Index

ABR *see* Available bit rate
Access:
  edge Diffserv, 230–3, 248–9
  passive monitoring, 337, 340
  quality of service, 183–9
Active network monitoring:
  CAC, 328
  deployment considerations, 364–71
  duration, 355–7
  frequency, 349, 351–7
  jitter, 360–2
  measurement metrics, 349, 358–64
  packet size, 350–1
  sampling frequency, 349, 351–5
  SLA, 335–6, 348–71
  testing, 348–50, 354–7
  topologies, 365–9
  traffic test streams, 348–50
Active queue management (AQM), 132–6
Admission control *see* Capacity admission control
AF *see* Assured forwarding
Aggregate Diffserv-based classification, 319
Aggregate shaping, 139–40, 229–30
Aggregation RSVP, 320–5
Allocation models, 404–5
Any-to-any VPNs, 17–18
Application end-system losses, 11, 36, 54
Application engineering, 198–9
Application isolation, 242
Application signaling interaction, 314–16
Application SLA requirements, 24–76
  data applications, 58–75
  interactive data applications, 70–4
  video, 38–58
  VoIP, 26–37
AQM *see* Active queue management
Architectures:
  IP QOS, 141–83
  IPv6 QOS, 170–1
  MPLS QOS, 171–83
  quality of service, 141–83
  see also Diffserv; Intserv
Assured forwarding (AF), 156–8, 240
Asymmetry factors, 393
Asynchronous transfer mode (ATM), 190–4
Audio streams, 57
Autonomous systems, 378
Availability considerations, 20–2, 363–4
Available bit rate (ABR), 191
Average delay, 360
Average queue depths, 345

Backbone Diffserv deployment, 210, 249–67
  classes, 253–6, 258–61
  design, 256–63
  marking, 263–7
  meta-language, 257–8
Backbone propagation delay, 216
Bandwidth:
  active monitoring, 363
  backbone Diffserv, 251–3, 255
  CAC, 277–82, 292–302
  deploying Diffserv, 210–11, 251–3, 255

Bandwidth (*Contd*)
managers, 292–302
over-provisioning, 376–7, 382–8
scheduling, 112–28
sizing, 412–13
SLA metrics, 12–18
traffic engineering, 376–7, 382–8, 393, 412–13
video conferencing, 57–8
Batch sampling, 353
Bearer classes, 243
Best-effort service, 89–90, 307
BGP *see* Border Gateway Protocol
Bidirectional "B" frames, 39
Bidirectional reservations, 60, 284, 327
Bit rates, 191–2
Border Gateway Protocol (BGP), 379–80
Broadcast Video Services, 41–3
BTC *see* Bulk Transport Capacity
Bucket mechanisms, 101–8, 138
Buffers, 128–9, 347
Bulk Transport Capacity (BTC), 13
Business data throughput-optimized class, 262
Bytes, 273, 340–5

CAC *see* Capacity admission control
Call admission control, 276–7
Call manager-bandwidth manager interaction, 297–8
Call-sequence of events, 298–302, 314–16
Capacity: SLA metrics, 12–18
Capacity admission control (CAC), 275–334
bandwidth managers, 292–302
information requirements, 285–6
Intserv over Diffserv, 316–20, 323–4
Intserv/RSVP, 303–26
MBAC, 328–9
measurements-based algorithms, 286, 288–9
NSIS, 283, 326–8
parameterized algorithms, 286–7
resource managers, 292–302
RSVP, 282–3, 303–26
signaling, 326–8
taxonomy, 282–5
topology-awareness, 283, 290–302
usefulness, 277–82
Capacity planning, 182, 255, 259–60
see also Core capacity planning
CBR *see* Constant bit rate
Cell loss ratio (CLR) 2 QOS, 191
Characteristics of VoIP codecs, 26–9
Churn, 324–5
CIF *see* Common interchange format
Classes:
backbone Diffserv, 253–6, 258–61
class-capacity, 12
class selector PHB, 158–9, 174–5
class of service, 88–9
edge Diffserv, 213–18, 221–5, 233–9, 241–4
Classification:
active monitoring, 357–8
backbone Diffserv, 257–8
Diffserv, 147–8, 257–8
Intserv, 303
passive monitoring, 338–9
quality of service toolsets, 93, 94–9
Client-side processing delays, 71
Clock synchronization, 370–1
CLR *see* Cell loss ratio
Codecs, 26–9, 57
Codepoint assignment and management, 152–4
Code of Practice: MPEG, 49–51
Color-aware policers, 108–11
Color markers, 102–8, 239, 339–42
Committed burst, 194
Committed information rate, 194
Common interchange format (CIF), 55
Complementary technologies to QOS, 197–8

Complex classification, 95–6, 357
Component availability, 20–1
Compression, 28
Conditioning, 78–9, 147–8, 340
Congestion:
  backbone Diffserv, 255
  Diffserv, 160–5, 255
  packet loss, 9
  TCP, 61–7
  video streaming, 48
  VoIP, 34–5
Connectivity, 20–1, 363–4
Constant bit rate (CBR), 25, 191
Constraint based path computation, 398–9
Control classes (Ctrl):
  backbone Diffserv, 254, 256, 260
  edge Diffserv, 213, 218, 223–4
Controlled load service, 307
Controlling tunneling, 403
Control planes, 93–4, 284–5, 325
Convergence, 197
Core capacity planning, 375–89
  analysis, 388–9
  bandwidth over-provisioning, 376–7, 382–8
  methodology, 376–7
  network topology overlaying, 388–9
  over-provisioning factors, 376–7, 382–8
  simulations, 377, 385–6, 388–9
  traffic demand matrices, 376, 377–82
Core Diffserv deployment, 210, 249–67
  see also Backbone Diffserv deployment
Core links, 338, 340
Core meshes, 409–10, 411
Core traffic matrices, 347–8
Ctrl *see* Control classes
Customer-facing classes, 213–18, 221–5

Data application SLA requirements, 58–75
Data planes, 92–141, 284–5, 325
De-aggregation routers, 321–2
Decoder delay, 43
Decryption delay, 43
Deep packet inspection, 96
Default PHB, 158
Deficit Round Robin (DRR), 121–3
De-jitter buffers, 31–3, 42
Delay:
  active monitoring, 358–62
  application SLA requirements, 24–5
  budget allocation, 215–17
  core capacity planning, 385–8
  interactive data applications, 71–2
  scheduling algorithms, 124
  SLA metrics, 4–8
  TCP, 59, 67–9
  video conferencing, 57–8
  video streaming, 40–7
  VoIP, 29–33, 215–17
Demand:
  core capacity planning, 376, 377–82
  traffic engineering, 389–413
  video-on-demand, 43–6, 47
Deploying Diffserv, 209–73
  network backbone, 210, 249–67
  network core, 210, 249–67
  network edge, 210, 211–49
  random early detection, 263, 268–72
  weighted random early detection, 239, 263, 268–72
Deployment:
  active monitoring, 349, 364–71
  MPLS TE, 408–11
  traffic engineering, 391–4
Design: Diffserv, 211, 218–40, 256–63
Differentiated services architecture *see* Diffserv
Diffserv Code Point (DSCP) marking, 149, 151–4, 165–70, 244–5
Diffserv (differentiated services architecture):
  active monitoring, 357–8
  ATM layer 2 QOS, 193–4
  core capacity planning, 387

Diffserv (*Contd*)
data plane QOS mechanisms, 98
deployment, 209–73
meta-language, 218–21, 229–38, 257–8, 264
network backbone, 210, 249–67
network core, 210, 249–67
network edge, 210, 211–49
weighted random early detection, 239, 263, 268–72
design, 211, 218–40, 256–63
explicit congestion notification, 160–5
frame relay layer 2 QOS, 195
Intserv, CAC, 316–20, 323–4
IP multicast, 182
IP QOS architectures, 147–70
MPLS QOS architectures, 173–81
MPLS TE, 404–8
Per-Domain Behaviors, 159–60
Per-Hop Behaviors, 149, 154–9
random early detection, 239, 263, 268–72
service level agreements, 78–9, 211–18, 233–7, 241–2, 253–6
traffic classification and conditioning, 147–8
tunneling models, 165–70, 175–81
Diffserv Field Codepoints Registry (DSCR), 153
Digital Video Broadcasting (DVB), 48
Discard probability, 268, 271
Discrete services, 58
Dropping, 128–37
advanced concepts, 136–7
edge Diffserv design, 222
passive monitoring, 342–6
router QOS implementation, 186
DRR *see* Deficit Round Robin
DS *see* Differentiated services
DSCP *see* Diffserv Code Point
DSCR *see* Diffserv Field Codepoints Registry
DVB *see* Digital Video Broadcasting
Ear-to-mouth delay, 29–30, 215–16
ECMP *see* Equal costs multipath
ECN *see* Explicit congestion notification
ECR *see* Egress committed rates
Edge conditioning classes, 157
Edge Diffserv deployment, 212–44
classes, 213–18, 221–5, 233–9, 241–4
design, 218–40
high-speed design, 218–25, 234–5
low-speed edge design, 225–8
meta-language, 218–21, 229–38
policies, 210
SLA specifications, 212–18
video, 239–40
VoIP, 213, 214–17, 221–3, 232–3, 240, 245–9
Edge keys, 211–12
Edge-to-core mapping, 254, 264–7
EF *see* Expedited forwarding
EFCI *see* Explicit Forward Congestion Indication
Egress committed rates (ECR), 214
Elastic applications' utility functions, 279–80
Embedded agents, 364–5
E model, 23
End-system losses:
packet loss, 11
video streaming, 40, 54
VoIP, 29–30, 36, 215–16
End-system MBAC, 282, 328–9
End-to-end delay, 4, 29–30, 40, 215–16
End-to-end links, 387
End-to-end reservations, 306–7, 387
End-to-end SLAs, 77
Engineered SLAs, 76–8
Equal costs multipath (ECMP), 369–70, 395–6
Ethernet, 196–7
Excess burst, 194
Expedited forwarding (EF), 155–6, 221, 226, 228

EXP inferred PHB selection, 174–5
Explicit congestion notification (ECN), 160–5
Explicit Forward Congestion Indication (EFCI), 164–5
Explicit mapping, 266
Explicit standard class, 260
Exponential weighting constant, 269–70
External agents, 364–5
External traffic demands, 378–9

Failure case optimization, 391–2
Fairness, 119–21, 123–4
Fair queuing, 119–21
Fast IGP convergence, 197
Fast recovery congestion control, 66
Fast reroute technologies, 198
Fast retransmit congestion control, 66
FCFS *see* First-come first served
FEC *see* Forward error correction
FECN *see* Forward explicit congestion notification
FIFO *see* First-in first-out
FILTERSPEC, 311, 312
Finger-to-eye delay, 40
Firewall pinhole configurations, 326
First-come first served (FCFS), 112
First-in first-out (FIFO), 112–13, 125–6, 225–6
Flow:
  bandwidth thresholds, 280
  data plane QOS mechanisms, 94–5
  descriptors, 311
  FLOWSPEC, 311, 312
  statistics aggregation, 379–80
Forecast demand simulations, 377
Forward error correction (FEC), 43, 49–51
Forward explicit congestion notification (FECN), 164–5
Frames:
  delays, 43
  frame-based codecs, 27
  relay, 194–5
  video streaming, 39–40
Frequency of monitoring, 349, 351–7
Full mesh topologies, 366–7

Gaming, 24, 74–6
GCRA (Generic Cell Rate Algorithm), 138
General Internet Signaling Protocol (GIST), 327
Generalized Process Sharing (GPS), 119
Generic Cell Rate Algorithm (GCRA), 138
GIST (General Internet Signaling Protocol), 327
GOP *see* Group of Pictures
GPS (Generalized Process Sharing), 119
Group of Pictures (GOP), 39–40, 48, 56
Guaranteed service, 306–7

HD *see* High definition
Head drop, 131
Hierarchical mesh topologies, 368–9
Hierarchical shaping, 228–30
High definition (HD) format, 55
High percentile delay, 359–60
High-speed design, 218–25, 234–5
History of IP QOS architectures, 141–2
Hopping, 149, 154–9, 174–5, 216, 318–19, 322
Hose models, 17–18
Hub and spoke VPNs, 16–17

ICR (ingress committed rates), 214
IETF (Internet Engineering Task Force), 3–4
"I" frames, 39
IGP *see* Interior gateway routing protocol
Implicit classification, 95
Implicit standard class, 260
In-contract marking, 340–2
In-contract traffic, 271–2
Inelastic application's utility functions, 280–1

Information requirements, 285–6
Ingress committed rates (ICR), 214
Ingress marking, 100
Inner core meshes, 410, 411
Input drops, 347
Integrated services architecture *see* Intserv
Interactive data applications, 70–6
Interactivity of video streaming, 40
Interface FIFO, 125–6
Interior gateway routing protocol (IGP), 295–6, 305, 390, 394–7
Interleaving, 140–1, 226–7
Internal traffic demands, 378–9
Internet Engineering Task Force (IETF), 3–4
Inter-provider SLAs, 77–8
Intra "I" frames, 39
Intserv (integrated services architecture):
  CAC, 303–26
  definitions, 303–4
  Diffserv, 303–4, 316–20, 323–4
  IP multicast, 182–3
  IP QOS architectures, 147
  MPLS QOS architectures, 172–3
  quality of service, 79
  quality of service toolsets, 93
  RSVP, 172–3, 182–3
  service level agreements, 78–9
IP backbone Diffserv, 263
IP flow statistics aggregation, 379–80
IP multicast, 181–3
IP performance metrics (IPPM), 3–4, 349
IPPM (IP performance metrics), 3–4, 349
IP precedence, 144–5, 146
IP quality of service (IP QOS):
  access routers, 183–9
  architectures, 141–83
    Diffserv, 147–70
    history, 141–2
    Integrated Services, 147
    IP precedence, 144–5, 146
    IPv6 QOS, 147, 170–1
    MPLS QOS architectures, 171–83
    multicast, 181–3
    precedence, 144–5, 146
    service types, 142–4, 145–6
  complementary technologies, 197–8
  definitions, 91
  history, 141–2
  IP precedence, 144–5, 146
  IPv6 QOS, 147, 170–1
  MPLS QOS architectures, 171–83
  service types, 142–4, 145–6
IP RSVP, 304
IP security protocols, 327–8
IP traffic engineering, 389–413
IP tunneling, 165–70
IPv6 QOS architectures, 147, 170–1

Jitter:
  active monitoring, 360–2
  SLA metrics, 7–8
  TCP, 69
  video conferencing, 57
  video streaming, 46–7
  VoIP, 31–3

Label inferred PHB selection, 175
Label switch paths (LSP), 380
LAN *see* Local area networks
Latency, 221–2, 234
Layer 1 CAC, 306
Layer 2 CAC, 306
Layer 2 marking, 98
Layer 2 overheads, 13–16
Layer 2 QOS, 98, 189–97
Layer 3 CAC, 283, 327
Lead-times, 393
Leaky buckets, 138
LFI *see* Link fragmentation and interleaving
Link bandwidth, 251–3, 255
Link capacity, 12
Link fragmentation and interleaving (LFI), 140–1, 226–7
Link metrics, 394–5

Link utilization, 385–8
Local area networks (LAN), 306
Logical network topology, 388–9
Losses:
  loss distances, 9, 362
  loss periods, 9, 362
  TCP, 59, 69–70
  video streaming, 47–54
  VoIP, 33–6
Lower effort PDB, 160
Lower layer errors, 9–10, 35, 48–9
Low-speed edge Diffserv design, 225–8
LSP *see* Label switch paths

Maintenance: MPLS TE, 403
Mapping Diffserv, 193–4
Mapping edge-to-core schemes, 264–7
Marketed SLAs versus engineered SLAs, 76–8
Marking:
  backbone Diffserv, 263–7
  color markers, 102–8, 239, 339–42
  Diffserv Code Point, 149, 151–4, 165–70, 244–5
  edge Diffserv, 244–5, 246
  IP QOS architectures, 149, 151–4
  passive monitoring, 339–42
  quality of service toolsets, 93, 99–111
  router QOS implementation, 186
Mark probability denominator, 271
Maximum allocation models, 404–5
Maximum queue thresholds, 268, 270–1
Maximum rate enforcement, 93, 339–40
MBAC *see* Measurement-based admission control
Mean Opinion Score (MOS), 23
Measurement-based admission control (MBAC), 286, 288–9, 328–9
Measurement metrics, 349, 358–64
Measuring equal cost multiple paths, 369–70
Mechanics of data plane QOS, 92–141
Meshes, 16–17, 366–9, 409–11
Message processing, 308–14
Meta-language, 218–21, 229–38, 257–8, 264
Metering, 111
Metrics:
  active monitoring, 349, 358–64
  service level agreements, 3–24
Middleware processing, 45
Minimum delay, 359
Minimum queue thresholds, 268, 270–1
Minimum rate assurance, 93
MLPPP (Multilink Point-to-Point Protocol), 141
Mobility, 327–8
Monitoring *see* Network monitoring
MOS (Mean Opinion Score), 23
Motion Picture Expert Group (MPEG), 38–40, 47, 49–51, 55–6
Mouth-to-ear delay, 29–30, 215–16
MPEG *see* Motion Picture Expert Group
MPLS *see* Multi-protocol label switching
Multicast reservations, 41–2, 181–3, 284, 304
Multi-field classification, 95–6, 357
Multi-level strict priority, 125–6
Multilink Point-to-Point Protocol (MLPPP), 141
Multiple path measurements, 369–70
Multi-protocol label switching (MPLS):
  backbone Diffserv, 265, 267
  EXP fields, 98
  LSP accounting, 380
  QOS architectures, 171–83
  RSVP-TE, 325–6
  traffic engineering, 93–4, 296, 397–413
  tunneling, 175–81
Multi-protocol tunnels, 165, 175–81

Negative acknowledgements, 52
Network address translation, 326

Network asymmetry, 393
Network availability, 20–1, 363–4
Network backbone, 210, 249–67
Network core, 210, 249–67
Network delays, 4–7, 29–30, 41–5, 59, 67–9, 72
Network edge, 210, 211–49
Networked Virtual Environments (NVEs), 74
Network element failures, 10–11, 35–6, 52–3, 278–9
Network engineering, 198–9, 389–90
Networking working case conditions, 278
Network losses, 59, 69–70
Network monitoring, 335–73
  active, 335–6, 348–71
  passive, 335, 336–48
Network routing model, 388–9
Network topology overlaying, 388–9
Network transmission delays, 41, 42, 43, 45
Next generation networks (NGN), 294–302
Next Steps in Signaling *see* NSIS
NGN (Next generation networks), 294–302
Non real-time VBR, 191
NSIS (Next Steps in Signaling), 283, 326–8
NSIS Signaling Layer Protocols (NSLPs), 327
NSIS Transport layer Protocol (NTLP), 327
NVEs *see* Networked Virtual Environments

Objective measures, 23, 24
Ockham's razor, 273
Off-path CAC, 283
One-rate token bucket policers, 101–2
One-way delay, 4, 29–30, 40, 358
On-line gaming, 24, 74–6
Only Path messages, 334
On-path network signaled CAC, 282
Outer core mesh, 409–10
Out-of-contract marking, 340–2
Out-of-contract traffic, 271–2
Over-provisioning factors, 376–7, 382–8

Packet loss, 9–11, 24–5, 33–6, 362
Packet marking, 93, 99–111
Packet numbers, 340–5
Packet re-ordering, 19, 37, 57, 363
Packet size, 350–1
Parameterized algorithms, 286–7
Partial mesh topologies, 367
Passive network monitoring, 339–42
  CAC, 328–9
  classification, 338–9
  core traffic matrices, 347–8
  dropping, 342–6
  per-link statistics, 337–8
  policing, 339–42
  polling, 337, 345
  queuing, 342–6
  SLA, 335, 336–48
  traffic matrices, 347–8
Paths:
  active monitoring, 349
  capacity, 12
  computation, 398–9
  coupling, 282–3
  message processing, 308–14
PathTear messages, 334
PDB *see* Per-Domain Behaviors
Percentile delay, 359–60
Perceptual Evaluation of Speech Quality (PESQ), 23
Per-class core capacity planning, 387
Per-classification rules, 338–9
Per-Domain Behaviors (PDB), 79, 159–60
Per-flow admission control, 318–19
Per-flow sequence preservation, 18–19
Performance metrics, 349
Per-hop Behaviors (PHB), 149, 154–9, 174–5, 216
Periodic sampling, 351–2

Per-link statistics, 337–8
Personal video recorders (PVR), 43
Perturbation factors, 226
Per-VPN edge-marking, 267
PESQ (Perceptual Evaluation of Speech Quality), 23
"P" frames, 39
PHB *see* Per-Hop Behaviors
Physical redundancy, 53
Pipesize, 270–1
Pipe tunneling model, 16–18, 168–70, 178–81
Play-out delay: VoIP, 31–3
Point-of-presence (POP), 378
Poisson sampling, 352, 353, 354
Poisson traffic, 383–4
Policing, 100–11, 186, 222, 339–42
Policy: information distribution, 398
Polling, 337, 345
POP (point-of-presence), 378
Ports, 357–8
Positive acknowledgement with retransmission, 60–1
Precedence, 144–5, 146
Predictive coded "P" frames, 39
Pre-emption priority levels, 286
Premium data delay-optimized class (Prm-delay), 233–7, 261–2
Premium data loss-optimized class (Prm-loss), 236–9, 262
Premium data (Prm) classes:
  backbone Diffserv, 254, 256, 259–60, 261–3
  edge Diffserv, 223, 233–9
Premium data throughput-optimized class (Prm-th), 213, 217–18, 223, 233–9, 262
Prioritized Diffserv, 254–6
Priority scheduling, 93, 114–15, 125–6, 240, 286
Private networks, 263, 265, 267
Prm *see* Premium data
Prm-delay *see* Premium data delay-optimized class
Prm-loss *see* Premium data loss-optimized class
Prm-th *see* Premium data throughput-optimized class
Probability of delay/discard, 268, 271, 385–6
Probe packets, 348
Processing delays, 6, 8, 71–2
Professional-MPEG [PRO-MPEG] forum, 49–51
Propagation delay, 5–6, 8, 216, 417
Protocols, 357–8
  see also individual protocols
Public switched telephony networks (PSTN), 294–302
PVR (personal video recorders), 43

QCIF *see* Quarter common interchange format
QoE *see* Quality of experience
QOS *see* Quality of service
QOS Signaling: CAC, 327
Quality of experience (QoE), 22–4, 58, 364
Quality of service (QOS):
  best-effort service, 89–90
  CAC, 327
  classification, 93, 94–9
  class of service, 88–9
  complementary technologies, 197–8
  data plane mechanisms, 92–141
  definition, 87–94
  dropping, 128–37
  introduction, 2–3
  Intserv, 79
  IP multicast, 181–3
  layer 2 technologies, 98, 189–97
  limitations, 198–9
  link fragmentation and interleaving, 140–1
  marking, 93, 99–111

Quality of service (*Contd*)
mechanics, 92–141
metering, 111
multicast, 181–3
packet marking, 93, 99–111
policing, 100–11
policy, 183–9
queuing, 112–28
reasons for, 91
requirements, 2–3, 12, 16, 19, 30, 34
routers, 183–9
scheduling, 112–28
shaping, 137–40
signaling, 327
time frames, 90–1
toolsets, 91–141
type of service, 88–9
Quarter common interchange format (QCIF), 55
Queues/queuing:
buffers, 128–9
data plane QOS mechanisms, 112–28
edge Diffserv, 246–9
FIFO, 112–13
passive monitoring, 342–6
premium data delay-optimized class, 234–5
simulations, 385–6
SLA metrics, 6, 8, 15
thresholds, 268, 270–1
see also Scheduling

Random early detection (RED), 132–7, 186, 239, 263, 268–72, 344–6
Random sampling, 352–3
Rating Factor, 23
Real-time (RT) classes, 242, 253–4, 256, 258–9
Real-time transmission (RTT), 43, 51–2
Real-time VBR, 191
Received stream metric measurements, 349
Receiver-initiated reservations, 304–5, 327
RECEIVER TSPEC, 311
RED *see* Random early detection
Regional boundaries, 318
Regional meshes, 410–11
Remote control video streaming, 41, 44
Re-ordering packets, 19, 37, 57, 363
Reroute technologies, 198
ReSerVation Protocol *see* RSVP
ReSerVation Protocol-traffic engineering *see* RSVP-TE
Reservation setup, 307–14
Resizing, 324–5
Resource information distribution, 398
Resource managers, 292–302
Resource requirements, 285
Responsiveness, 281–2
ResvConf messages, 334
Round robin, 116–19, 121–3
Round trip time (RTT) delay, 4–5, 358
Route pinning, 417
Routers/routing:
CAC, 305–6
edge Diffserv, 230–3, 242–3
protocol classes, 242–3
quality of service, 183–9
RSVP (ReSerVation Protocol):
aggregation, 320–5
application signaling interaction, 314–16
CAC, 282–3, 303–26
definitions, 304–7
IP multicast, 182–3
MPLS QOS architectures, 172–3
MPLS TE, 399–402
reservation setup, 307–14
signaling interaction, 314–16
RSVP-TE (ReSerVation Protocol-traffic engineering), 325–6
RT *see* Real-time
RTT *see* Real-time transmission; Round trip time
Russian doll models, 405

Sampling frequency, 349, 351–5
Scalability, 147
Scheduling:
  advanced concepts, 126–8
  ATM layer 2 QOS, 192
  data plane QOS mechanisms, 112–28
  edge Diffserv design, 228–30, 240
  FIFO, 112–13
  Intserv, 303
  premium data delay-optimized class, 235–6
  SLA metrics, 6, 8, 15
  which algorithm?, 123–5
  see also Queuing
Secure tunneling, 165
Security protocols, 327–8
Segmented SLAs, 77
Self-induced VoIP queuing delay, 246–9
Self-similar traffic, 383–4
Sender-initiated reservations, 327
Sequence preservation, 18–19
Serialization delay, 6–7, 8
Server-side processing delays, 71
Service availability, 21–2, 364
Service classes, 213–18, 221–5, 253–6, 258–61
Service level agreements (SLA), 1–4
  active monitoring, 335–6, 348–71
  application requirements, 24–76
    data applications, 58–75
    video, 38–58
    Voice over IP, 26–37
  availability factors, 20–2
  backbone Diffserv, 253–6
  bandwidth, 12–18
  CAC, 285–6
  differentiation, 242
  Diffserv, 78–9, 211–18, 233–7, 241–2, 253–6
  edge Diffserv, 212–18, 233–4, 236–7, 241
  edge keys, 211–12
  engineered versus marketed, 76–8
  Intserv, 78–9
  marketed versus engineered, 76–8
  metrics, 3–24, 349, 358–64
    availability factors, 20–2
    bandwidth, 12–18
    network delay, 4–7
    packet loss, 9–11
    per-flow sequence preservation, 18–19
    quality of experience, 22–4
    sequence preservation, 18–19
    throughput, 12–18
  network delay, 4–7
  network monitoring, 335–73
  packet loss, 9–11
  passive monitoring, 335, 336–48
  premium data classes, 233–4, 236–7
  quality of experience, 22–4
  requirements, 211
  sequence preservation, 18–19
  specifications, 78, 212–18, 233–7, 241, 253–6
  throughput, 12–18
  video, 38–58
  Voice over IP, 26–37
Service octets, 96–8, 142–4, 145–6
Service types, 142–4, 145–6
Session establishment, 60
Setting tunnel bandwidth, 412–13
Set-top-box (STB) processing, 41, 42, 44–5
Shaping:
  ATM layer 2 QOS, 192
  data plane QOS mechanisms, 102, 137–40
  edge Diffserv design, 228–30
  frame relay layer 2 QOS, 195
  policers, 137–8
  SLA metrics, 15
Short pipe tunneling model, 181
Signaling, 243, 314–16, 326–8
Silence suppression: VoIP, 36

Simple classification, 96–9, 357
Simple IP-in-IP tunnels, 165
Simple network management protocol (SNMP), 336
Simplicity in scheduling algorithms, 124–5
Simulations in capacity planning, 377, 385–6, 388–9
Single rate three color markers (SR-TCM), 102–6, 339–42
Size factors, 324–5
SLA *see* Service level agreements
Sliding acknowledgement windows, 61
Slow start congestion control, 61–3
SNMP (simple network management protocol), 336
Soft state, 306
Source marking, 99
Spatial redundancy, 53
SR-TCM *see* Single rate three color markers
Standard classes (Std):
  backbone Diffserv, 254, 256, 260–1
  edge Diffserv, 213, 218, 224–5
Standard definition (SD) format, 54–5
Stateful inspection, 96
STB *see* Set-top-box
Std *see* Standard classes
Stratified random sampling, 352–3
Stream/streaming, 47, 57, 95, 348–50
  see also Video streaming
Strict priority, 125–6
Subjective measures, 23, 24
Switching delay, 6, 8, 216
Synchronizing clocks, 370–1
Synthetic traffic test streams, 348
Systematic TE deployment, 396, 409–11
System monitoring, 346–7

Tactical TE deployment: MPLS TE, 408–9
Tail drop, 129–32, 186, 222, 343–4
Taxonomy of CAC, 282–5
TCM *see* Three-color markers
TCP *see* Transmission Control Protocol
Telephony networks, 294–302
Temporal redundancy, 53–4
Testing:
  duration, 355–7
  frequency, 349, 354–7
  test rates, 354–5
  test streams, 348–50
Three-color markers (TCM), 106–8, 239, 340–2
Threshold exceeded count delay, 360
Throughput:
  active network monitoring, 363
  SLA metrics, 12–18
  TCP applications, 59–70
  video streaming, 54–6
  VoIP, 36–7
Tight SLA services, 211–12
Time frames, 90–1
Token bucket mechanisms, 101–8, 138
Toolsets for QOS, 91–141
Topologies: active monitoring, 365–9
Topology-awareness, 283, 290–302, 319
TOS *see* Type of service
Traffic assignment to tunnels, 402–5
Traffic classes, 95, 97
Traffic classification, 147–8
Traffic conditioning, 78–9, 147–8, 340
Traffic demand matrices, 376, 377–82
Traffic engineering, 389–413
  bandwidth, 376–7, 382–8, 393, 412–13
  CAC, 325–6
  deployment, 391–4
  Diffserv-aware MPLS TE, 404–8
  IGP based, 390, 394–7
  multi-protocol label switching, 397–413
  RSVP, 325–6
  tunnels, 300, 402–5
Traffic management classes, 242–3
Traffic matrices, 347–8
Traffic metering, 111
Traffic shapers, 15

Traffic test streams, 348–50
Transmission Control Protocol (TCP), 59–70, 161–5
Transmission delays, 41, 42, 43, 45
Transport stream packets, 47
TR-TCM *see* Two rate three color markers
Trust boundaries, 110–11
Tunneling:
  bandwidth sizing, 412–13
  CAC, 300, 324
  Diffserv, 165–70, 175–81
  MPLS Diffserv, 175–81
  MPLS TE, 397–404, 412–13
  next generation networks, 300
  pipe model, 168–70, 178–81
  uniform model, 166–8, 176–8
  voice CAC, 300
Two rate three color markers (TR-TCM), 106–8, 239, 340–2
Type of service (TOS), 88–9, 142–4, 145–6

UBR (unspecified bit rate), 192
Unicast reservations, 284, 304, 307–14, 327
Unidirectional reservations, 284, 304
Uniform tunneling model, 166–8, 176–8
Universal edge-marking, 267
Unmanaged access router services, 230–3
Unspecified bit rate (UBR), 192
Utility functions, 279–80

VAD *see* Voice activation detection
Variable bit rate (VBR), 191
VC *see* Virtual circuits
Video:
  backbone Diffserv, 262
  conferencing, 57–8
  edge Diffserv design, 239–40
  quality of experience, 24
  SLA requirements, 38–58
  streaming, 38–57
    delay, 40–7
    jitter, 46–7
    loss impacts, 47–54
    packet re-ordering, 57
    throughput, 54–6
Video-on-demand (VOD), 43–6, 47
Virtual circuits (VC), 190–4, 320
Virtual paths (VP), 320
Virtual private networks (VPN), 16–18, 172, 267
VOD *see* Video-on-demand
Voice activation detection (VAD), 36
Voice class maximum rate enforcement, 339–40
Voice QoE, 23
VoIP (Voice over IP):
  delay, 29–33
  edge Diffserv, 213, 214–17, 221–3, 232–3, 240, 245–9
  jitter, 31–3
  loss impacts, 33–6
  packet re-ordering, 37
  SLA requirements, 26–37
  throughput, 36–7
VPN *see* Virtual private networks
VP (Virtual paths), 320

Weighted bandwidth scheduling, 115–25
Weighted fair queuing (WFQ), 119–21
Weighted random early detection (WRED):
  backbone Diffserv, 263
  data plane QOS mechanisms, 136, 137
  Diffserv deployment, 239, 263, 268–72
  passive monitoring, 346
  router QOS implementation, 186
Weighted round robin (WRR), 116–19
Weighted tail drop, 131–2, 343–4
WFQ (weighted fair queuing), 119–21
Worst-case delay bounds, 124
WRED *see* Weighted random early detection
WRR (weighted round robin), 116–19