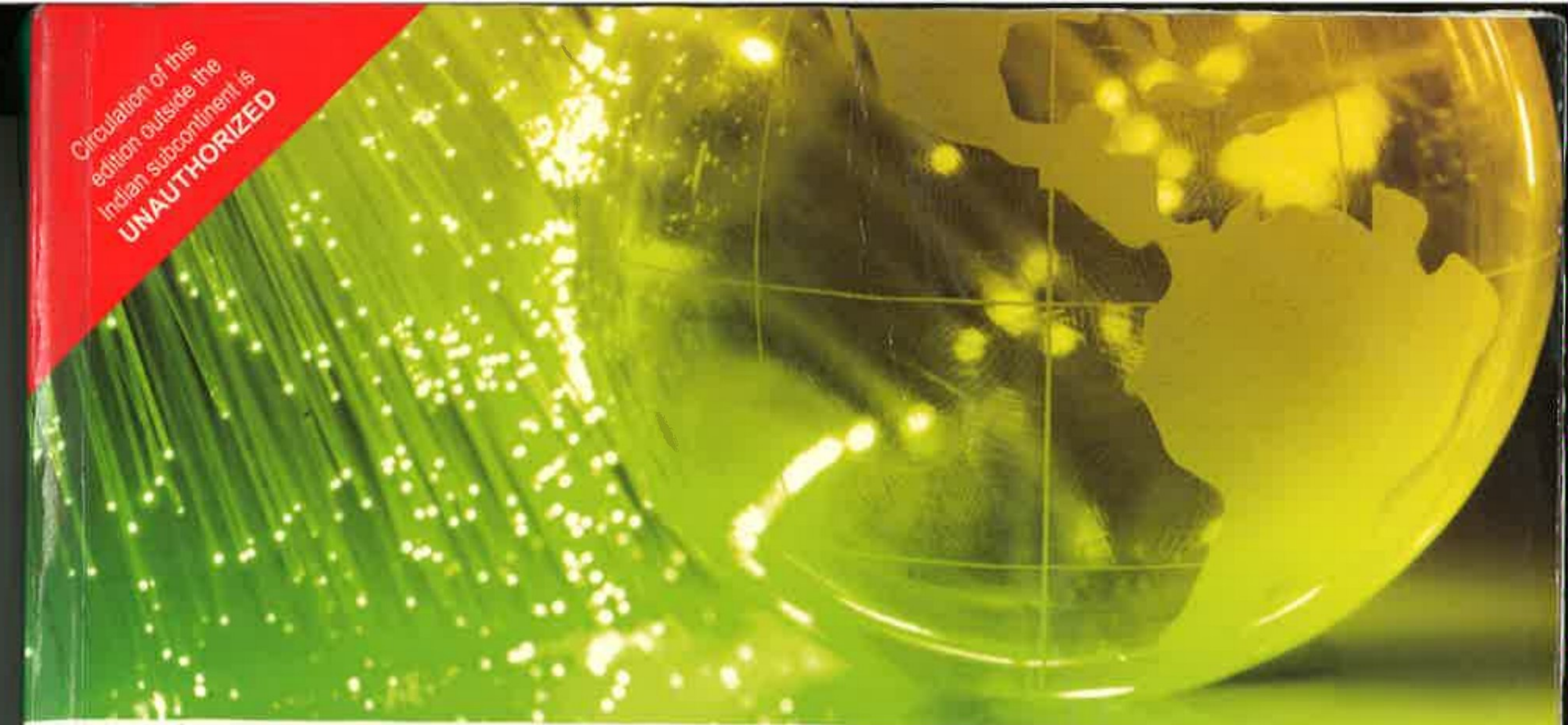


Circulation of this
edition outside the
Indian subcontinent is
UNAUTHORIZED



High Speed Networks and Internets

Performance and Quality of Service

Second Edition

William Stallings

ALWAYS LEARNING

PEARSON



The author and publisher of this book have used their best efforts to ensure the book's accuracy and to provide the most up-to-date information available. The author and publisher assume no responsibility for any errors or omissions, or for any consequences arising from the use of the information contained in this book. The author and publisher also assume no responsibility for any damage or loss, whether actual or consequential, arising from the use of the information contained in this book.

Copyright © 2005 by Pearson Education, Inc.
This volume is published by Addison-Wesley Longman, Inc., and Benjamin Cummings Publishing Co.

This book is published subject to the condition that it shall not be used for any other purpose, by any person, and no part may be reproduced without the publisher's prior written consent in any form of copying or recording, including electronic and mechanical, including photocopying, recording, or by any information storage and retrieval system. During the lifetime of this copyright, any third party who reproduces or transmits this book in any form or by any means, electronic or mechanical, including photocopying, recording, or by any information storage and retrieval system, without the prior written permission of the publisher, is liable to the publisher for damages.

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1
ISBN 0-201-30922-5

This edition is manufactured in India and is authorized for sale only in India, Bangladesh, Pakistan, Nepal, Sri Lanka and the Maldives. Distribution of this edition outside of these territories is strictly prohibited.

Published by Dorling Kindersley India Pvt. Ltd., a division of Pearson Education in New Delhi, India.
Head Office: 7th Floor, Knowledge Park III, Sector 62, Gurgaon - 125 001, India.
Regional Office: 11 Connaught Place, New Delhi 110 008, India.
Printed by Sri Ganga Press Pvt. Ltd.

CONTENTS

Preface xiii

PART ONE BACKGROUND 1

CHAPTER 1 Introduction 3

- 1.1 A Brief Networking History 4
- 1.2 The Need for Speed and Quality of Service 13
- 1.3 Advanced TCP/IP and ATM Networks 18
- 1.4 Outline of the Book 21
- Appendix 1A Internet and Web Resources 23

CHAPTER 2 Protocols and the TCP/IP Suite 27

- 2.1 The Need for a Protocol Architecture 27
- 2.2 The TCP/IP Protocol Architecture 28
- 2.3 The OSI Model 36
- 2.4 Internetworking 37
- 2.5 Recommended Reading and Web Site 44
- 2.6 Problems 44

CHAPTER 3 TCP and IP 47

- 3.1 Transmission Control Protocol (TCP) 47
- 3.2 User Datagram Protocol 50
- 3.3 The Internet Protocol (IP) 51
- 3.4 IPv6 59
- 3.5 Recommended Reading and Web Sites 68
- 3.6 Problems 69

PART TWO HIGH-SPEED NETWORKS 71

CHAPTER 4 Frame Relay 73

- 4.1 Packet-Switching Networks 73
- 4.2 Frame Relay Networks 82
- 4.3 Recommended Reading and Web Sites 88
- 4.4 Problems 89

CHAPTER 5 Asynchronous Transfer Mode 91

- 5.1 ATM Protocol Architecture 92
- 5.2 ATM Logical Connections 93
- 5.3 ATM Cells 98

- 5.4 ATM Service Categories 104
- 5.5 ATM Adaptation Layer (AAL) 107
- 5.6 Recommended Reading and Web Sites 118
- 5.7 Problems 118

CHAPTER 6 High-Speed LANs 121

- 6.1 The Emergence of High-Speed LANs 122
- 6.2 Ethernet 123
- 6.3 Fibre Channel 140
- 6.4 Wireless LANs 144
- 6.5 Recommended Reading and Web Sites 152
- 6.6 Problems 153

PART THREE PERFORMANCE MODELING AND ESTIMATION 155

CHAPTER 7 Overview of Probability and Stochastic Process 159

- 7.1 Probability 159
- 7.2 Random Variables 164
- 7.3 Stochastic Processes 170
- 7.4 Recommended Reading and Web Site 179
- 7.5 Problems 179

CHAPTER 8 Queuing Analysis 183

- 8.1 How Queues Behave—A Simple Example 184
- 8.2 Why Queuing Analysis 188
- 8.3 Queuing Models 189
- 8.4 Single-Server Queues 197
- 8.5 Multiserver Queues 199
- 8.6 Examples 200
- 8.7 Queues with Priorities 205
- 8.8 Networks of Queues 206
- 8.9 Other Queuing Models 210
- 8.10 Estimating Model Parameters 211
- 8.11 Recommended Reading and Web Site 214
- 8.12 Problems 215

CHAPTER 9 Self-Similar Traffic 219

- 9.1 Self-Similarity 220
- 9.2 Self-Similar Data Traffic 223
- 9.3 Examples of Self-Similar Data Traffic 232
- 9.4 Performance Implications of Self-Similarity 237
- 9.5 Modeling and Estimation of Self-Similar Data Traffic 241
- 9.6 Recommended Reading and Web Site 244
- 9.7 Problems 245
- Appendix 9A The Hurst Self-Similarity Parameter 245

PART FOUR CONGESTION AND TRAFFIC MANAGEMENT 249

CHAPTER 10 Congestion Control in Data Networks and Internets 253

- 10.1 Effects of Congestion 254
- 10.2 Congestion and Control 259
- 10.3 Traffic Management 262
- 10.4 Congestion Control in Packet-Switching Networks 264
- 10.5 Frame Relay Congestion Control 264
- 10.6 Recommended Reading and Web Sites 270
- 10.7 Problems 271

CHAPTER 11 Link-Level Flow and Error Control 275

- 11.1 The Need for Flow and Error Control 276
- 11.2 Link Control Mechanisms 279
- 11.3 ARQ Performance 288
- 11.4 Recommended Reading 299
- 11.5 Problems 300
- Appendix 11A High-Level Data Link Control 302

CHAPTER 12 TCP Traffic Control 309

- 12.1 TCP Flow Control 309
- 12.2 TCP Congestion Control 322
- 12.3 Performance of TCP Over ATM 340
- 12.4 Recommended Reading and Web Sites 352
- 12.5 Problems 353

CHAPTER 13 Traffic and Congestion Control in ATM Networks 355

- 13.1 Requirements for ATM Traffic and Congestion Control 356
- 13.2 ATM Traffic-Related Attributes 361
- 13.3 Traffic Management Framework 366
- 13.4 Traffic Control 367
- 13.5 ABR Traffic Management 380
- 13.6 GFR Traffic Management 391
- 13.7 Recommended Reading 395
- 13.8 Problems 396

PART FIVE INTERNET ROUTING 397

CHAPTER 14 Overview of Graph Theory and Least-Cost Paths 401

- 14.1 Elementary Concepts of Graph Theory 402
- 14.2 Shortest Path Length Determination 409
- 14.3 Recommended Reading 415
- 14.4 Problems 415

CHAPTER 15 Interior Routing Protocols 419

- 15.1 Internet Routing Principles 419
- 15.2 Distance-Vector Protocol: RIP 426
- 15.3 Link-State Protocol: OSPF 433
- 15.4 Recommended Reading and Web Site 441
- 15.5 Problems 442

CHAPTER 16 Exterior Routing Protocols and Multicast 443

- 16.1 Path-Vector Protocols: BGP and IDRP 443
- 16.2 Multicasting 450
- 16.3 Recommended Reading and Web Site 465
- 16.4 Problems 465

**PART SIX QUALITY OF SERVICE
IN IP NETWORKS 467****CHAPTER 17 Integrated and Differentiated Services 469**

- 17.1 Integrated Services Architecture (ISA) 470
- 17.2 Queuing Discipline 477
- 17.3 Random Early Detection 485
- 17.4 Differentiated Services 492
- 17.5 Recommended Reading and Web Sites 500
- 17.6 Problems 502
- Appendix 17A Real-Time Traffic 503

CHAPTER 18 Protocols for QoS Support 507

- 18.1 Resource Reservation: RSVP 508
- 18.2 Multiprotocol Label Switching 521
- 18.3 Real-Time Transport Protocol (RTP) 533
- 18.4 Recommended Reading and Web Sites 544
- 18.5 Problems 545

PART SEVEN COMPRESSION 547**CHAPTER 19 Overview of Information Theory 549**

- 19.1 Information and Entropy 549
- 19.2 Coding 554
- 19.3 Recommended Reading 561
- 19.4 Problems 561

CHAPTER 20 Lossless Compression 563

- 20.1 Run-Length Encoding Techniques 564
- 20.2 Facsimile Compression 567

- 20.3 Arithmetic Coding 574
- 20.4 String-Matching Algorithms 581
- 20.5 Recommended Reading and Web Site 587
- 20.6 Problems 588

CHAPTER 21 Lossy Compression 591

- 21.1 Discrete Cosine Transform 592
- 21.2 Wavelet Compression 598
- 21.3 JPEG Image Compression 608
- 21.4 MPEG Video Compression 619
- 21.5 Recommended Reading and Web Sites 625
- 21.6 Problems 627

APPENDICES**APPENDIX A Standards and Standards-Setting Organizations 629**

- A.1 The Importance of Standards 629
- A.2 Standards and Regulation 630
- A.3 Internet Standards and the Internet Society 631
- A.4 The International Telecommunications Union 635
- A.5 IEEE 802 Standards 636

APPENDIX B Sockets 639

- B.1 Versions of Sockets 640
- B.2 Sockets, Socket Descriptors, Ports, and Connection 641
- B.3 The Client/Server Model of Communication 642
- B.4 Sockets Elements 644
- B.5 Stream and Datagram Sockets 660
- B.6 Run-Time Program Control 665
- B.7 Remote Execution of a Windows Console Application 669

GLOSSARY 679**REFERENCES 687****INDEX 701**

INDEX

- A**
- AAL**, 21, 91, 107-117
 - PDU, 109
 - protocol, 108-111
 - services, 108
 - types, 110
 - services, 107-108
 - type 1, 111-112
 - type 2, 111, 112
 - type 3/4, 111, 112-115, 116
 - type 5, 111, 114, 115-117
 - transmission example, 117
- ABR**. *See* Available bit rate (ABR)
- Acceptable use policies**, 6
- Accept policy**
 - TCP, 320-321
- Access point**, 148
- Acknowledge policy**
 - TCP, 321-322
- Acknowledgment number**
 - TCP field, 48
- ACR**
 - ABR, 381
- Acronyms**, 701
- Adaptive retransmission timer**
 - TCP implementations, 316-320
- Adaptive routing**
 - Internet routing, 421-424
- Address**
 - HDLC frame structure, 302
- Address field extension**, 87
- Addressing schemes**, 39
- Adjacency matrix**, 402
- Adjacent vertex**, 402
- Admission control**
 - ISA, 473, 474
- Advanced ATM networks**, 18-21
- Advanced Research Projects Agency (ARPA)**, 4-5
- Advanced TCP/IP networks**, 18-21
- Aggregate peak demand**
 - VPC, 369
- Alignment**
 - type 3/4 AAL, 114
- Allowed cell rate (ACR)**
 - ABR, 381
- American National Standards Institute (ANSI)**, 636
- Anchor frame**
 - MPEG, 621
- ANSI**, 636
- Anycast**
 - IPv6 addresses, 65
- Applicability statement**
 - Internet standards, 634
- Application**
 - OSI, 37
- Application-defined packet**
 - RTCP, 544
- Application Delay Sensitivity and Criticality**
 - comparison, 18
- Application layer**
 - communication task, 30
- Application-level framing**
 - RTP, 534-535
- Areas**
 - OSPF, 439-440
- Arithmetic coding**, 574-581
- JPEG 2000**, 619
- ARPA**, 4-5
- ARPANET**, 4-5, 7, 28
- ARQ**
 - performance, 288-299
- Association**
 - Agency (ARPA), WL, 149
- Assured forwarding PHB**, 499-500
 - codepoints, 500
- Asynchronous IO**, 666-669
- Asynchronous transfer mode (ATM)**. *See* ATM
- ATM**, 91-118
 - adaptation, 21
 - available bit rate (ABR), 106
 - cell
 - format, 98
 - cells, 99-103
 - constant bit rate (CBR), 104-105
 - control signaling, 97-98
 - exercise problems related to, 118-120
 - GFC field, 100
 - guaranteed frame rate (GFR), 106-107
 - header format, 99-100
 - HEC, 101-103
 - layer traffic and congestion control
 - objectives, 366-367
 - logical connections, 93-98
 - non-real-time service, 105-107
 - non-real-time variable bit rate (nrt-VBR), 105
 - protocol architecture, 92-98
 - real-time service, 104-105
 - real-time variable bit rate (rt-VBR), 105

- ATM, (*cont.*)
 service categories, 104-107
 service category attributes, 362
 traffic and congestion control requirements, 356-361
 traffic-related attributes, 361-366
 unspecified bit rate (UBR), 105-106
 virtual channel connection uses, 94-95
 virtual path/virtual channel characteristics, 95-97
- ATM Adaptation Layer (AAL). *See* AAL
- ATM bit rate services, 106
- ATM Forum, 11
- ATM hot links
 Web sites, 118
- ATM LAN, 12
- ATM market
 developmental milestones, 12
- ATM networks, 3, 12, 20-21
 arrival, 8-9
 definition, 11
 digraph, 409
 traffic and congestion control, 355-395
 exercise problems related to, 396
- ATM switch buffer layout, 347
- ATM WAN, 12
- AT & T Center for Internet research
 Web site for, 352
- Authentication
 WL, 149
- Authentication header
 IPv6 extension header, 60
- Autocorrelation function, 171
- Autocorrelation functions, 173
- Autocovariance, 171
- Autonomous systems
 Internet routing, 425
 sample, 436
- Available bit rate (ABR), 21-22
 ATM, 106
 ATM attributes, 361
 capacity allocation, 386-391
 parameters, 387
 rate control, 380-384
 TCP vs. ATM, 343-346, 350-351
 traffic management, 380-391
- Average rate
 throughput characteristics, 155
- Axiomatic, 160
- B**
- Backpressure, 259
- Backward
 explicit congestion, 262
- Backward explicit congestion notification (BECN), 268
- Backward RM (BRM) cell, 384
- 1000BASE-CX
 ethernet, 138
- 1000BASE-LX
 ethernet, 137
- 1000BASE-SX
 ethernet, 137
- 100BASE-T4
 ethernet, 135
- 1000BASE-T
 ethernet, 138
- Battery power consumption
 WL, 147
- Bayes's theorem, 163-164
 illustration, 164
- BBN, 5
- BCS parameter
 ATM, 365
- BECN, 268
- Beginning tag
 type 3/4 AAL, 114
- Behavior aggregate
 DS, 493
- Behavior class selector (BCS)
 parameter
 ATM, 365
- Bellman-Ford algorithm,
 413-414
 vs. Dijkstra's algorithm,
 414-415
- Best-effort, 16
- Best-effort service, 106
- BFS, 406-410
- BGP, 443-449
- Bias, 214
- Bidirectional interpolated
 MPEG, 624
- Binary
 explicit congestion, 262
- Binary exponential backoff, 125
- Binary feedback schemes
 ABR, 387-388
- Bind
 to local port, 645-646
- Bit-round fair queuing (BRFQ)
 ISA, 479-481
- Block motion compensation,
 622
- Bolt Beranek and Newman
 (BBN), 5

- Border gateway protocol (BGP), 443-448
 routing information exchange, 448-449
- Breadth-first search (BFS)
 algorithm, 408-409
 spanning tree, 406-410
- BRFQ
 ISA, 479-481
- Bridge, 38, 39
- Bridge frame handling
 ethernet, 131
- BRM cell, 384
- Broadband
 definition, 11
- Broadband ISDN, 10-13
 factors guiding, 11
- Broadcast
 multicasting, 451
- Brownian motion process,
 174-176
 self-similar traffic, 225
- Buffer allocation size
 type 3/4 AAL, 114
- Buffer management
 GFR mechanism, 392
- Bus LAN
 frame transmission, 125
- BYE
 RTCP, 544
- Byte ordering, 646-647
- C**
- CAD, 14, 123
- Calculating percentiles
 examples, 201-202
- Call control signaling, 83
- Call establishment
 virtual paths, 95
- Cantor set to five levels
 recursion, 222
- CAPC
 ABR, 388-391
- CBR. *See* Constant bit rate (CBR)
- CCITT, 9-10
- CCT, 100
- CDVT
 ATM, 363-364
- Cell, 92
- Cell delay variation
 ATM, 357-361
- Cell delay variation tolerance (CDVT)
 ATM, 363-364
- Cell flow
 ABR, 382-384
- Cell insertion time
 ATM, 366
- Cell loss priority (CLP), 100
- Cell loss ratio (CLR)
 ATM forum, 364-365
- Cell relay. *See* Asynchronous transfer mode
- Cell relay retreat
 Web sites, 118
- Cell sequence integrity, 96
- Centralized server farms, 14, 123
- Cerf, Vint, 6
- CERN, 7
- Certain event, 160
- Changing element, 569
- Charles Spurgeon's ethernet
 web site
 Web sites, 152
- Checksum
 field, 49
 TCP, 34
 TCP field, 48
- Child vertices, 405
- Choke packet, 261
- CIR, 266-267
- Circuit emulation
 AAL, 108
- CIX, 7
- Class A addresses, 55
- Class B addresses, 55
- Class C addresses, 55
- Classifier
 DS, 493, 497
 ISA, 475
- Client connection
 accepting, 652-653
 listening for incoming, 652
- Client program
 initiate connections, 661-663
 initiating connection, 656-657
- Client/server model of communication, 642-643
- CLP, 100
- CLR
 ATM forum, 364-365
- Coding, 554-561
 efficiency, 557-558
 Coefficient of variation, 199
- Collocated network operation
 WL, 147
- Commercial Information Interchange (CIX), 7
- Committed burst size
 congestion control, 267
- Committed information rate (CIR), 266-267
- Common part convergence sublayer (CPCS)
 AAL, 109-110
 user-to-user indication, 116

- Common part indicator
 type 5 AAL, 116
- Common path indicator
 type 3/4 AAL, 113
- Communication network, 39
- Communication task
 layers, 29
- Complement, 160
- Component transform
 JPEG 2000, 619
- Compression, 23
 Haar wavelets, 603
- Compression pointers, 588
- Computer-aided design (CAD),
 14, 123
- Conditional probability,
 162-163
- Conformance definition
 ATM, 364
- Congestion
 ATM attributes, 361
 effects, 254-259
- Congestion and traffic management, 22
- Congestion avoidance
 congestion control, 265
 illustration, 335
- Congestion avoidance using
 proportional control (CAPC)
 ABR, 388-391
- Congestion control, 58, 259-262
 ABR, 386
 attributes
 ATM, 365
 data networks and Internets,
 253-270
 exercise problems related to, 271-273
 frame relay, 264-270
 techniques, 265
 mechanisms, 260
 packet-switching networks,
 264
 RTCP, 539
 traffic management, 262-264
- Congestion recovery
 procedures
 congestion control, 266
- Connection, 641-642
- Connection admission control
 VPC, 370-371
- Connection duration
 ATM, 366
- Connection-oriented QoS
 support
 MPLS, 522
- Connection to backbone LAN
 WL, 147
- Connection traffic descriptor
 ATM, 363-364
- Constant bit rate (CBR)
 ATM, 104-105
 ATM attributes, 361
 illustrated, 358
- Constrain-based routing
 algorithm
 MPLS, 532
- Continuous
 random variable, 165
- Continuous-state leaky bucket
 algorithm, 374
- Continuous-time definition
 self-similar traffic, 224-225
- Continuous-time stochastic
 process, 170
- Control
 HDLC frame structure, 302
- Controlled cell transfer (CCT),
 100
- Control plane
 ATM, 93
- Convergence sublayer (CS)
 AAL, 108
- Corporate wide area network-
 ing needs, 14-15
- Correlation coefficient, 168, 171
- Counting-to-infinity problem,
 430-431
- CPCS, 109-110, 116
- CRC
 SAR PDU, 115, 116
- Credit based
 explicit congestion, 262
- CS
 AAL, 108
- CSNET, 6
- Cut-through switch
 ethernet, 131
- Cycle, 403
- Cyclic redundancy check
 (CRC)
 SAR PDU, 115
 type 5 AAL, 116
- D**
- DA. *See* Destination address (DA)
- Damaged EJ
 flow control, 286-288
- Damaged frame
 flow control, 286
- Damaged RR
 flow control, 286
- DARPA, 28
- Data
 IP field, 52
 transfer

- Data, (*cont.*)
 - steps, 41
- Database server
 - examples, 200-201
 - multicasting, 451
- Data circuit-terminating equipment, 84
- Data flows
 - RSVP, 513
- Datagram, 78
- Datagram fragments, 53
- Datagram sockets, 660-665
- Data link
 - OSI, 37
- Data link connection identifier (DLCI), 87-88
- Data link connections, 88
- Data offset
 - TCP field, 48
- Data representation, 646-647
- Data stream push, 48-49
- Data terminal equipment, 84
- Data transfer
 - HDLC, 305
 - stages, 88
- DCE (data circuit-terminating equipment), 84
- DCF
 - WL, 149
- Decompression
 - JPEG, 612
- Defense Advanced Research Projects Agency (DARPA), 28
- Delay, 17
 - ISA, 472
- Delay characteristics, 156
- Delay jitter, 504
- Delay variation, 17
 - delay characteristics, 156
- Deliver policy
 - TCP, 320
- Density function, 165
- Destination
 - RSVP, 513
- Destination address (DA)
 - ethernet, 127
 - IP field, 52
 - IPv6 header, 62
- Destination options header, 68
- Destination port
 - TCP, 34
 - TCP field, 48
- Destination subnetwork
 - address
 - router J, 35
- Deterministic data transfer
 - self-similar traffic example, 237
- Differentiated services (DS), 20, 492-500
 - boundary node
 - DS, 493
 - codepoints
 - DS, 493
 - configuration and operation, 496-497
 - domain, 493
 - domains, 496
 - exercise problems related to, 502-503
 - field, 494-496
 - interior node, 493
 - node, 493
- Digital electronics, 15-18
- Digital still camera, 15-16
- Digital video disk (DVD), 15
- Digraph, 403-404
- DIJK59, 410
- Dijkstra's algorithm, 410-413
 - MOSPF, 458
 - shortest-path routing, 406
- Directed graph, 403-404
- Disassociation
 - WL, 149
- Discard policy
 - ISA, 473
- Discard strategy
 - congestion control, 265
- Disconnect
 - HDLC, 305-307
- Discrete cosine transform, 592-598
- Discrete random variable, 165
- Discrete-time definition
 - self-similar traffic, 227-229
- Discrete-time stochastic process, 170
- Discrete-value stochastic process, 170
- Discrete wavelet transform (DWT)
 - JPEG 2000, 619
- Distance-vector algorithm
 - application, 428
- Distance-vector protocol, 426-432
- Distance-vector routing, 426-428
 - algorithm, 426-427
- Distributed Bellman-Ford algorithm, 428-429
- Distributed computation
 - multicasting, 451
- Distribution function, 165
- Distributions, 165-167
- Distribution system
 - WL, 148
- DLCI, 87-88
- Dotted decimal notation, 55
- Dropper
 - DS, 497
- Dropping
 - DS, 493
- Drop-tail policy
 - vs. RED, 491
- DS. *See* Differentiated services (DS)
- DTE (data terminal equipment), 84
- DVD, 15
- DWT
 - JPEG 2000, 619
- Dynamic configuration
 - WL, 147
- Dynamic routing, 19
- Dynamic window sizing
 - congestion
 - window management, 332-334

E

- Early packet discard
 - TCP vs. ATM, 346-347
- Edges, 402. *See also* Vertices
- EFCI (explicit forward congestion indication)
 - ABR, 384
- EGP, 426
- Egress
 - MPLS, 531
- Elastic applications, 16
- Elastic traffic
 - ISA, 471
- Encapsulating security payload header
 - IPv6 extension header, 60
- End systems, 38, 39
- End tag
 - type 3/4 AAL, 114
- End-to-end
 - flow control, 278
- Enhanced proportional rate control algorithm (EPRCA)
 - ABR, 388-391
- Ensemble averages, 178
- Entropy, 551-553
- Entropy function
 - properties, 553-554
- Entry-to-exit
 - flow control, 278
- EPRCA
 - ABR, 388-391
 - ERICA
 - ABR, 388-391
 - Error control, 275-299
 - exercise problems related to, 300-301
 - Error-free sliding window
 - flow control, 295
 - Error-free stop-and-wait
 - flow control, 288-289
 - Error protection function, 103
 - ESS
 - WL, 148
 - Estimating H
 - self-similar traffic, 243-244
 - Ethernet, 19, 123-140
 - backbone strategy
 - example, 136
 - 10BASE5 medium specification, 128
 - 10BASE-T medium specification, 128
 - 100BASE-X, 134-135
 - bus topology LAN, 123-124
 - CSMA/CD, 124-128
 - data rate and distance
 - options, 139
 - fast ethernet, 133-134
 - 10-Gbps, 138-140
 - gigabit ethernet, 135-138
 - hubs and switches, 128-131
 - IEEE 802.3 medium options, 127-128
 - layer 3 switches, 131-132
 - MAC frame, 126-127
 - self-similarity performance
 - improvement, 237-239
 - traffic
 - self-similar traffic examples, 232-235
 - types of layer 2 switches, 131
 - European Laboratory for Particle Physics, 7
 - Event, 160
 - Excess burst size
 - congestion control, 267
 - Expected value. *See* Mean value
 - Expedited forwarding PHB, 498
 - Explicit congestion signaling, 261-262
 - Explicit forward congestion indication
 - ABR, 384
 - ATM, 379
 - Explicit rate feedback schemes
 - ABR, 388
 - Explicit rate indication for congestion avoidance (ERICA)
 - ABR, 388-391
 - Explicit rate marking
 - ABR, 384
 - Explicit routing
 - MPLS, 531-532
 - Explicit signaling
 - congestion avoidance, 268-270
 - congestion control, 266
 - Exponential averaging
 - TCP traffic control, 319
 - Exponential distribution, 166
 - Exponential population
 - sample means, 212
 - Exponential probability
 - density, 167
 - Exponential probability distribution, 167
 - Exponential smoothing
 - coefficients
 - TCP traffic control, 318
 - Extended service set (ESS)
 - WL, 148
 - Exterior routing protocols, 443-464
 - application, 425-426
 - exercise problems related to, 465-466
 - External signaling, 21

F

- Fabric
 - FC, 141
- Facilities requests
 - router J, 35
- Facsimile compression, 567-573
- Fair buffer allocation
 - EPD
 - TCP vs. ATM, 347-350
- Fair capacity allocation
 - ABR, 386
- Fair queuing (FQ)
 - ISA, 478
- Fair share
 - ABR, 388
- Fast ethernet, 121
 - characteristics, 122
- Fast forward/reverse searches
 - MPEG, 621
- Fast recovery
 - example, 339
 - window management, 336-338
- Fast retransmit
 - window management, 334, 337
- FC-3 common services, 143
- FC-2 framing protocol, 142
- FC-4 mapping, 143
- FC-0 physical media, 142
- FCS. *See* Frame check sequence (FCS)
- FC-1 transmission protocol, 142
- FEC
 - MPLS, 524-525, 530-531
- FECN
 - congestion control, 270
- Feedback mechanisms
 - ABR, 381
- FF style
 - RSVP, 518
- Fibre channel, 121, 140-144
 - applications, 144
 - characteristics, 122
 - elements, 141-142
 - network, 142
 - physical media and topologies, 143-144
 - prospects, 144
 - protocol architecture, 142-143
- Fibre channel industry association
 - Web sites, 152
- FIFO queuing
 - ISA, 477-478
- File Transport Protocol (FTP), 5, 35-36
 - traffic
 - self-similar traffic example, 236
- Filter spec
 - RSVP, 513
- First-in-first-out (FIFO) queuing
 - ISA, 477-478
- First moment. *See* Mean value
- First-order statistics, 171
- Fixed-filter (FF) style
 - RSVP, 518
- Fixed routing
 - interior routing protocols, 420-421
- Fixed-size packets, 92
- Flag
 - HDLC frame structure, 302
- Flag fields function, 87
- Flags
 - IP field, 52
 - TCP field, 48

- Flooding
 - example, 434
 - link-state routing, 433-434
- Flow control
 - multiple protocol layers, 277
 - perspectives
 - sending and receiving, 312
 - scope, 277
- Flow descriptor
 - RSVP, 513
- Flow label
 - IPv6 header, 62
 - IPv6 standard, 63-64
 - rules, 63-64
- Flowspec
 - RSVP, 513
- Fluttering
 - Internet routing, 423
- Forward
 - explicit congestion, 26
- Forward DCT
 - sequential DCT-based mode, 609
- Forward explicit congestion notification (FECN)
 - congestion control, 270
- Forwarding equivalence class (FEC)
 - MPLS, 524-525, 530-531
- Forward RM (FRM) cell, 384
- FQ
 - ISA, 478
- Fractional Brownian motion process
 - self-similar traffic, 225-227
- Fragmentation
 - example, 54
 - IP, 52-54
- Fragment header
 - IPv6, 67
 - IPv6 extension header, 60
- Fragment offset
 - fragment header, 67
 - IP field, 52
- Frame check sequence (FCS)
 - ethernet, 127
 - fields function, 87
 - HDLC frame structure, 302
- Frame merge
 - MPLS, 524
- Frame ordering
 - MPEG, 623
- Frame relay, 9-10, 73-88
 - congestion control, 264-270
 - digraph, 409
 - exercise problems related to, 89-90
- Frame relay forum
 - Web sites, 89
- Frame relay networks (FRN), 82-89
 - architecture, 84-86
 - call control, 88
 - protocol stacks, 84
 - user data transfer, 86-88
- Frame relay virtual connections, 85
- Frame transmission bus LAN, 125
- FRM cell, 384
- FRN. *See* Frame relay networks (FRN)
- FTP. *See* File Transport Protocol (FTP)
- Full-duplex operation
 - ethernet, 135
- Function call
 - sockets, 648-651
- G
 - GCRA. *See* Generic cell rate algorithm (GCRA)
 - General data services
 - AAL, 108
 - Generalized processor sharing (GPS)
 - ISA, 481-483
 - Generic cell rate algorithm (GCRA), 364, 379
 - equivalent versions, 373
 - simplified frame-based, 394
 - Generic flow control (GFC), 100-101
 - ATM, 99
 - Gethostbyname()
 - sockets, 648-651
 - GFC, 99-101
 - GFR. *See* Guaranteed Frame Rate (GFR)
 - Gigabit ethernet, 121
 - characteristics, 122
 - media options, 138
 - Web sites, 152
 - Glossary, 679-685
 - Go-back-N ARQ
 - flow control, 286-288, 297-298
 - Goodbye (BYE)
 - RTCP, 544
 - GPS
 - ISA, 481-483
 - Graphically oriented browser, 7
 - Graph theory, 401-409
 - exercise problems related to, 415-418
 - Guaranteed Frame Rate (GFR), 21-23
 - ATM, 106-107

ATM attributes, 361
 conformance definition, 393
 traffic management, 391-395

H

- Haar wavelets, 600-602
 - mother
 - matrix, 606
 - representation, 605-606
- Handoff/roaming
 - WL, 147
- HDLC (high-level data link control), 81-84, 302-307
 - commands and responses, 304
 - operation, 303-307
 - user data transfer, 86-88
- Header checksum
 - IP field, 52
- Header error control (HEC)
 - algorithm, 103
 - field, 100, 101-102
 - operation at receiver, 102
 - performance
 - RBE impact, 103
- Header extension length
 - hop-by-hop options header, 65
 - routing header, 68
- Header hub (HHUB), 128
- Heavy-tailed distributions
 - self-similar traffic, 231
- HEC. *See* Header error control (HEC)
- HHUB, 128
- Hierarchical
 - JPEG, 608
- Hierarchical mode
 - JPEG, 617
- High-level data link control. *See* HDLC
- High-speed LANs, 13-14, 121-151
 - characteristics, 122
 - exercise problems related to, 153
- High-speed local backbone, 14, 123
- High-speed networks, 22
 - Web sites, 24-25
- High-speed wireless LANs, 121
- Hop-by-hop options header, 65-66
 - IPv6 extension header, 60
- Hop-by-hop routing
 - MPLS, 531-532
- Hop limit
 - IPv6 header, 62

- Host-to-host layer
 - communication task, 30
- Hot scope
 - flow control, 278
- Hub, 128
- Huffman code, 555-557
 - characteristics, 558-561
- Hurst self-similarity parameter, 245-247
- I
 - IAB, 28-29, 38, 631
 - ICMP (Internet Control Message Protocol), 65
 - ICR
 - ABR, 381
 - Ideal network utilization, 256
 - Ideal performance, 256-257
 - Identification
 - fragment header, 67
 - IP field, 52
 - IDN, 8-9
 - IDRP, 450
 - IEEE 802
 - standards, 636-637
 - IEEE 802.11 architecture, 148
 - IEEE 802.3 100BASE-T
 - options, 134
 - IEEE 802.3 frame format, 127
 - IESG, 632
 - IETF, 31-32, 631, 633
 - IGMP. *See* Internet group management protocol (IGMP)
 - IGP, 426
 - IHUB, 128
 - Implicit congestion signaling, 261
 - Implicit signaling
 - congestion control, 266
 - Incident vertices, 402
 - Independence, 162
 - Independent, 168
 - Independent increments, 173-178
 - Inelastic traffic
 - ISA, 472
 - requirements, 17
 - Information
 - HDLC frame structure, 302
 - history, 550-551
 - Information measure
 - single outcome, 552
 - Information theory, 549-561
 - exercise problems related to, 561-562
 - Ingress
 - MPLS, 531
 - Initial cell rate (ICR)
 - ABR, 381
 - Initialization
 - HDLC, 304
 - Integrated digital network (IDN), 8-9
 - Integrated layer processing
 - RTP, 535
 - Integrated Services Architecture (ISA), 20, 470-476
 - approach, 472-473
 - components, 474-475
 - exercise problems related to, 502-503
 - services, 475-477
 - Integrated services digital network (ISDN), 9-10
 - analysis
 - self-similarity performance improvement, 237-239
 - broadband aspects, 10-12
 - Interarea multicast forwarders, 459-461
 - Interarea multicasting, 459-461
 - Inter-AS multicast forwarders, 461
 - Inter-AS multicasting, 461
 - Inter-domain routing protocol (IDRP), 450
 - Interfaces, 40
 - Interior gateway protocol (IGP), 426
 - Interior routing protocols
 - application, 425-426
 - Intermediate hubs (IHUB), 128
 - Intermediate systems, 38, 39
 - Internal signaling, 20
 - International Organization for Standardization (ISO), 36
 - International Telecommunication Union (ITU), 635-637
 - Telecommunication Standardization Sector, 80, 635-636
 - AAL, 107
 - ATM, 92
 - T recommendations
 - ATM, 95
 - work
 - factors guiding, 11
 - Internet, 39
 - standards, 631
 - Internet Architecture Board (IAB), 28-29, 38, 631
 - Internet Control Message Protocol, 65
 - Internet engineering steering group (IESG), 632
 - Internet Engineering Task Force (IETF), 31-32, 631
 - areas, 633
 - Internet evolution, 23-25
 - chronology, 5
 - Internet group management protocol (IGMP), 456-459
 - IPv6, 457-458
 - message format, 456
 - operation, 457
 - Internet growth
 - measures, 8
 - Internet Header Length
 - IP field, 51
 - Internet interconnection points, 7
 - Internet layer
 - communication task, 29-30
 - Internet organizations, 631-633
 - Internet Protocol (IP), 3-6, 3-7, 16, 30-31, 51-59. *See also* IPv4; IPv6
 - datagram, 34
 - exercise problems related to, 69-70
 - header
 - information, 53
 - Internets, 19-20
 - module
 - performs tasks, 53
 - multicast initiative
 - Web site, 465
 - operation, 32-35
 - over ATM
 - AAL, 108
 - Internet RFC publication
 - process, 634
 - Internet routing, 22-23
 - Internet routing principles, 419-426
 - exercise problems related to, 442
 - Internet service provider (ISP), 397
 - Internet society, 631-635
 - Internet standards
 - categories, 634
 - Internet traffic
 - ISA, 470-477
 - Internetwork Control level, 58
 - Internetworking, 37-43
 - Internetworking example, 40-42
 - Internetworking terms, 39

- Interoperability lab
 - Web sites, 152
- Interpolation
 - MPEG, 623
- Intersection, 160
- Interval arithmetic coding, 579-581
- Intraframe
 - MPEG, 623
- Intranets, 38
- Inward data collection, 50
- IP. *See* Internet Protocol (IP)
- IPng. *See* IPv6
- IPv4
 - addresses, 54-55
 - formats, 55
 - options, 59
 - TOS field, 495
 - type of service field, 51
- IPv6, 20, 30-31, 59-68
 - addresses, 64-65
 - extension headers, 66
 - formats, 60
 - headers, 62-65
 - order, 60-61
 - packet extension headers, 61
 - RFCs, 60
- ISA. *See* Integrated Services Architecture (ISA)
- ISDN. *See* Integrated services digital network (ISDN)
- ISO, 36
- ISP, 397
- ITU. *See* International Telecommunication Union (ITU)
- ITU-T. *See* International Telecommunication Union (ITU)
- J**
- Jackson's theorem, 208
- Jacobson's RTO calculation, 329
- Jitter
 - ISA, 472
- Joint photographic experts group (JPEG)
 - 2000, 617-619
 - image compression, 608-618
 - lossless compression mode, 616
 - modes of operation, 608
 - sequential DCT-based algorithm, 609
 - Web sites, 627
- JPEG. *See* Joint photographic experts group (JPEG)
- Jumbo Payload option
 - IPv6, 65-67
- K**
- Kahn, Bob, 6
- Kendalls' notation, 196
- L**
- Label
 - MPLS, 524, 530-531
- Label distribution
 - MPLS, 532-533
- Label format
 - MPLS, 528
- Label merging
 - MPLS, 524
- Label placement
 - MPLS, 528
- Label stack
 - MPLS, 524, 529-530
- Label stacking
 - MPLS, 526-528
- Label swap
 - MPLS, 524
- Label swapping
 - MPLS, 524
- Label switched hop
 - MPLS, 524
- Label switched path (LSP)
 - MPLS, 524, 530-531
- Label switched router (LSR)
 - MPLS, 524
- Label switched router operation, 523-524
- LAN. *See* Local area network (LAN)
- LAPB (Link Access Protocol-Balanced), 81-83
 - control protocol, 86
 - core formats, 87
 - core protocol, 84-86
 - user data transfer, 86-88
- LAPF (Link Access Procedure for Frame Mode Bearer Services), 84
- Latency/speed effects
 - ATM, 357
- Layered protocol, 27-45
- Leaf
 - graph, 405
- Leaky bucket algorithm, 375, 376
- Least-cost routing algorithms
 - example, 411
- Length
 - type 3/4 AAL, 114
 - type 5 AAL, 116
- Length indication
 - SAR PDU, 115
- Length/type

- ethernet, 127
- License-free operation
 - WL, 147
- Limited transmit
 - window management, 338-340
- Line-oriented browser, 7
- Link Access Procedure for Frame Mode Bearer Services, 84
- Link Access Protocol-Balanced. *See* LAPB
- Link control mechanisms, 279-288
- Link costs
 - OSPI, 437-438
- Link-level flow control, 275-299
 - exercise problems related to, 300-301
- Link-state protocol, 433-441
- Link-state routing, 433-434
- LINX, 7
- LLC. *See* Logical link control (LLC)
- Local area network (LAN), 121-122
 - emulation
 - AAL, 108
 - hubs and switches, 130
 - trends, 13
- Logical link control (LLC)
 - data
 - ethernet, 127
 - level, 148
 - WL, 149-151
- London Internet Exchange (LINX), 7
- Long-haul circuit-switching telecommunication
 - basic operation, 74
- Long memory process, 172
- Long-range dependence
 - self-similar traffic, 229-230
- Long term
 - ATM, 367
- Loop, 402
- Looping
 - interior routing, 424
- Lossless
 - JPEG, 608
- Lossless compression, 563-587
 - exercise problems related to, 588-589
 - JPEG, 611
 - Web site, 588
- Lossless mode
 - JPEG, 614-616
- Lossy compression, 591-625

exercise problems related to, 627

- Lost calls cleared, 210
- Lost calls delayed, 210
- Lost calls held, 211

LSP

- MPLS, 524, 530-531

LSR

- MPLS, 523-524

LZ77 algorithm, 582-584

LZ78 algorithms, 584-587

LZW algorithms, 584-587

LZW example, 586

M

MAC layer

- WL, 149

Macroblocks

- MPEG, 621

Management agent

- ISA, 474

Management control plane

- ATM, 93

Marker

- DS, 497

Marking

- DS, 493

Matrix representation

- wavelet compression, 602-605

MaxCTD

- ATM forum, 364-365

Maximize reliability

- link cost, 437

Maximize throughput

- link cost, 437

Maximum burst size (MBS)

- ATM, 363-364

Maximum cell transfer delay (maxCTD)

- ATM forum, 364-365

Maximum packet sizes, 39-40

MBS

- ATM, 363-364

MCR, 363-364, 381

MDCR

- ATM, 366

Mean value, 165

Medium access control (MAC)

- layer
 - WL, 149

Merge point

- MPLS, 524

Message identifier

- type 3/4 SAR PDU, 115

Metasignaling channel, 97

Meter

- DS, 497

Metering

DS, 493

M flag

- fragment header, 67

Minimize delay

- link cost, 438

Minimize monetary cost

- link cost, 437

Minimum cell rate (MCR)

- ABR, 381
- ATM, 363-364

Minimum desired cell rate (MDCR)

- ATM, 366

Minimum path distance, 409

Minimum path length, 410

Mixed configuration

- ethernet, 135

Mixer

- RTP, 537

MMR code, 572-573

Model parameters

- estimating, 211-214

Modified Huffman code, 568-569

Modified modified READ (MMR) code, 572-573

Modified READ (MR)

- code, 569-572
- table, 572

MOSPF, 458-461

Mother wavelet, 600

Motion compensation

- MPEG, 621-623

Moving picture experts group (MPEG), 619-626

- block diagram, 620
- standards, 624-625
- video compression, 619-625
- Web sites, 627

MPEG. *See* Moving picture experts group (MPEG)

MPLS. *See* Multiprotocol label switching (MPLS)

MPLS. *See* Multiprotocol label switching (MPLS)

MPOA

- AAL, 108

MR

- code, 569-572

Multicast, 443-464

- addresses, 450
- exercise problems related to, 465-466
- IPv6 addresses, 65
- routing protocols, 20
- transmission example, 454

Multicast extensions to open shortest path first (MOSPF), 458-461

Multicasting

- requirements, 453-456
- strategies
 - traffic generated, 453

Multimedia

- multicasting, 451

Multiple random variables, 168-169

Multiple unicast strategy

- multicasting, 452-454

Multiprotocol encapsulation over ATM (MPOA)

- AAL, 108

Multiprotocol label switching (MPLS), 521-533

- domain, 524
- edge node, 524
- egress node, 524
- ingress node, 524
- label, 524
- node, 524
- operation, 523-526
- Web sites, 545

Multiprotocol support

- MPLS, 523

Multiresolution analysis, 600

Multiresolution format

- JPEG 2000, 617

Multiserver problem

- examples, 203-205

Multiserver queues, 193, 199-200

Mutually exclusive, 160

N

National Science Foundation (NSF), 6

Negatively correlated, 169

Neighbor acquisition

- BGP, 445

Neighbor reachability

- BGP, 446

Network

- configuration, 421
- OSI, 37

Network access layer

- communication task, 29

Network addresses, 55

Network contribution

- ATM, 359-361

Network control level, 57

Network fundamentals, 21-22

Networking history, 4-13

Networking links

- Web sites, 44

Network interface

- flow control, 278

Network-network interface, 98

- Network reachability
 - BGP, 446
- Network response
 - congestion control, 270
- Network-to-network application
 - VPC, 368
- New York's regional network
 - NYSERnet, 7
- Next-generation IP. *See* IPv6
- Next header
 - fragment header, 67
 - hop-by-hop options header, 65
 - IPv6 header, 62
 - routing header, 68
- Noah effect, 235
- Nodes, 402. *See also* Vertices
 - FC, 141
- Nonblocking socket calls, 665-669
- Non-real-time variable bit rate (nrt-VBR)
 - ATM, 105
 - ATM attributes, 361
- Normal
 - link cost, 437
- Normal distribution, 167-168
- Normal probability density, 167
- Nrt-VBR
 - ATM, 105, 361
- NSF, 6
- NSFNET, 6
- Null suppression
 - data compression, 564-565
- Number of nodes
 - WL, 147
- O**
- OAM (operation and maintenance) cells
 - ATM, 360
- One-dimensional compression
 - Haar wavelets, 601
- One-dimensional DCT, 592-597
- Open shortest path first protocol (OSPF), 56, 433-440
 - packet format, 440-441
 - packet header, 440
 - Web site, 441
- Open Systems Interconnection (OSI)
 - layers, 37
 - protocol model, 19, 27, 36-37
- Operation and maintenance cells
 - ATM, 360
- Options
 - hop-by-hop options header, 65
 - IP field, 52
 - TCP field, 48
- Option type field
 - IPv6, 65-67
- Order
 - graphs, 402
- OSI. *See* Open Systems Interconnection (OSI)
- OSPF. *See* Open shortest path first protocol (OSPF)
- Outcome, 160
- Output
 - sample netstat, 642
- Outward data dissemination, 50
- P**
- Packet, 253
- Packet discard
 - ISA, 473
- Packet loss, 17
 - ISA, 472
- Packet Radio, 6
- Packet scheduler
 - ISA, 475
- Packet switching, 19
- Packet-switching network (PSN), 73-81
 - advantages, 75
 - application, 209-210
 - basic operation, 74
 - congestion control, 80, 264
 - datagram approach, 76
 - digraph, 409
 - failure, 80
 - interior routing protocols, 420
 - routing, 80
 - technique, 77-80
 - use, 75
 - virtual circuit approach, 79
 - virtual circuit service, 81
 - X.25, 80-82
- Packet-switching technology and protocols, 5
- Pad
 - ethernet, 127
- Padding
 - IP field, 52
- Parallel edges, 402
- Parameter a
 - flow control, 291-293
- Parent vertex, 405
- Partial packet discard
 - TCP vs. ATM, 346-347
- Path, 402
- Path distances
 - graphs, 404
- Path lengths
 - graphs, 404
- Path-vector protocols, 443-450
- Path-vector routing, 444-445
- Payload length
 - IPv6 header, 62
- Payload type field
 - ATM, 99
 - coding, 99
- PCF
 - WL, 149
- PCR. *See* Peak cell rate (PCR)
- PDU, 34-35, 109-111
- Peak cell rate (PCR), 362
 - ABR, 381
 - algorithm
 - VPC, 372-373
- Peak rate
 - throughput characteristics, 155
- Peak-to-peak cell delay variation
 - ATM forum, 364-365
- Peer layers, 28
- Pel, 568
- Performance modeling and estimation, 22
- Performance Systems International, 7
- Per-hop behavior (PHB)
 - DS, 493, 498-500
- Periodogram
 - self-similar traffic, 243
- PHB
 - DS, 493, 498-500
- Physical
 - OSI, 37
- Physical layer
 - communication task, 29
- Physical layer specification, 21
- Picture element, 568
- PIM, 461-464
- Pixel, 568
- Point coordination function (PCF)
 - WL, 149
- Poisoned reverse, 431
- Poisson counting process, 176
- Poisson distribution, 166-167
- Poisson increment process, 176-177
- Policing
 - GFR mechanism, 392
- Ports, 641-642
- Positively correlated, 169
- Power spectral density, 173
- Power spectrum. *See* Spectral density

- Power workgroups, 14, 123
- Practical performance, 247-259
- Preamble
 - ethernet, 126
- Prediction
 - MPEG, 621, 623
- Prediction modes
 - MPEG, 623
- Presentation
 - OSI, 37
- Privacy
 - WL, 149
- Probability, 159-164
 - classical definition, 162
 - common set of axioms, 160
 - exercise problems related to, 179-181
 - functions, 167
 - relative frequency definition, 162
 - Web site, 179
- Processor sharing (PS)
 - ISA, 479-480
- Progressive DCT-based
 - JPEG, 608
- Progressive DCT-based mode
 - JPEG, 614
- Protocol, 27-45
 - exercise problems related to, 44-45
 - IP field, 52
 - key features, 28
- Protocol architecture
 - need for, 27-28
 - TCP vs. ATM, 341
- Protocol data unit (PDU), 109-111
 - AAL, 109
 - TCP/IP architecture, 34-35
- Protocol fundamentals, 21-22
- Protocol independent multicast (PIM), 461-464
- PS
 - ISA, 479-480
- PSINet, 7
- PSN. *See* Packet-switching network (PSN)
- Public network infrastructure, 12
- Pure arithmetic coding, 576-579
 - example, 578
- Push function flag, 48-49
- Q**
- Quality of service (QoS), 13-18, 96-97
 - ATM attributes, 361
 - eligibility test mechanism
 - GFR, 393-395
- Internet, 16-18
- IP networks, 23
 - parameters
 - ATM attributes, 361
 - ATM forum, 364-365
 - RTCP, 539
 - support
 - exercise problems related to, 545-546
 - protocols, 507-544
- Quantization
 - sequential DCT-based mode, 609-610
- Queues
 - data network, 255
 - multiserver vs. multiple single-server, 194
 - networks, 206-210
 - parameters, 190
 - priorities, 205-206
 - service, 58
 - switch or router
 - input and output, 255
 - tandem, 208
- Queueing
 - analysis, 156, 183-214
 - assumptions, 196
 - behavior, 184-188
 - exercise problems related to, 215-218
 - discipline, 56, 477-485
 - exercise problems related to, 502-503
 - ISA, 473
 - ISA implementation, 477-485
 - models, 189-197
 - characteristics, 191-193
 - process
 - example, 192
 - relationships, 194-197
 - system
 - structure and parameters, 190
 - Web site, 215
- R**
- Raj Jain's home page
 - Web site for, 352
- Random access
 - JPEG 2000, 617
 - MPEG, 621
- Random bit errors
 - HEC performance
 - impact, 103
- Random early detection (RED)
 - algorithm, 487-491
 - design goals, 486-487
 - exercise problems related to, 502-503
 - ISA, 485-491
 - Random variables, 164-165
 - exercise problems related to, 179-181
 - Rate allocator
 - JPEG 2000, 619
 - Rate based
 - explicit congestion, 262
 - READ
 - code, 569-572
 - Real-time applications, 50
 - Real-time communication requirements, 505-506
 - Real-time traffic, 503-506
 - characteristics, 503-505
 - Real-time transport protocol (RTP), 20, 533-545
 - concepts, 536
 - data transfer protocol, 535-536
 - fixed header, 537-539
 - protocol architecture, 534-536
 - Web sites, 545
 - Real-time transport protocol (RTP) control protocol (RTCP), 539-544
 - formats, 541
 - Real-time variable bit rate (rt-VBR)
 - ATM, 105
 - ATM attributes, 361
 - Real-time workgroups
 - multicasting, 451
 - Reassembly
 - IP, 52-54
 - Reassociation
 - WL, 149
 - Receiver action
 - TCP/IP operation, 43
 - Receiver-initiated reservation
 - RSVP, 511-512
 - Receiver report
 - RTCP, 543
 - Recursion
 - cantor set to five levels, 222
 - RED. *See* Random early detection (RED)
 - Region of interest (ROI)
 - JPEG 2000, 617
 - Regulation
 - concepts, 630-631
 - Relative element address designate (READ)
 - code, 569-572
 - Relative frequency approach, 162

- Relative rate marking
 - ABR, 384
- Reliability, 40
- Request-response, 50
- Res
 - fragment header, 67
- Reservation attribute
 - RSVP, 517
- Reservation protocol
 - ISA, 474
- Reserved
 - fragment header, 67
 - TCP field, 48
- Resource management (RM)
 - cell fields
 - initial values, 386
 - cell format
 - ABR, 384-386
 - cells, 382-383
 - virtual paths
 - ATM, 368-369
- Resource reservation, 508-521
- Resource Reservation Protocol.
 - See RSVP
- Response times
 - projected *versus* actual, 189
- Retransmission strategy,
 - 315-316
 - TCP flow control, 315
- Retransmission timer management (RTO)
 - exponential RTO backoff,
 - 328-330
 - Jacobson's algorithm,
 - 326-329
 - TCP, 326-330
 - variance estimation, 326-329
- Retransmit policy
 - TCP, 321
- RFC 793, 47, 49
- RFC 1122, 47
- RFC 1349, 56
- RFC 1812, 56, 58
- RFC 2205
 - RSVP, 510
- RFC 2460
 - guidelines, 62
- RFC publication, 631-633
- RFC types, 634-635
- RIP, 426-432
- RM. See Resource management (RM)
- ROI
 - JPEG 2000, 617
- Round-trip propagation time
 - ATM, 366
- Round-trip time (RTT),
 - 334-336
 - Karn's algorithm, 330
- variance estimation, 326-328
- Router, 38, 39-40
 - configuration, 421
- Router action
 - TCP/IP operation, 42
- Router Alert option
 - IPv6, 65-67
- Route recording
 - IPv4 option, 59
- Route selection, 56
 - ISA, 475
 - MPLS, 531-532
- Routine level
 - precedence subfield, 57-58
- Routing algorithm
 - ISA, 473
- Routing function, 420-424
- Routing header, 68
 - IPv6 extension header, 60
- Routing Information Protocol (RIP), 426-432
 - limitations, 432
 - packet format, 431-432
- Routing metric, 56
- Routing philosophies
 - comparison, 434
- Routing protocol
 - ISA, 474
- Routing tables, 422
- Routing type
 - routing header, 68
- R/S plot
 - self-similar traffic, 242
- RSVP (Resource Reservation Protocol), 20-21, 508-521
 - filtering, 514-517
 - goals and characteristics,
 - 510-512
 - host model, 520
 - operation, 514-519
 - protocol mechanisms,
 - 520-521
 - reservation styles, 517
 - Web sites, 545
 - working group
 - Web sites, 545
- RTCP, 539-544
- RTO. See Retransmission timer management (RTO)
- RTP. See Real-time transport protocol (RTP)
- RTT. See Round-trip time (RTT)
- Rt-VBR
 - ATM, 105, 361
- Run-length encoding techniques, 564-567

Run-time program control, 665-669

S

- SA
 - ethernet, 127
- Sample space, 160
- Sampling, 211-213
- Sampling errors, 213-214
- SAR
 - PDU, 108, 111
- SATNET, 6
- Scheduling
 - GFR mechanism, 392-393
- SCR, 362-363
- SCSI
 - FC, 143
- SDES
 - RTCP, 543
- SDH (synchronous digital hierarchy), 21, 360
- Second moment, 165
- Second-order statistics, 171
- Security
 - IPv4 option, 59
- Segmentation, 40
- Segmentation and reassembly (SAR)
 - PDU, 111
 - sublayer
 - AAL, 108
- Segments left
 - routing header, 68
- Segment type
 - type 3/4 SAR PDU, 115
- Selective cell discard
 - UPC function, 378
- Selective drop
 - rule, 348
- Selective-reject ARQ, 295
 - flow control, 288
- Self-similar data traffic,
 - 223-231
 - examples, 232-237
 - modeling and estimation,
 - 241-244
- Self-similarity, 220-223
 - performance implications,
 - 237-241, 239
- Self-similar storage model, 240
- Self-similar time series, 221
- Self-similar traffic, 219-244
 - exercise problems related to,
 - 245
 - models
 - applicability, 240-241
 - Web site, 245
- Semantics
 - protocol, 28

- Semipermanent VCC, 97-98
- Semipermanent virtual channel
 - connections, 96
- Sender action
 - TCP/IP operation, 41-43
- Sender report
 - RTCP, 542
- Sender selection
 - RSVP, 517
- Send policy
 - TCP, 320
- Separate queue
 - ABR, 388
- Sequence number
 - TCP, 34
 - TCP field, 48
 - type 3/4 SAR PDU, 115
- Sequential DCT-based
 - JPEG, 608
- Sequential DCT-based mode
 - JPEG, 609-613
- Server program
 - passively await connection,
 - 663-665
 - passively awaiting connection,
 - 658-661
- Service access point, 109
- Service area
 - WL, 147
- Service level agreement
 - DS, 493
- Session
 - OSI, 37
 - RSVP, 513
- SE style
 - RSVP, 518
- SFD
 - ethernet, 127
- Shaper
 - DS, 497
- Shaping
 - DS, 493
- Shared-explicit (SE) style
 - RSVP, 518
- Shielded twisted pair (STP)
 - ethernet, 133
- Shortest-path distance
 - BFS algorithm, 408
- Shortest path length determination, 409-415
- Short memory process, 172
- Signaling system number 7
 - self-similar traffic example,
 - 236
- Signaling system number 8, 20
- Simple graph, 402
- Simple Mail Transfer Protocol (SMTP), 35
- Simple path, 402

- Single FIFO queue
 - ABR, 388
- Single-server model
 - examples, 203
- Single-server queue, 189-190.
 - 197-199
 - formulas, 197
 - mean number, 198
 - mean residence time, 198
- Single-server queues
 - priority categories, 205
- Size
 - graphs, 402
- Sliding-window ARQ
 - flow control, 295-296
- Sliding-window techniques
 - flow control, 282-285
- Slow start
 - illustration, 335
 - window management,
 - 331-332
- Small computer system interface (SCSI)
 - FC, 143
- SMTP, 35
- Socket, 639-677
 - address, 644-645
 - closing, 654-656
 - connecting, 647-648
 - creation, 644
 - descriptors, 641-642
 - elements, 644-660
 - sending and receiving messages,
 - 653-654
 - versions, 640-641
- Soft state
 - RSVP, 512
- SONET (synchronous optical network), 21
- Source address
 - IP field, 52
 - IPv6 header, 62
- Source address (SA)
 - ethernet, 127
- Source description (SDES)
 - RTCP, 543
- Source port
 - TCP field, 48
- Source routing
 - IPv4 option, 59
- Source traffic descriptor
 - ATM, 362-364
- Spanning tree, 405-406
 - multicast group, 456
- Spectral density, 172-173
 - self-similar traffic, 230
- Spectral selection
 - progressive DCT-based
 - compression, 614

- Speed of service, 13-18
- Split horizon rule, 431
- Spurgeon's ethernet web site
 - Web sites, 152
- Standard deviation, 165
- Standardization process,
 - 632-637
- Standards
 - concepts, 630-631
- Start frame delimiter (SFD)
 - ethernet, 127
- Stationary random process, 173
- Stationary stochastic processes,
 - 172
- Statistical multiplexing
 - VPC, 369
- Statistical parameters, 213
- Stochastic process. See Random process
- Stochastic processes,
 - 170-179
 - exercise problems related to,
 - 179-181
- Stop and wait
 - flow control, 279-282
- Stop-and-wait ARQ
 - flow control, 288-290
 - with errors, 290
- Storage model, 239
- Storage network industry
 - association
 - Web sites, 152
- Store-and-forward switch
 - ethernet, 131
- STP
 - ethernet, 133
- Stream, 660-665
- String-matching algorithms,
 - 581-587
- Subgraph, 405-406
- Subnetwork, 32, 38, 39
 - ethernet, 132
 - service, 56
- Successive approximation
 - progressive DCT-based
 - compression, 614
- Sustainable cell rate algorithm
 - VPC, 376-377
- Sustainable cell rate (SCR),
 - 362-363
- Switched virtual channel
 - connections, 96
- Switching network, 77
- Symbol blocking
 - Huffman code, 558-559
- Synchronous digital hierarchy,
 - 21, 360
- Synchronous optical network,
 - 21

- Syntax protocol, 28
- T**
- Tagging
 - GFR mechanism, 392
- TCP, 30, 47-51
 - congestion control, 322-340
 - context, 325
 - congestion control measures implementation, 326
 - credit allocation mechanism example, 311
 - exercise problems related to, 69-70
 - flow
 - context, 325
 - implementation policy options, 320
 - and IP, 19
 - operation, 32-35
 - performance vs. ATM, 340-351
 - segment, 34
 - segment pacing, 324
 - traffic
 - self-similar traffic example, 236
 - traffic control, 309-382
 - exercise problems related to, 353-354
 - user datagram protocol, 50-51
 - window size, 313
 - TCP/IC concepts, 33
 - TCP/IP, 3
 - applications, 35-36
 - architecture
 - Protocol Data Units, 34
 - example
 - configuration, 40
 - layers, 29
 - networks, 18-21
 - operation, 41-43
 - Protocol Architecture, 28
 - vs. OSI, 38
 - suite, 27-45
 - exercise problems related to, 44-45
 - Technical specification
 - Internet standards, 634
 - Teleconferencing
 - multicasting, 451
 - TELNET, 5, 35-36
 - traffic
 - self-similar traffic example, 236
 - Terminal equipment, 100
 - Three-symbol sequence
 - probability intervals, 576
 - Throughput, 17
 - ISA, 472
 - WL, 147
 - Throughput characteristics, 155
 - Time average, 178
 - Time reassembly
 - CBR cells, 358
 - Timestamp, 49-50
 - IPv4 option, 59
 - Time to live
 - IP field, 52
 - processing
 - MPLS, 528
 - Timing
 - protocol, 28
 - Token bucket, 379
 - Tomlinson, Ray, 5
 - Topologies
 - physical media and topologies, 143
 - TOS. *See* Type of service (TOS)
 - Total length
 - IP field, 52
 - Total probability
 - illustration, 164
 - Traffic class, 62-63
 - IPv6 header, 62
 - Traffic conditioning
 - DS, 493
 - Traffic conditioning agreement (TCA)
 - DS, 493
 - Traffic conditioning function
 - elements, 497
 - Traffic control
 - ATM, 367-379
 - Traffic descriptors
 - ATM attributes, 361
 - Traffic engineering
 - MPLS, 522
 - Traffic management
 - congestion control, 262-264
 - Traffic parameters
 - ATM attributes, 362
 - VCC, 96
 - Traffic rate management
 - congestion control, 266-267
 - Traffic shaping
 - CGRA algorithm, 378-379
 - Traffic streams
 - partitioning and merging, 207
 - Transfer delay
 - delay characteristics, 156
 - Transition dependencies
 - Huffman code, 559-560
 - Translator
 - RTP, 537

- Transmission Control Protocol. *See* TCP
- Transmission media
 - physical media and topologies, 143
- Transmission robustness and security
 - WL, 147
- Transport
 - OSI, 37
- Transport layer
 - communication task, 30
- Tree-based representation
 - LZW, 587
- Trees
 - graphs, 404
- Trial, 162
- Two-dimensional compression
 - Haar wavelets, 606
- Two-dimensional DCT,
 - 597-598
- Two-level star topology
 - ethernet, 129
- Type of service (TOS), 437-439
 - concept, 437
 - field, 56
 - default values, 57
 - IP, 56-59
 - IP field, 51
 - routing, 56-57
- Typical premises network
 - configuration, 133
- U**
- UBR. *See* Unspecified bit rate (UBR)
- UDP, 16, 30
- Uncorrelated, 169
- UNI. *See* User-network interface (UNI)
- Unicast
 - IPv6 addresses, 65
- Uniform resource location (URL), 7
- Union, 160
- UNIX-like operating systems, 640
- Unshielded twisted pair (UTP)
 - ethernet, 133
- Unspecified bit rate (UBR),
 - 21
 - ATM, 105-106
 - ATM attributes, 361
 - TCP vs. ATM, 343-346
- UPC
 - VPC, 371-378
- Urgent data signaling, 49
- Urgent function flag, 48-49
- Urgent pointer

- TCP field, 48
- URL, 7
- Usage monitoring, 96
- Usage parameter control (UPC)
 - actions, 377
 - VPC, 371-378
- USENET newsgroups, 25
- User data, 82
- User Datagram Protocol (UDP), 16, 30
- User data transfer, 86-88
- User-network interface (UNI),
 - 10, 98, 100
 - ATM, 359, 362
 - cell arrival, 375
- User plane
 - ATM, 93
- User response
 - congestion control, 270
- User-to-network application
 - VPC, 368
- User-to-network signaling
 - virtual channel, 97
- User-to-user application
 - VPC, 368
- User-to-user signaling virtual
 - channel, 97
- UTP
 - ethernet, 133
- UUNET Technologies, 7
- V**
- Variability
 - throughput characteristics, 155
- Variable-bit-rate (VBR)
 - video
 - self-similar traffic example, 237
 - voice and video
 - AAL, 108
- Variance, 165
- Variance-time plot
 - self-similar data traffic, 241-242
- VBR, 108, 237
- VCC, 93, 368-370
- VCI. *See* Virtual channel identifier (VCI)
- Venn diagrams, 161
- Version
 - IP field, 51
 - IPv6 header, 62
- Vertices, 402
 - distance between, 403
- Very-large-scale integration (VLSI), 636
- Video compression algorithm
 - MPEG, 620-621
- Virtual channel
 - definition, 96
- Virtual channel connection (VCC), 93, 368-370
 - configuration, 369
- Virtual channel identifier (VCI)
 - ATM, 99
 - definition, 96
 - restriction
 - VPC, 97
- Virtual channel link
 - definition, 96
- Virtual circuit, 78, 85
 - use, 81
- Virtual path
 - advantages, 94
 - call establishment, 95
 - definition, 96
- Virtual path concept, 93
- Virtual path connection (VPC),
 - 368-370
 - characteristics, 97
 - configuration, 369
 - definition, 96
 - establishment
 - customer controlled, 98
 - network controlled, 98
 - semipermanent, 98
- Virtual path identifier (VPI)
 - ATM, 99
 - definition, 96
- Virtual path link
 - definition, 96
- Virtual private network (VPN)
 - support
 - MPLS, 523
- Virtual scheduling algorithm,
 - 374
 - VPC, 372-373
- VLSI, 636
- VPC. *See* Virtual path connection (VPC)
- VPI, 96, 99
- VPN support
 - MPLS, 523
- W**
- WAN, 12
- Wavelet
 - Web sites, 627
- Wavelet compression, 598-607
- Wavelets, 599-601
- Web resources, 23-25
- Weighted digraph, 403-404
- Weighted fair queuing (WFQ)
 - ISA, 483-485
- Weighted graph, 403-404
- WFQ
 - ISA, 483-485
- WF style
 - RSVP, 517
- Whittle's estimator
 - self-similar traffic, 242-243
- Wide area network (WAN), 12
- Wide sense stationary, 172
- Wild-card-filter (WF) style
 - RSVP, 517
- Wild-card multicast receiver,
 - 459-461
- Window
 - TCP field, 48
- Window-limited mode
 - TCP vs. ATM, 350-351
- Window management
 - TCP, 331-340
- Window scale factor, 49
- Window scale parameter
 - effect, 314
- Windows console application
 - remote execution, 669-677
- Window size
 - effect on performance, 313-315
- Wireless ethernet compatibility
 - alliance
 - Web sites, 152
- Wireless LAN, 121-122,
 - 144-151
 - alliance
 - Web sites, 152
 - applications, 145-146
 - characteristics, 122
 - example single-cell configuration, 146
 - IEEE 201.11 architecture, 147
 - IEEE 802.11 physical layer, 150-151
 - IEEE 802.11 protocol layers, 149-150
 - IEEE 802.11 services, 149
 - requirements, 146-147
- World wide web (WWW), 7-8
 - self-similar traffic
 - example, 235-236
- X**
- X.25, 88
- X.25 protocol control information, 82, 84
- Z**
- Zig-zag-scan, 611
- Zip compression scheme, 581



High Speed Networks and Internets

Performance and Quality of Service

Second Edition

William Stallings

William Stallings offers the most comprehensive technical book to address a wide range of design issues of high-speed TCP/IP and ATM networks in print to date.

In this second edition, this award-winning and best-selling author steps up to the leading edge of integrated coverage of key issues in the design of high-speed TCP/IP and ATM networks to include the following topics:

- Unified coverage of integrated and differentiated services.
- Up-to-date and comprehensive coverage of TCP performance.
- Thorough coverage of next-generation Internet protocols including (RSVP), (MPLS), (RTP), and the use of Ipv6.
- Unified treatment of congestion in data networks; packet-switching, frame relay, ATM networks, and IP-based internets.

This edition is manufactured in India and is authorized for sale only in India, Bangladesh, Bhutan, Pakistan, Nepal, Sri Lanka and the Maldives.

ISBN 978-81-775-8569-8



www.pearsoned.co.in