 5.7 KEY TERMS 153
 5.8 SUMMARY 153
 5.9 PRACTICE SET 154
 Exercises 154

Chapter 6 Delivery and Forwarding of IP Packets 160

6.1 DELIVERY 161
 Direct Delivery 161
 Indirect Delivery 161
 6.2 FORWARDING 162
 Forwarding Based on Destination Address 162
 Forwarding Based on Label 176

6.3	STRUCTURE OF A ROUTER	178
	Components	178
6.4	FURTHER READING	181
	Books	182
	RFCs	182
6.5	KEY TERMS	182
6.6	SUMMARY	182
6.7	PRACTICE SET	183
	Exercises	183
	Research Activities	184
Chapter 7 Internet Protocol Version 4 (IPv4)		186
7.1	INTRODUCTION	187
7.2	DATAGRAMS	187
7.3	FRAGMENTATION	192
	Maximum Transfer Unit (MTU)	192
	Fields Related to Fragmentation	193
7.4	OPTIONS	197
	Format	197
	Option Types	198
7.5	CHECKSUM	205
	Checksum Calculation at the Sender	205
	Checksum Calculation at the Receiver	205
	Checksum in the IP Packet	206
7.6	IP OVER ATM	207
	ATM WANs	208
	Routing the Cells	208
7.7	SECURITY	210
	Security Issues	210
	IPSec	211
7.8	IP PACKAGE	211
	Header-Adding Module	212
	Processing Module	213
	Queues	213
	Routing Table	214
	Forwarding Module	214
	MTU Table	214
	Fragmentation Module	214
	Reassembly Table	215
	Reassembly Module	215
7.9	FURTHER READING	216
	Books	216
	RFCs	217
7.10	KEY TERMS	217
7.11	SUMMARY	217
7.12	PRACTICE SET	218
	Exercises	218
	Research Activities	219

Chapter 8 Address Resolution Protocol (ARP) 220

- 8.1 ADDRESS MAPPING 221
 - Static Mapping 221
 - Dynamic Mapping 222
- 8.2 THE ARP PROTOCOL 222
 - Packet Format 223
 - Encapsulation 224
 - Operation 224
 - Proxy ARP 226
- 8.3 ATMARP 228
 - Packet Format 228
 - ATMARP Operation 229
 - Logical IP Subnet (LIS) 232
- 8.4 ARP PACKAGE 233
 - Cache Table 233
 - Queues 235
 - Output Module 235
 - Input Module 236
 - Cache-Control Module 237
 - More Examples 238
- 8.5 FURTHER READING 240
 - Books 240
 - RFCs 240
- 8.6 KEY TERMS 240
- 8.7 SUMMARY 241
- 8.8 PRACTICE SET 241
 - Exercises 241

Chapter 9 Internet Control Message Protocol Version 4 (ICMPv4) 244

- 9.1 INTRODUCTION 245
- 9.2 MESSAGES 246
 - Message Format 246
 - Error Reporting Messages 246
 - Query Messages 253
 - Checksum 256
- 9.3 DEBUGGING TOOLS 257
 - Ping 257
 - Traceroute 259
- 9.4 ICMP PACKAGE 262
 - Input Module 263
 - Output Module 263
- 9.5 FURTHER READING 264
 - Books 264
 - RFCs 264
- 9.6 KEY TERMS 264
- 9.7 SUMMARY 265

- 9.8 PRACTICE SET 265
 - Exercises 265
 - Research Activities 267

Chapter 10 Mobile IP 268

- 10.1 ADDRESSING 269
 - Stationary Hosts 269
 - Mobile Hosts 269
- 10.2 AGENTS 270
 - Home Agent 271
 - Foreign Agent 271
- 10.3 THREE PHASES 271
 - Agent Discovery 271
 - Registration 273
 - Data Transfer 275
- 10.4 INEFFICIENCY IN MOBILE IP 277
 - Double Crossing 277
 - Triangle Routing 277
 - Solution 277
- 10.5 FURTHER READING 278
 - Books 278
 - RFCs 278
- 10.6 KEY TERMS 278
- 10.7 SUMMARY 279
- 10.8 PRACTICE SET 279
 - Exercises 279
 - Research Activities 280

Chapter 11 Unicast Routing Protocols (RIP, OSPF, and BGP) 282

- 11.1 INTRODUCTION 283
 - Cost or Metric 283
 - Static versus Dynamic Routing Tables 283
 - Routing Protocol 283
- 11.2 INTRA- AND INTER-DOMAIN ROUTING 284
- 11.3 DISTANCE VECTOR ROUTING 285
 - Bellman-Ford Algorithm 285
 - Distance Vector Routing Algorithm 287
 - Count to Infinity 291
- 11.4 RIP 293
 - RIP Message Format 294
 - Requests and Responses 295
 - Timers in RIP 296
 - RIP Version 2 297
 - Encapsulation 299
- 11.5 LINK STATE ROUTING 299
 - Building Routing Tables 300

11.6	OSPF	304
	Areas	304
	Metric	305
	Types of Links	305
	Graphical Representation	307
	OSPF Packets	307
	Link State Update Packet	309
	Other Packets	317
	Encapsulation	320
11.7	PATH VECTOR ROUTING	320
	Reachability	321
	Routing Tables	322
11.8	BGP	323
	Types of Autonomous Systems	323
	Path Attributes	324
	BGP Sessions	324
	External and Internal BGP	324
	Types of Packets	325
	Packet Format	325
	Encapsulation	329
11.9	FURTHER READING	329
	Books	329
	RFCs	330
11.10	KEY TERMS	330
11.11	SUMMARY	330
11.12	PRACTICE SET	331
	Exercises	331
	Research Activities	333
Chapter 12		Multicasting and Multicast Routing Protocols 334
12.1	INTRODUCTION	335
	Unicasting	335
	Multicasting	336
	Broadcasting	338
12.2	MULTICAST ADDRESSES	338
	Multicast Addresses in IPv4	339
	Selecting Multicast Address	341
	Delivery of Multicast Packets at Data Link Layer	342
12.3	IGMP	343
	Group Management	344
	IGMP Messages	344
	IGMP Protocol Applied to Host	347
	IGMP Protocol Applied to Router	351
	Role of IGMP in Forwarding	352
	Variables and Timers	354
	Encapsulation	355
	Compatibility with Older Versions	355
12.4	MULTICAST ROUTING	355
	Optimal Routing: Shortest Path Trees	355

- 12.5 ROUTING PROTOCOLS 358
 - Multicast Link State Routing: MOSPF 358
 - Multicast Distance Vector 360
 - DVMRP 364
 - CBT 364
 - PIM 366
- 12.6 MBONE 367
- 12.7 FURTHER READING 368
 - Books 368
 - RFCs 368
- 12.8 KEY TERMS 368
- 12.9 SUMMARY 369
- 12.10 PRACTICE SET 369
 - Exercises 369
 - Research Activities 371

Part 3 Transport Layer 373

Chapter 13 Introduction to the Transport Layer 374

- 13.1 TRANSPORT-LAYER SERVICES 375
 - Process-to-Process Communication 375
 - Addressing: Port Numbers 375
 - Encapsulation and Decapsulation 378
 - Multiplexing and Demultiplexing 379
 - Flow Control 379
 - Error Control 382
 - Combination of Flow and Error Control 383
 - Congestion Control 385
 - Connectionless and Connection-Oriented Services 386
- 13.2 TRANSPORT-LAYER PROTOCOLS 389
 - Simple Protocol 390
 - Stop-and-Wait Protocol 391
 - Go-Back-*N* Protocol 395
 - Selective-Repeat Protocol 403
 - Bidirectional Protocols: Piggybacking 408
- 13.3 FURTHER READING 409
- 13.4 KEY TERMS 409
- 13.5 SUMMARY 410
- 13.6 PRACTICE SET 411
 - Exercises 411
 - Research Activities 413

Chapter 14 User Datagram Protocol (UDP) 414

- 14.1 INTRODUCTION 415
- 14.2 USER DATAGRAM 416
- 14.3 UDP SERVICES 417
 - Process-to-Process Communication 417
 - Connectionless Services 418

	Flow Control	418
	Error Control	418
	Congestion Control	420
	Encapsulation and Decapsulation	420
	Queuing	421
	Multiplexing and Demultiplexing	423
	Comparison between UDP and Generic Simple Protocol	423
14.4	UDP APPLICATIONS	424
	UDP Features	424
	Typical Applications	426
14.5	UDP PACKAGE	426
	Control-Block Table	426
	Input Queues	426
	Control-Block Module	426
	Input Module	427
	Output Module	428
	Examples	428
14.6	FURTHER READING	430
	Books	430
	RFCs	430
14.7	KEY TERMS	430
14.8	SUMMARY	430
14.9	PRACTICE SET	431
	Exercises	431
	Chapter 15 Transmission Control Protocol (TCP)	432
15.1	TCP SERVICES	433
	Process-to-Process Communication	433
	Stream Delivery Service	434
	Full-Duplex Communication	436
	Multiplexing and Demultiplexing	436
	Connection-Oriented Service	436
	Reliable Service	436
15.2	TCP FEATURES	437
	Numbering System	437
	Flow Control	438
	Error Control	438
	Congestion Control	439
15.3	SEGMENT	439
	Format	439
	Encapsulation	441
15.4	A TCP CONNECTION	442
	Connection Establishment	442
	Data Transfer	444
	Connection Termination	446
	Connection Reset	448
15.5	STATE TRANSITION DIAGRAM	449
	Scenarios	450

- 15.6 WINDOWS IN TCP 457
 - Send Window 457
 - Receive Window 458
- 15.7 FLOW CONTROL 459
 - Opening and Closing Windows 460
 - Shrinking of Windows 462
 - Silly Window Syndrome 463
- 15.8 ERROR CONTROL 465
 - Checksum 465
 - Acknowledgment 465
 - Retransmission 466
 - Out-of-Order Segments 467
 - FSMs for Data Transfer in TCP 467
 - Some Scenarios 468
- 15.9 CONGESTION CONTROL 473
 - Congestion Window 473
 - Congestion Policy 474
- 15.10 TCP TIMERS 478
 - Retransmission Timer 478
 - Persistence Timer 481
 - Keepalive Timer 482
 - TIME-WAIT Timer 482
- 15.11 OPTIONS 482
- 15.12 TCP PACKAGE 489
 - Transmission Control Blocks (TCBs) 490
 - Timers 491
 - Main Module 491
 - Input Processing Module 495
 - Output Processing Module 496
- 15.13 FURTHER READING 496
 - Books 496
 - RFCs 496
- 15.14 KEY TERMS 496
- 15.15 SUMMARY 497
- 15.16 PRACTICE SET 498
 - Exercises 498
 - Research Activities 501

Chapter 16 Stream Control Transmission Protocol (SCTP) 502

- 16.1 INTRODUCTION 503
- 16.2 SCTP SERVICES 504
 - Process-to-Process Communication 504
 - Multiple Streams 504
 - Multihoming 505
 - Full-Duplex Communication 506
 - Connection-Oriented Service 506
 - Reliable Service 506

16.3	SCTP FEATURES	506
	Transmission Sequence Number (TSN)	506
	Stream Identifier (SI)	506
	Stream Sequence Number (SSN)	507
	Packets	507
	Acknowledgment Number	509
	Flow Control	509
	Error Control	509
	Congestion Control	510
16.4	PACKET FORMAT	510
	General Header	510
	Chunks	511
16.5	AN SCTP ASSOCIATION	519
	Association Establishment	519
	Data Transfer	521
	Association Termination	524
	Association Abortion	524
16.6	STATE TRANSITION DIAGRAM	525
	Scenarios	526
16.7	FLOW CONTROL	529
	Receiver Site	529
	Sender Site	530
	A Scenario	530
16.8	ERROR CONTROL	531
	Receiver Site	532
	Sender Site	532
	Sending Data Chunks	534
	Generating SACK Chunks	534
16.9	CONGESTION CONTROL	535
	Congestion Control and Multihoming	535
	Explicit Congestion Notification	535
16.10	FURTHER READING	535
	Books	536
	RFCs	536
16.11	KEY TERMS	536
16.12	SUMMARY	536
16.13	PRACTICE SET	537
	Exercises	537
	Research Activities	539
Part 4 Application Layer		541
Chapter 17 Introduction to the Application Layer		542
17.1	CLIENT-SERVER PARADIGM	543
	Server	544
	Client	544
	Concurrency	544

- 20.3 Socket Interfaces 546
- Communication Using UDP 554
- Communication Using TCP 558
- 20.4 Predefined Client-Server Applications 564
- 17.2 PEER-TO-PEER PARADIGM 564
- 17.3 FURTHER READING 565
- 17.4 KEY TERMS 565
- 17.5 SUMMARY 565
- 17.6 PRACTICE SET 566
- Exercises 566

Chapter 18 Host Configuration: DHCP 568

- 18.1 INTRODUCTION 569
- Previous Protocols 569
- DHCP 570
- 18.2 DHCP OPERATION 570
- Same Network 570
- Different Networks 571
- UDP Ports 572
- Using TFTP 572
- Error Control 573
- Packet Format 573
- 18.3 CONFIGURATION 576
- Static Address Allocation 576
- Dynamic Address Allocation 576
- Transition States 576
- Other Issues 578
- Exchanging Messages 579
- 18.4 FURTHER READING 579
- Books and RFCs 579
- 18.5 KEY TERMS 580
- 18.6 SUMMARY 580
- 18.7 PRACTICE SET 580
- Exercises 580
- Research Activities 581

Chapter 19 Domain Name System (DNS) 582

- 19.1 NEED FOR DNS 583
- 19.2 NAME SPACE 584
- Flat Name Space 584
- Hierarchical Name Space 584
- Domain Name Space 585
- Domain 587
- Distribution of Name Space 587
- 19.3 DNS IN THE INTERNET 589
- Generic Domains 589
- Country Domains 590

	Inverse Domain	591
	Registrar	592
19.4	RESOLUTION	593
	Resolver	593
	Mapping Names to Addresses	593
	Mapping Addresses to Names	593
	Recursive Resolution	593
	Iterative Resolution	594
	Caching	594
19.5	DNS MESSAGES	595
	Header	596
19.6	TYPES OF RECORDS	598
	Question Record	598
	Resource Record	599
19.7	COMPRESSION	600
19.8	ENCAPSULATION	604
19.9	REGISTRARS	604
19.10	DDNS	604
19.11	SECURITY OF DNS	605
19.12	FURTHER READING	605
	Books	606
	RFCs	606
19.13	KEY TERMS	606
19.14	SUMMARY	606
19.15	PRACTICE SET	607
	Exercises	607
	Research Activities	608
	Chapter 20 Remote Login: TELNET and SSH	610
20.1	TELNET	611
	Concepts	611
	Time-Sharing Environment	611
	Network Virtual Terminal (NVT)	613
	Embedding	614
	Options	615
	Symmetry	618
	Suboption Negotiation	618
	Controlling the Server	618
	Out-of-Band Signaling	620
	Escape Character	620
	Modes of Operation	621
	User Interface	623
	Security Issue	624
20.2	SECURE SHELL (SSH)	624
	Versions	624
	Components	624
	Port Forwarding	625
	Format of the SSH Packets	626

- 20.3 FURTHER READING 626
 - Books 626
 - RFCs 627
- 20.4 KEY TERMS 627
- 20.5 SUMMARY 627
- 20.6 PRACTICE SET 628
 - Exercises 628
 - Research Activities 629

Chapter 21 File Transfer: FTP and TFTP 630

- 21.1 FTP 631
 - Connections 631
 - Communication 633
 - Command Processing 635
 - File Transfer 639
 - Anonymous FTP 642
 - Security for FTP 643
 - The sftp Program 643
- 21.2 TFTP 643
 - Messages 644
 - Connection 646
 - Data Transfer 647
 - UDP Ports 649
 - TFTP Example 650
 - TFTP Options 650
 - Security 651
 - Applications 651
- 21.3 FURTHER READING 652
 - Books 652
 - RFCs 652
- 21.4 KEY TERMS 652
- 21.5 SUMMARY 653
- 21.6 PRACTICE SET 653
 - Exercises 653
 - Research Activities 655

Chapter 22 World Wide Web and HTTP 656

- 22.1 ARCHITECTURE 657
 - Hypertext and Hypermedia 658
 - Web Client (Browser) 658
 - Web Server 659
 - Uniform Resource Locator (URL) 659
- 22.2 WEB DOCUMENTS 660
 - Static Documents 660
 - Dynamic Documents 660
 - Active Documents 663
- 22.3 HTTP 664
 - HTTP Transaction 664

- Conditional Request 670
- Persistence 670
- Cookies 672
- Web Caching: Proxy Server 675
- HTTP Security 675
- 22.4 FURTHER READING 676
 - Books 676
 - RFCs 676
- 22.5 KEY TERMS 676
- 22.6 SUMMARY 676
- 22.7 PRACTICE SET 677
 - Exercises 677
 - Research Activities 678

**Chapter 23 Electronic Mail: SMTP, POP, IMAP,
and MIME 680**

- 23.1 ARCHITECTURE 681
 - First Scenario 681
 - Second Scenario 682
 - Third Scenario 682
 - Fourth Scenario 683
- 23.2 USER AGENT 684
 - Services Provided by a User Agent 684
 - User Agent Types 685
 - Sending Mail 685
 - Receiving Mail 686
 - Addresses 686
 - Mailing List or Group List 686
- 23.3 MESSAGE TRANSFER AGENT: SMTP 687
 - Commands and Responses 687
 - Mail Transfer Phases 691
- 23.4 MESSAGE ACCESS AGENT: POP AND IMAP 693
 - POP3 694
 - IMAP4 695
- 23.5 MIME 695
 - MIME Headers 695
- 23.6 WEB-BASED MAIL 700
 - Case I 700
 - Case II 701
- 23.7 E-MAIL SECURITY 701
- 23.8 FURTHER READING 702
 - Books 702
 - RFCs 702
- 23.9 KEY TERMS 702
- 23.10 SUMMARY 702
- 23.11 PRACTICE SET 703
 - Exercises 703
 - Research Activities 704

- Chapter 24 Network Management: SNMP 706**
- 24.1 CONCEPT 707
 - Managers and Agents 707
 - 24.2 MANAGEMENT COMPONENTS 708
 - Role of SNMP 708
 - Role of SMI 708
 - Role of MIB 709
 - An Analogy 709
 - An Overview 710
 - 24.3 SMI 711
 - Name 711
 - Type 712
 - Encoding Method 713
 - 24.4 MIB 715
 - Accessing MIB Variables 716
 - Lexicographic Ordering 718
 - 24.5 SNMP 719
 - PDU's 719
 - Format 721
 - Messages 722
 - 24.6 UDP PORTS 724
 - 24.7 SECURITY 725
 - 24.8 FURTHER READING 725
 - Books 725
 - RFCs 725
 - 24.9 KEY TERMS 726
 - 24.10 SUMMARY 726
 - 24.11 PRACTICE SET 726
 - Exercises 726
 - Research Activity 727
- Chapter 25 Multimedia 728**
- 25.1 INTRODUCTION 729
 - 25.2 DIGITIZING AUDIO AND VIDEO 730
 - Digitizing Audio 730
 - Digitizing Video 730
 - 25.3 AUDIO AND VIDEO COMPRESSION 731
 - Audio Compression 731
 - Video Compression 731
 - 25.4 STREAMING STORED AUDIO/VIDEO 736
 - First Approach: Using a Web Server 736
 - Second Approach: Using a Web Server with Metafile 737
 - Third Approach: Using a Media Server 738
 - Fourth Approach: Using a Media Server and RTSP 738
 - 25.5 STREAMING LIVE AUDIO/VIDEO 739
 - 25.6 REAL-TIME INTERACTIVE AUDIO/VIDEO 740
 - Characteristics 740

- 25.7 RTP 744
 - RTP Packet Format 745
 - UDP Port 746
- 25.8 RTCP 746
 - Sender Report 746
 - Receiver Report 747
 - Source Description Message 747
 - Bye Message 747
 - Application-Specific Message 747
 - UDP Port 747
- 25.9 VOICE OVER IP 748
 - SIP 748
 - H.323 750
- 25.10 QUALITY OF SERVICE 752
 - Flow Characteristics 752
 - Flow Classes 753
 - Techniques to Improve QoS 753
 - Resource Reservation 757
 - Admission Control 758
- 25.11 INTEGRATED SERVICES 758
 - Signaling 758
 - Flow Specification 758
 - Admission 759
 - Service Classes 759
 - RSVP 759
 - Problems with Integrated Services 762
- 25.12 DIFFERENTIATED SERVICES 762
 - DS Field 762
- 25.13 RECOMMENDED READING 764
 - Books 764
 - RFCs 764
- 25.14 KEY TERMS 764
- 25.15 SUMMARY 765
- 25.16 PRACTICE SET 766
 - Exercises 766

Part 5 Next Generation 767

Chapter 26 IPv6 Addressing 768

- 26.1 INTRODUCTION 769
 - Notations 769
 - Address Space 772
 - Three Address Types 772
 - Broadcasting and Multicasting 773
- 26.2 ADDRESS SPACE ALLOCATION 773
 - Assigned and Reserved Blocks 775
- 26.3 GLOBAL UNICAST ADDRESSES 778
 - Three Levels of Hierarchy 779

- 26.4 AUTOCONFIGURATION 781
- 26.5 RENUMBERING 782
- 26.6 FURTHER READING 782
 - Books 782
 - RFCs 782
- 26.7 KEY TERMS 783
- 26.8 SUMMARY 783
- 26.9 PRACTICE SET 783
 - Exercises 783

Chapter 27 IPv6 Protocol 786

- 27.1 INTRODUCTION 787
 - Rationale for Change 787
 - Reason for Delay in Adoption 787
- 27.2 PACKET FORMAT 788
 - Base Header 788
 - Flow Label 789
 - Comparison between IPv4 and IPv6 Headers 790
 - Extension Headers 790
 - Comparison between IPv4 and IPv6 795
- 27.3 TRANSITION FROM IPv4 TO IPv6 796
 - Dual Stack 796
 - Tunneling 797
 - Header Translation 797
- 27.4 FURTHER READING 798
 - Books 798
 - RFCs 798
- 27.5 KEY TERMS 798
- 27.6 SUMMARY 799
- 27.7 PRACTICE SET 799
 - Exercises 799
 - Research Activity 799

Chapter 28 ICMPv6 800

- 28.1 INTRODUCTION 801
- 28.2 ERROR MESSAGES 802
 - Destination-Unreachable Message 802
 - Packet-Too-Big Message 803
 - Time-Exceeded Message 803
 - Parameter-Problem Message 804
- 28.3 INFORMATIONAL MESSAGES 804
 - Echo-Request Message 804
 - Echo-Reply Message 805
- 28.4 NEIGHBOR-DISCOVERY MESSAGES 805
 - Router-Solicitation Message 805
 - Router-Advertisement Message 806
 - Neighbor-Solicitation Message 806

- Neighbor-Advertisement Message 807
- Redirection Message 808
- Inverse-Neighbor-Solicitation Message 808
- Inverse-Neighbor-Advertisement Message 808
- 28.5 **GROUP MEMBERSHIP MESSAGES 809**
 - Membership-Query Message 809
 - Membership-Report Message 810
 - Functionality 810
- 28.6 **FURTHER READING 812**
 - Books 812
 - RFCs 812
- 28.7 **KEY TERMS 812**
- 28.8 **SUMMARY 812**
- 28.9 **PRACTICE SET 813**
 - Exercises 813
 - Research Activities 813

Part 6 Security 815

Chapter 29 Cryptography and Network Security 816

- 29.1 **INTRODUCTION 817**
 - Security Goals 817
 - Attacks 818
 - Services 819
 - Techniques 819
- 29.2 **TRADITIONAL CIPHERS 820**
 - Key 821
 - Substitution Ciphers 821
 - Transposition Ciphers 824
 - Stream and Block Ciphers 825
- 29.3 **MODERN CIPHERS 826**
 - Modern Block Ciphers 826
 - Data Encryption Standard (DES) 828
 - Modern Stream Ciphers 830
- 29.4 **ASYMMETRIC-KEY CIPHERS 831**
 - Keys 832
 - General Idea 832
 - RSA Cryptosystem 834
 - Applications 836
- 29.5 **MESSAGE INTEGRITY 836**
 - Message and Message Digest 836
 - Hash Functions 837
- 29.6 **MESSAGE AUTHENTICATION 838**
 - HMAC 838
- 29.7 **DIGITAL SIGNATURE 839**
 - Comparison 839
 - Process 840

- Signing the Digest 841
- Services 842
- RSA Digital Signature Scheme 843
- Digital Signature Standard (DSS) 844
- 29.8 ENTITY AUTHENTICATION 844
 - Entity versus Message Authentication 844
 - Verification Categories 845
 - Passwords 845
 - Challenge-Response 845
- 29.9 KEY MANAGEMENT 847
 - Symmetric-Key Distribution 847
 - Symmetric-Key Agreement 850
 - Public-Key Distribution 851
- 29.10 FURTHER READING 853
- 29.11 KEY TERMS 853
- 29.12 SUMMARY 854
- 29.13 PRACTICE SET 855
 - Exercises 855
 - Research Activities 856

Chapter 30 Internet Security 858

- 30.1 NETWORK LAYER SECURITY 859
 - Two Modes 859
 - Two Security Protocols 861
 - Services Provided by IPSec 864
 - Security Association 865
 - Internet Key Exchange (IKE) 868
 - Virtual Private Network (VPN) 868
- 30.2 TRANSPORT LAYER SECURITY 869
 - SSL Architecture 869
 - Four Protocols 872
- 30.3 APPLICATION LAYER SECURITY 875
 - E-mail Security 875
 - Pretty Good Privacy (PGP) 876
 - Key Rings 878
 - PGP Certificates 878
 - S/MIME 881
 - Applications of S/MIME 885
- 30.4 FIREWALLS 885
 - Packet-Filter Firewall 885
 - Proxy Firewall 886
- 30.5 RECOMMENDED READING 887
- 30.6 KEY TERMS 887
- 30.7 SUMMARY 888
- 30.8 PRACTICE SET 888
 - Exercises 888
 - Research Activities 889

Part 7 Appendices 891

Appendix A Unicode 892

Appendix B Positional Numbering Systems 896

Appendix C Error Detection Codes 904

Appendix D Checksum 914

Appendix E HTML, XHTML, XML, and XSL 920

Appendix F Client-Server Programming in Java 926

Appendix G Miscellaneous Information 932

Glossary 935

References 955

Index 957