Numerics

1+1 redundancy, 12
1:1 redundancy, 12
   Cisco IOS architecture, 39, 62
   control processor cards, 12
   control planes, 36
1:N redundancy, 12
5-9s availability, 6

A

ABRs (area border routers), 74
access networks, 293
address aggregation, 25
address classes, 24
Address Family Identifier (AFI) field, 153–154, 169, 174
address lookup, 24
   BGP, 147
   double lookups, 29
   edge LSRs, 56
   FECs, 44
   IP, 26–28
   label lookup (versus), 50, 53
   labels, 44
   LSRs, 164
   metrics, 26
   MPLS, 164
   route caching, 29
   routers, 26
   strides, 27
   temporal versus spatial locality, 29
   tries, 26–28
address mapping, 31
Address messages (LDP), 192
address prefixes, 25
Address Resolution Protocol (ARP), 31, 53
adjacencies, 31, 67
   ARP, 53
   broadcast networks, 76, 113
   cycling through down states, 115
   flaps, 71, 107
   graceful restart, 67
   Hello adjacencies
      establishing, 189–190
      maintaining, 190–191
      packets, 70, 109
      processing, 81
      holding timers, 110
      IS-IS, 107–110
      LDP, 189–191
      master/slave status, 76
      NBMA networks, 76
      OSPF, 75–76
      reacquisition, 118–119
      RouterDeadInterval timers, 75
      T1 timers, 123
      three-way handshakes, 109
Adj-RIBs-In, 148
Adj-RIBs-Out, 148
Advertisement messages (LDP), 191
advertisements (BGP), 144
AFI (Address Family Identifier) field, 153–154, 169, 174
aggregates (CIDR), 25
aggregation (addressing), 25
ALLSPFRouters addresses, 75
Any Transport over MPLS (AToM), 55, 275
APS (Automatic Protection Switch), 9, 12, 17, 280
area border routers (ABRs), 74
areas
   not-so-stubby, 78
   OSPF, 73
   stub, 77
ARP (Address Resolution Protocol), 31, 53
AS external LSAs (type 5), 77–78
AS_PATH lists (BGP), 146
AS_SEQUENCE lists (BGP), 146
AS_SET lists (BGP), 146
ASBR summary LSAs (type 4), 77–78
ASBRs (autonomous system boundary routers), 74
Asynchronous Transfer Mode (ATM), 48
AToM (Any Transport over MPLS), 55, 275
authentication, 19
Automatic Protection Switch (APS), 9, 12, 17, 280
autonomous systems, 67, 137, 146
availability, 6. See also reliability
   carrier-class, 6, 11
   control/forwarding planes, 35
DPM, 6
DPY, 6
edge routers, 9
fault tolerance, 7
five-nines, 6
MPLS networks, 256
MTBF/MTTR, 6
packet-switched networks, 11
redundancy, 7
reliability (versus), 6
service view, 11
software upgrades (in-service), 295–296
unavailability (versus), 6

B

backbone areas (OSPF), 73
backbone routers, 74
backup designated routers (BDRs), 76
backup paths, 7
backup tunnels, 55
BDRs (backup designated routers), 76
BFD (Bidirectional Forwarding Detection), 288–290
access networks, 293
detecting IGP neighbor liveness, 290
FRR, 292–293
IP/MPLS networks, 294–295
LSPs, 291
PWs, 292
BGP (Border Gateway Protocol), 8, 137
advertising labeled routes, 171
control processor cards, 138
control-plane components, 138
End-Of-RIB markers, 153–156
external reachability information, 109
FIBs, 138
forwarding-plane components, 138
FSM, 142
label distribution, 169
label-to-FEC bindings, 46
labeled routes (withdrawing), 171
LDP, 221
line cards, 138
messages, 141–142
MPLS
control planes, 168
graceful restart/NSF interoperability, 182–183
interrelationship, 168–169
NSF, 140, 166, 168
path attributes, 143, 146
AS_PATH, 146
LOCAL_PREF, 149
MP_REACH_NLRI, 169
MP_UNREACH_NLRI, 169
NEXT_HOP, 147
protocol extensions, 168
recursive paths, 31
restarting BGP speaker behavior, 154–155
route flaps, 138–140
RIBs, 138
routings, 140–144
fluctuations, 138
instability, 138
reflection, 149–150, 171
selection, 149
tables, 25
speakers, 137, 141
internal/external, 144
RIBs, 148
RRs, 150
states, 142–143
BGP with an MPLS graceful restart mechanism.

See BGP/MPLS networks
BGP/MPLS networks
advertising labeled BGP routes, 171
control planes, 168
protocol interrelationship, 168–169
restarting, 166–167
withdrawing labeled BGP routes, 171
BGP/MPLS restarts
graceful restart, 173–175, 179–180
helper LSR behavior, 178
network deployment, 181–182

BGP with an MPLS graceful restart mechanism.

See BGP/MPLS networks
BGP/MPLS networks
advertising labeled BGP routes, 171
control planes, 168
protocol interrelationship, 168–169
restarting, 166–167
withdrawing labeled BGP routes, 171
BGP/MPLS restarts
graceful restart, 173–175, 179–180
helper LSR behavior, 178
network deployment, 181–182
restarting LSR behavior, 175–178
mitigating detrimental effects, 173
binary tries, 26
Bidirectional Forwarding Detection (BFD), 288–290
access networks, 293
detecting IGP neighbor liveness, 290
FRR, 292–293
IP/MPLS networks, 294–295
LSPs, 291
PWs, 292
black holes, 70, 75, 83, 109, 114
Border Gateway Protocol. See BGP
bypass tunnels, 55, 284–285

C

carrier supporting carrier (CSC), 270–271
carrier-class networks, 6
router expectations, 11
CEF (Cisco Express Forwarding), 33–34
cell-mode LSRs, 48
Checkpoint Procedures for LDP (LDP CDP), 200
churns (BGP), 140
CIDR (classless interdomain routing), 25–26
Cisco Express Forwarding (CEF), 33–34
Cisco IOS architecture
1:1 redundancy, 39, 62
cell-plane software, 15
label-distribution protocols, 53
MPLS SSO/NSF, 61
NSF, 39–40
SSO, 39–40
TFIB/MFI, 50
Cisco IS-IS restarts, 128–129
CSNPs, 129
IETF IS-IS restarts (versus), 128
interoperability, 132–134
operation, 130
PSNPs, 129
classful addressing, 24
CIDR (versus), 26
IP forwarding, 25
classless addressing, 25
classless interdomain routing (CIDR), 25–26
complete sequence number packets (CSNPs), 111
congestion indication (IS-IS), 112–113
constraint-based path calculation, 55
control capabilities (routers), 132
control planes, 8
1:1 redundancy, 36
adjacency flaps, 107
BGP, 138
BGP/MPLS networks, 168
Cisco IOS architecture, 15
control processor cards, 12
FIBs, 23
forwarding planes (separating), 19, 36
forwarding planes (versus), 35
IP, 23, 106
restart, 35–36
separating forwarding planes, 35
SSO, 37
tunneling protocols, 8
LDP, 197–198
maintaining state, 13–14
MPLS, 53–54, 61, 163–164
applications, 55
separating forwarding planes, 54
SSO, 57–59
MPLS-TE, 258
NSF, 37
OSPF, 69
recovery periods, 35
restarts, 13, 15, 132
routers, 12
RSVP-TE, 236
SSO, 15
stateful components, 35
stateless components, 35
unplanned restarts, 13
control processor cards, 12
1:1 redundancy, 12
active versus standby, 13
BGP, 138
reducing fault effects, 36
restartability, 16
RIBs, 69
router processors (Cisco), 39, 61
CSC (carrier supporting carrier), 270–271
CSNPs (complete sequence number packets), 111, 129
data encryption, 19
data planes, 277
  APS, 280
  FRR, 281–284
  protection/restoration, 278–280
  IP layer, 280
  MPLS layer, 281–284
  optical layer, 279–280
databases, 70, 110–112
  exchange process (OSPF), 75
  synchronization
    IETF IS-IS restarts, 119–120
    OSPF, 70–71
    timers, 118, 121
Database Description packets, 75
defects per million (DPM), 6
denial-of-service (DoS) attacks, 18
depths (label stacks), 45
designated IS (DIS) routers, 113
designated routers (DRs), 76
Dijkstra algorithm.
  See SPF (Shortest Path First) algorithm
DIS (designated IS) routers, 113
Discovery messages (LDP), 191
disposition (label), 52
distributed forwarding
  CEF, 34
  data rates, 30
  IP forwarding, 30–32
  MPLS, 56
  time criticality, 30
DOD (downstream on-demand) mode, 46, 193
  DU mode (versus), 219–220
  LDP
    graceful restart, 213–219
    nonrestarting LSRs (egress neighbors), 218
    nonrestarting LSRs (ingress neighbors), 217–218
    nonrestarting LSRs (transit neighbors), 218–219
    restarting LSRs (egress), 215–216
    restarting LSRs (ingress), 214–215
    restarting LSRs (transit), 216–217
DoNotAge bits, 90
DoS (denial-of-service) attacks, 18
downstream modes (LDP), 192
downstream on-demand mode. See DOD (downstream on-demand) mode
downstream unsolicited mode. See DU (downstream unsolicited) mode
downtime, 5–6. See also network outages
carrier-class routers, 11
  causes, 10
  link failures, 17
  software upgrades, 17
downtime per year (DPM), 6
DPM (defects per million), 6
DPY (downtime per year), 6
DRs (designated routers), 76
DU (downstream unsolicited) mode, 46, 194
  DOD mode (versus), 219–220
  LDP graceful restart, 203–204, 208–209, 212
eBGP (external BGP) sessions, 144
edge LSRs, 46, 164
  address lookup, 56
  label disposition, 52
  label imposition, 51
  Layer 2/3 services, 164–165
edge routers, 8
EGP (Exterior Gateway Protocol), 140
egress LSRs, 46
element nodes, 26
encoding (labels), 48
encryption (data), 19
End-Of-RIB markers, 153–156
enhanced IS-IS, 108
ERO (EXPLICIT_ROUTE) objects, 233
established state (BGP), 142–143
Ethernet, 48
expansion (prefix), 27
EXPLICIT_ROUTE objects (RSVP-TE), 233
explicitly routed LSPs, 47
Exterior Gateway Protocol (EGP), 140
external BGP (eBGP) sessions, 144
external/internal speakers (BGP), 144
F

F (Forwarding State) bits, 154
failures (network/services), 5
Fast ReRoute. See FRR (Fast ReRoute)
fault tolerance, 7, 35
availability, 7
data-plane protection, 277
MPLS networks, 257
MPLS-based recovery, 277–285
OAM mechanisms, 287–290
network design, 11
restarts, 201–203
security, 18–19
software upgrades (in-service), 295–296
FEC (forwarding equivalence class), 44, 164
address lookups, 44
label mappings, 45–46, 54, 176
LSP associations, 188–189
Layer 2 circuit IDs, 197
NHLFE (FTN) entries, 197
NHLFE (FTN) maps, 50
next-hop mappings, 54
FIBs (Forwarding Information Bases), 23, 31, 106
BGP, 138
building, 32, 56
line cards, 69
m-tries, 31
RIBs (versus), 30
routers, 31
RSVP-TE, 238
SPF algorithm, 73, 111
synchronizing with RIBs, 32, 56
filtering (packets), 19
FILTERSPEC objects (RSVP), 229
finite state machines (FSMs)
OSPF, 85, 93
BGP, 142
firewalls, 19
five-nines availability, 6
flags, 112
flaps (adjacency/route), 107, 138–140
flooding, 75, 105
IS-IS, 112
Link-State Acknowledgment packets, 75
OSPF, 68–70
FLOWSPEC objects (RSVP), 229
forwarding
ATM versus MPLS, 48
FEC, 44
FIBs, 23
IP, 23–24, 35–36
loops, 114
routers, 132
states
IP, 12, 39
LDP, 197–198
MPLS, 12, 166
tables
FECs, 44
IP forwarding plane, 23
L3VPNs, 266–267
route caching (versus), 29
VPNs (166
forwarding planes, 12
adjacency flaps, 107
BGP, 138
control planes, 19, 35–36
FIBs, 23, 31, 106
IP, 23
control planes (separating), 35
NSF, 36
operations, 24
tasks, 23
LDP, 197
MPLS, 53–54, 61, 163–164
control planes (separating), 54
label-stack operations, 51–54
NSF, 43, 58
MPLS-TE, 258
NSF, 37
OSPF, 69
RSVP-TE, 236
scalability, 35, 54
Forwarding State (F) bits, 154
FR (Frame Relay), 48
FRR (Fast ReRoute), 17, 50, 55, 281–284
BFD, 292–293
link failures, 17
FSMs (finite-state machines)
BGP, 142
OSPF, 85, 93
FT ACK TLV, 202
FT Protection TLV, 202
FT Session TLV, 201, 204–205
FTN (FEC-to-NHLFE) entries, 197
FTN (FEC-to-NHLFE) maps, 50

**G–H**

Generic Routing Encapsulation (GRE), 8
GR. See graceful restarts (GRs)
grace LSAs, 89
planned/unplanned restarts, 92–93
reason TLV, 90
graceful restarts (GRs), 67
  BFD, 294–295
  BGP, 151–161
  BGP/MPLS, 173–175, 179–180
    helper LSR behavior, 178
    network deployment, 181–182
    restarting LSR behavior, 175–178
IETF OSPF Working Group, 100
LDP, 201–203
  DOD mode, 213–219
  DU mode, 203–204, 208–209, 212
  exchanging initial capability, 204
  GR versus FT, 203
  interoperability, 221–222
  network deployment, 220–221
  nonrestarting peers, 206–207
  restarting peers, 207–208
  session failure, 205
  session reestablishment, 205
  state recovery, 205
OSPF, 89–100
reason TLV, 90
RSVP-TE, 237–239, 245–247
  control-plane restart, 239
  exchanging initial capability, 239
  network deployment, 248
  nonrestarting LSRs, 244–245
  recovery procedure, 242
  reestablishing Hello communication, 240
  restarting LSRs, 241, 243–244
GRE (Generic Routing Encapsulation), 8

hardware redundancy, 11
head-end restarts (RSVP-TE), 243
Hello adjacencies
  establishing, 189–190
  maintaining, 190–191
  packets, 70, 109
  processing, 81
Hello packets
  OSPF, 70
  RS bits, 80
HELLO_ACK object messages (RSVP-TE), 235
HELLO_REQUEST object messages (RSVP-TE), 235
helper nodes, 113
helper speakers (BGP), 154
hierarchical routing (IS-IS), 108–109
holding timers, 110
hop-by-hop routed LSPs, 47

I (Init) bits, 82
iBGP (internal BGP) sessions, 144
idle state (BGP), 142–143
IETF (Internet Engineering Task Force)
  LDP, 187, 200
  MPLS-TE, 264
  RSVP-TE, 238
IETF IS-IS restarts, 115–116
  adjacency reacquisition, 118–119
  Cisco IS-IS restarts (versus), 128
  database synchronization, 119–120
  interoperability, 132
  LSP generation/flooding, 120–121
  nonrestarting routers, 121–122
  operation, 124
    restarting routers, 126–128
    starting routers, 124–125
  restart TLV, 116–117
  restarting routers (with preserved FIB), 118–121
  SPF computation, 121
  starting routers (without preserved FIB), 122–123
  timers (T1–T3), 118
IETF OSPF Working Group, 100
IGPs (interior gateway protocols), 72
IIHs (IS-IS Hellos), 109, 116
ILMs (incoming label maps), 50, 197
Implicit NULL labels, 52
imposition (label), 51
incoming label maps (ILMs), 50, 197
incoming labels, 45
ingress LSRs, 46
Init (I) bits, 82
in-service software upgrades, 295–296
Integrated IS-IS, 108
interarea paths (OSPF), 78
interior gateway protocols (IGPs), 13
See IS-IS
internal BGP (iBGP) sessions, 144
internal/external speakers (BGP), 144
Internet Protocol (IP), 23
Internet routing architecture, 67–69
interoperability
BGP, 159–161
Cisco IS-IS restarts, 134
Cisco/IETF IS-IS restart, 132
OSPF restarts, 100–102
RSVP-TE, 248–249
interprocessor communication (IPC), 39
intra-area paths (OSPF), 78
intrusion detection/prevention, 19
IOS. See Cisco IOS architecture
IP (Internet Protocol), 23
IP forwarding, 23–24
addressing (classful/classless), 25
address lookup, 26–28
architectures, 28
distributed, 30–32
route caching, 29
CEF, 33–34
NSF, 36
IP networks
addressing, 24–25
ccontrol-plane protocols, 37
forwarding, 44
forwarding planes, 12, 24
forwarding tables, 28
IS-IS, 107
load balancing, 31
NSF, 36–40, 106
routing protocols, 8, 12
SSO, 35–36, 40
IP over MPLS, 55
IP/MPLS networks, 5
BFD, 294–295
control-plane protocols, 12
control-plane restart, 13
ccontrol-plane software, 8
forwarding planes, 12
forwarding states, 12
IP routing protocols, 8
IP tunneling protocols, 8
LSRs, 12
migrating legacy services, 5
MPLS signaling protocols, 8
network design, 19
OAM mechanisms, 17
protocols, 8
security, 18
service/network views, 11
IPC (interprocessor communication), 39
IS-IS (Intermediate System-to-Intermediate System), 8
dual routing, 107
flags, 116
Hello packets, 109
IP networks, 107
LDP, 221
levels, 68
LSPs, 68
restart TLV, 116–117
sequence number packets, 111
tree-way handshakes, 109
IS-IS Hellos (IIHs), 109
IS-IS restarts, 113–114
adjacency flaps, 107
Cisco, 128–131
detrimental effects, 105, 113
IETF restarts, 124–128
IETF versus Cisco, 131
mitigating detrimental effects, 113
Cisco restarts, 128–129
IETF IS-IS restarts, 115–128
network deployment, 132
original behavior, 105–107
306 IS-IS restarts

restarting routers, 115
starting routers, 115
state information, 128
IS-IS routing, 107–108
adjacencies, 110
congestion indication, 112–113
designated routers, 113
discovering neighbors, 109–110
establishing adjacencies, 109–110
hierarchical, 108–109
LSPs, 110–112

K–L

Keepalive messages (BGP), 141–142
keepalive timers (LDP), 190
L bits, 80
L2TP (Layer 2 Tunneling Protocol), 8
L2VPNs (Layer 2 virtual private networks), 50, 55, 164, 197, 272–273
control-plane failures, 274
forwarding tables, 166
VPWS, 275–277
L3VPNs (Layer 3 virtual private networks), 55, 164, 265
core-plane failures, 268
CSC, 270–271
multi-AS backbone, 269–270
single-AS backbone, 268–269
forwarding tables, 166
IPv6-based services, 268
label distribution, 268
MPLS, 50
PE-based, 265–266
PE-to-PE tunnels, 267
routing/forwarding tables, 266–267
Label Abort messages (LDP), 192
Label Distribution Protocol. See LDP
Label Mapping messages (LDP), 192
Label Request messages (LDP), 192
label-advertisement mode, 192
label-distribution control mode, 192
label-encoding techniques, 48
Label Information Bases. See LIBs
label-retention mode, 194
labels, 44
distribution (BGP), 169
DOD mode, 46
DU mode, 46
encoding techniques, 48
Implicit NULL, 52
imposition/disposition, 46
incoming versus outgoing, 45
label space, 50
label stacks, 45–46
label-to-FEC binding, 45
lookup, 50, 53, 163
MPLS forwarding, 51
label disposition, 46, 52
label imposition, 46, 51
label swapping, 51
recovering labels, 176
label-switched paths. See LSPs
Label-Switching Information Bases. See LFIBs
label-switching routers. See LSRs
label-to-FEC mappings, 176
Layer 2 Tunneling Protocol (L2TP), 8
Layer 2 virtual private networks. See L2VPNs
Layer 3 virtual private networks. See L3VPNs
LC-ATM (label-switching controlled ATM)
interaces, 48
LDP (Label Distribution Protocol), 8, 46, 187–188
active versus standby, 59
BGP, 221
Cisco IOS architecture, 53
control planes, 197–198
DOD mode, 193, 214
DU mode (versus), 219–220
graceful restarts, 213–219
restarting LSRs, 214
restarting LSRs (egress neighbors), 218
restarting LSRs (ingress), 215–216
restarting LSRs (ingress neighbors), 217–218
restarting LSRs (ingress), 215
restarting LSRs (transit neighbors), 218–219
restarting LSRs (transit), 216–217
DU mode, 194
graceful restarts, 203–204, 208–209, 212
DOD mode (versus), 219–220
FEC-to-label mappings, 54
FEC-to-LSP associations, 188–189
FIBs, 198
forwarding planes, 197
forwarding states, 197–198
graceful restarts
DOD, 214–219
exchanging initial capability, 204
GR versus FT, 203
interoperability, 221–222
network deployment, 220–221
nonrestarting peers, 206–207
restarting peers, 207–208
session failures, 205
session reestablishment, 205
state recovery, 205
Hello adjacencies
establishing, 189–190
maintaining, 190–191
hop-by-hop routed LSPs, 48
IETF, 187, 200
ILMs, 197
Implicit NULL labels, 52
IS-IS, 221
keepalive timers, 190
label-to-FEC bindings, 46
label-advertisement mode, 192
label-distribution control mode, 192
label-retention mode, 194
LDP CKP, 200
LFIIBs, 194
LIB/LFIB/routing interactions, 194–196
LSPs, 187, 197–198
Maximum Recovery Time, 206
messages, 191–192
MPLS, 43
MPLS forwarding state, 198
Neighbor Liveness Timer, 206
NHLFEs, 197
NSF, 197
OSPF, 221
peers, 189
PWs, establishing, 196–197
Recovery Time, 205
restarts, 198–199
methods, 201–203
mitigating detrimental effects, 200
routing, 194
TCP, 189
LDP CKP (Checkpoint Procedures for LDP), 200
leaf nodes, 26
level 1/2 LAN Hello (IS-IS), 109
LFIBs (Label-Switching Information Bases), 50, 163
building, 56
LDP, 194–196
RSVP-TE, 236
synchronizing with the LIB, 56
LIBs (Label Information Bases)
LDP, 194–196
RIBs (versus), 53
line cards
BGP, 138
CEF, 33
distributed forwarding, 30
FIBs, 69
forwarding-plane functions, 12
IPC, 39
MPLS networks, 8
synchronizing RIBs to FIBs, 32
link failures (mitigating), 17
link local signaling (LLS), 80
Link-State Acknowledgment (LSA) packets, 75
link-state advertisements. See LSAs
link-state databases. See LSDBs
link-state protocols, 68, 72, 105
Link-State Request packets, 75
Link-State Update packets, 75
LLS (link-local signaling), 80
load balancing, 31
locality (temporal versus spatial), 29
Loc-RIB, 148
LR (LSDB Resynchronization) bits, 82
LSAs (link-state advertisements), 13, 68
flooding, 70
grace LSAs, 89, 92–93
MaxAge, 77
OSPF, 76–79
self-originated LSAs, 85
types, 77
LSDB Resynchronization (LR) bits, 82
LSDBs (link-state databases), 68
OSPF, 70–71
purging LSAs, 77
resynchronization, 81
LSP_TUNNEL objects (RSVP-TE), 231
LSPs (label-switched paths), 8, 106, 166
adjacency flaps, 107
BFD, 291
congestion indication, 112–113
CSNPs, 111
database synchronization, 111, 114
explicitly routed/traffic engineered, 47
flags, 112
flooding, 112
fragmenting, 112
generation/flooding, 120–121
hop-by-hop routed, 47, 188
IS-IS, 109–112
LDP, 187, 197–198
MPLS, 61, 197–198
MPLS-TE, 226
nesting, 46
tunnels, 231
zeroth LSPs, 112
LSRefreshTime timer, 90
LSRs (label-switching routers), 45, 163
address lookup, 164
ATM, 48
cell mode, 48
DOD mode (LDP), 214–219
edge LSRs, 46, 164–165
frame mode, 48
label-distribution protocols, 46
LFIBs, 50
penultimate LSP LSR, 46
MPLS domains, 46
NSF, 58
recovery periods, 58
RSVP-TE
nonrestarting LSRs, 244–245
restarting LSRs, 241–244
transit LSRs, 46, 164
edge LSRs, 164
Ethernet, 48
FEC-to-label mappings, 46
forwarding, 50, 53
architecture, 56
ATM (versus), 48
forwarding planes, 12, 61
IP (versus), 50
label operations, 51
state, 166
FR, 48
FRR, 50
IP forwarding (versus), 50–53
L2VPNs, 50
L3VPNs, 50
Layer 2/3 services, 254
availability, 256
fault-tolerance techniques, 257
provider-provisioned VPNs, 254
service attributes, 256
VPN tunnels, 255–256
line cards, 8
LSPs, 47, 61
LSRs, 45
NSF, 43, 58–62
PPP, 48
protection layer interaction, 285
recovery, 277–285
routers, 7
separating control/forwarding planes, 53–54
signaling protocols, 12
SSO, 57–58, 62
MPLS/BGP networks
graceful restart/NSF interoperability, 182–183
MPLS-TE (Multiprotocol Label Switching traffic engineering), 50, 55, 226, 257
core networks, 8
downstream, 8
node failures, 17
via OAM mechanisms, 17
software outages, 12–17
planned, 10, 17
unplanned, 10–17
network partitioning, 108
network summary LSAs (type 3), 77–78
NEXT_HOP attributes (BGP), 147
next-hop label forwarding entries (NHLFEs), 50, 197, 238
NLRI (network layer reachability information), 141
NMBA (nonbroadcast multiaccess) networks, 75–76
node failures (mitigating), 17
nonrestarting routers (IETF IS-IS restarts), 121–122
nonstop forwarding. See NSF
Notification messages
BGP, 141–142
LDP, 191
not-so-stubby-areas (NSSAs), 78
NSF (nonstop forwarding), 15, 69, 106
BGP, 140, 159–161, 166–168
MTBF (mean time between failures), 6
m-tries (multibit-tries), 27
MTTR (mean time to repair), 6
multibit-tries (m-tries), 27
Multiprotocol Label Switching. See MPLS
multiservice edge (MSE) routers, 7

N

Neighbor Liveness Timer, 206
nesting (LSPs), 46
network design
core networks, 8
downstream, 8
fault tolerance, 11
IP/MPLS networks, 19
redundancy, 7
network layer reachability information (NLRI), 141
network LSAs (type 2), 77–78
network outages, 10. See also outages
causes, 10–11
mitigating
hardware outages, 11–12
link/node failures, 17
node-level outages, 17
software outages, 12–17
planned, 10, 17
unplanned, 10–17
network partitioning, 108
network summary LSAs (type 3), 77–78
NEXT_HOP attributes (BGP), 147
next-hop label forwarding entries (NHLFEs), 50, 197, 238
NLRI (network layer reachability information), 141
NMBA (nonbroadcast multiaccess) networks, 75–76
node failures (mitigating), 17
nonrestarting routers (IETF IS-IS restarts), 121–122
nonstop forwarding. See NSF
Notification messages
BGP, 141–142
LDP, 191
not-so-stubby-areas (NSSAs), 78
NSF (nonstop forwarding), 15, 69, 106
BGP, 140, 159–161, 166–168
MTBF (mean time between failures), 6
m-tries (multibit-tries), 27
MTTR (mean time to repair), 6
multibit-tries (m-tries), 27
Multiprotocol Label Switching. See MPLS
multiservice edge (MSE) routers, 7

N

Neighbor Liveness Timer, 206
nesting (LSPs), 46
network design
core networks, 8
downstream, 8
fault tolerance, 11
IP/MPLS networks, 19
redundancy, 7
network layer reachability information (NLRI), 141
network LSAs (type 2), 77–78
network outages, 10. See also outages
causes, 10–11
mitigating
hardware outages, 11–12
link/node failures, 17
node-level outages, 17
software outages, 12–17
planned, 10, 17
unplanned, 10–17
network partitioning, 108
network summary LSAs (type 3), 77–78
NEXT_HOP attributes (BGP), 147
next-hop label forwarding entries (NHLFEs), 50, 197, 238
NLRI (network layer reachability information), 141
NMBA (nonbroadcast multiaccess) networks, 75–76
node failures (mitigating), 17
nonrestarting routers (IETF IS-IS restarts), 121–122
nonstop forwarding. See NSF
Notification messages
BGP, 141–142
LDP, 191
not-so-stubby-areas (NSSAs), 78
NSF (nonstop forwarding), 15, 69, 106
BGP, 140, 159–161, 166–168
capable versus incapable neighbors, 40
Cisco IOS architecture, 39–40
defensive techniques, 18
external view, 40
IP, 36–39
  control-plane SSO, 37
  forwarding, 36
  neighboring-node perspective, 40
  separating control/forwarding, 37
LDP, 197
MPLS
  control-plane SSO, 59
  neighboring-node perspective, 62
routers, 36
RSVP-TE, 238
NSSAs (not-so-stubby areas), 78

O

OAM (operation, administration, and maintenance) mechanisms, 17, 287–290
OL (overload) bit, 112–113
one-for-N (1:N) redundancy, 12
one-for-one (1:1) redundancy, 12
one-plus-one (1+1) redundancy, 12
OOB (out-of-band) resynchronization, 82
OOBResynch bits, 82
Open messages (BGP), 141–142, 151
Open Shortest Path First. See OSPF
operation, administration, and maintenance (OAM) mechanisms, 17, 287–290
optional nontransitive (BGP path attribute), 146
optional transitive (BGP path attribute), 146
OSPF (Open Shortest Path First), 8
  areas, 73
  control-plane components, 69
databases
    Database Description packets, 75
    exchange process, 75
    synchronizing, 70–71
discovering neighbors, 75
flooding, 70
forwarding-plane components, 69
FSM, 85, 93
Hello packets, 70, 81
inter-area paths, 78
intra-area paths, 78
LDP, 221
link-state protocols, 68, 72
Link-State Request packets, 75
Link-State Update packets, 75
LSAs, 75, 77
restarting. See OSPF restarts
routing, 72–73
  adjacencies, establishing, 75–76
  hierarchical, 73–74
  link-state databases, synchronizing, 75–76
  LSAs, 76–79
  paths, selecting, 78–79
  router classification, 74
  tables, 73–74
SPF algorithm, 72
type 1/2 external paths, 79
OSPF restarts, 69–70
control-plane restarts, 69–71
detrimental effects, 70–71
graceful restarts
  neighboring router behavior, 95–96
  restarting router behavior, 93–94
interoperability, 100–102
mitigating detrimental effects, 79
graceful restarts, 89–92, 96, 99
graceful restarts versus restart signaling, 99–100
restart signaling, 80–81
neighbor awareness, 70
nonrestarting routers, 85–86
planned/unplanned, 79, 92–93
protocol extensions, 70
restart signaling, 86–89
restarting routers, 84
SPF calculations, 85
outages
  causes, 10–11
downtime, 5
mitigating
  hardware outages, 11–12
  link/node failures, 17
  node-level outages, 17
  via OAM mechanisms, 17
  software outages, 12–17
planned, 10, 17
unplanned, 10–17
node/link, 277
services, 256
outgoing labels, 45
out-of-band (OOB) resynchronization, 82
Overload (OL) bits, 112–113

PSB (path state block) messages, 227
pseudowires (PWs), 196–197, 292
PSNPs (partial sequence number packets), 111, 129
PWs (pseudowires), 196–197, 292

R

R (Restart State) bits, 82, 153
RA (Restart Acknowledgment) flags, 116
radix (tries), 26
reason TLV (graceful restarts), 90
RECORD_ROUTE objects (RSVP-TE), 233–234
recovery periods
MPLS, 58
routers, 35
RECOVERY_LABEL objects (RSVP-TE), 239
recursive paths, 30
redundancy, 7, 257
APS, 12
delay routers, 9
fault tolerance, 7
hardware, 11
IP control-plane protocols, 37
MPLS control-plane SSO, 59
schemes, 12
software approaches, 14
swichovers, 7, 15
refresh timers, 84
reliability. See also availability
availability (versus), 6–7
MTBF/MTTR, 6
routers, 9
service view, 11
reservation state block (RSB) messages, 229
resource exhaustion DoS attacks, 18
Resource Reservation Protocol. See RSVP
resources (networks), 18
Restart Acknowledgment (RA) flags, 116
Restart Request (RR) flags, 116
restart signaling
OSPF, 80–81, 86–89
graceful restart (versus), 99–100
Restart Signaling (RS) bits, 80
Restart State (R) bits, 153
restart TLV, 116–117
RESTART_CAP objects (RSVP-TE), 239
restartability, 15–17
restarting routers, 115
  adjacency reacquisition, 119
  CSNP, 120
  IETF IS-IS, 118–121
timers, 118
restarting speakers (BGP), 154
restarts
  BGP, 140
graceful restarts, 151–154
mitigating detrimental effects, 150–151
route flaps, 138–140
fault-tolerant restarts, 201–203
  grace LSAs, 92–93
head-end restarts (RSVP-TE), 243
  IS-IS, 113–114
detrimental effects, 105
IETF versus Cisco, 131
mitigating detrimental effects, 113–116
network deployment, 132
original behavior, 105–107

LDP
detrimental effects, 198–199
  methods, 201–203
mitigating detrimental effects, 200
midpoint restarts (RSVP-TE), 243
OSPF, 69–70
detrimental effects, 70–71
mitigating detrimental effects, 79
graceful restart, 89–92, 96, 99
  graceful restart versus restart
  signaling, 99–100
  restart signaling, 80–81
preserving state information, 131
protocol extensions, 69–70
RSVP-TE, 236–245
tail-end restarts, 244
RestartState bits, 81
restoration (data-plane failure), 278
  Resv messages (RSVP), 228–229
  ResvErr (reservation error) messages, 229
  Resvtimeout timer, 82
  RIBs (Routing Information Bases), 30, 69
  BGP, 138
  BGP speakers, 148
control processor cards, 69
End-of-RIB markers, 153, 155–156
LIBs (versus), 53
m-tries, 31
SPF algorithm, 73
updates, 31
route caching
  FIBs (versus), 31
  hit ratio, 29
IP forwarding, 29
route flaps, 138, 140, 167
route reflectors (RRs), 149–150, 171
route selection, 149
router LSAs (type 1), 77–78
router processors (RPs), 39, 61
RouterDeadInterval timers, 75, 88
routers, 23
  ABRs, 74
  address lookup, 26, 44
  adjacencies, 76
  ASBRs, 74
  ATM LSAs, 48
  autonomous systems (AS), 137
  backbone routers, 74
  BDRs, 76
  BGP, 25
  BGP speakers, 137, 144
  bottlenecks, 23
carrier-class routers, 10–11
cell-mode LSAs, 48
components, 8
cell-mode LSAs, 48
cell-mode LSAs, 48
cell-mode LSAs, 48
cell-mode LSAs, 48
cell-mode LSAs, 48
cell-mode LSAs, 48
cell-mode LSAs, 48
cell-mode LSAs, 48
cell-mode LSAs, 48
cell-mode LSAs, 48
cell-mode LSAs, 48
cell-mode LSAs, 48
cell-mode LSAs, 48
control/forwarding capabilities, 132
control-plane availability, 16
control-plane protocols, 12
carrier-class routers, 10–11
cell-mode LSAs, 48
control-plane software, 12
distributed routers (IS-IS), 113
downtime, 10
dr, 76
dr, 76
dr, 76
dr, 76
dr, 76
dr, 76
dr, 76
dr, 76
dr, 76
dr, 76
dr, 76
dr, 76
dr, 76
dr, 76
dr, 76
dr, 76
dr, 76
edge routers, 8
FIB, 31
flaxes, 116
forwarding process, 24
fragmenting LSPs, 112
frame-mode LSAs, 48
IGPs, 13
internal routers, 74
IP routers, 23
IS-IS restart TLV, 116–117
IS-IS restarts
  nonrestarting routers, 121–122
  restarting routers (with preserved FIB), 118–121
  starting routers (without preserved FIB), 122–123
link-state protocols (LSPs), 105
LSRs, 12, 45
MPLS networks, 7
MSE routers, 7
network partitioning, 108
NSF, 15, 36, 69
OSPF classifications, 74
OSPF restarts
  nonrestarting routers, 85–86
  restarting routers, 84–85
outages, 11
recovery periods, 35
reliability, 9
restarting routers, 115
  adjacency reacquisition, 119
  CSNP, 120
  IETF IS-IS, 126–128
  OSPF, 71
  T3 timers, 118
SPF algorithm, 111
SSO, 16
starting routers, 115, 124–125
traditional forwarding architectures, 28
routing
  BGP, 137, 140–144
domains, 67, 72
dual routing, 108
IGP, 72
interdomain routing, 137
Internet architecture, 67–69
IS-IS, 107–108
  congestion indication, 112–113
designated routers, 113
discovering neighbors, 109–110
establishing adjacencies, 109–110
hierarchical, 108–109
LSPs, 110, 112
  maintaining adjacencies, 110
  establishing adjacencies, 75–76
  hierarchical, 73–74
LSAs, 76–79
  selecting paths, 78–79
  synchronizing LSDBs, 75–76
Routing Information Bases. See RIBs
routing protocols, 8, 12
  active versus standby, 37, 59
  control processor cards, 36
  control software, 106
  FEC-to-next hop mappings, 54
  RIBs, 30
routing tables
  BGP, 25, 143
  L3VPNs, 266–267
  OSPF, 73–74
  reducing the size of, 25
RPs (router processors), 39, 61
RR (Restart Request) flags, 116
RRO (RECORD_ROUTE) objects, 233
RRs (route reflectors), 149–150, 171
RS (Restart Signaling) bits, 80
RSB (reservation state block) messages, 229
RSVP (Resource Reservation Protocol), 8, 227
  label-to-FEC bindings, 46
  MPLS-TE, 230
  Path messages, 227
  PathErr messages, 227
  Resv messages, 228–229
  ResvErr messages, 229
  soft state, 229
RSVP traffic engineered (RSVP-TE), 48, 187, 225
  control/forwarding-plane components, 236
detecting failures, 235–236
  EXPPLICIT_ROUTE objects, 233
  FIBs, 238
  graceful restart, 237–247
  Hello extensions, 235
  IETF, 238
  interoperability, 248–249
  LFIBs, 236
  LSP tunnels, 231
  LSP_TUNNEL objects, 231–232
  MESSAGE_ACK objects, 235
  new objects, 230–232, 239
RSVP traffic engineered (RSVP-TE)

NHLFE, 238
RECORD_ROUTE objects, 233–234
restarts, 236–245
SESSION_ATTRIBUTE objects, 232
soft state, 234
state lifetime, 234–235
SUMMARY_REFRESH messages, 235
traffic flows, 230
RSVP_HOP object (RSVP), 227, 229

SA (Suppress Adjacency Advertisement) flags, 117
SAFI (Subsequent Address Family Identifier) field, 153, 169, 173–174
scheduling, 24
security, 18
DoS attacks, 18
improving via fault-tolerant mechanisms, 18–19
send routing message flags. See SRMflags
send sequence number flags (SSNflags), 112
SENDER_TEMPLATE objects (RSVP), 227
SENDER_TSPEC objects (RSVP), 227
sequence number packets (IS-IS), 111
service-level agreements (SLAs), 11
services (networks), 10, 256
outages, 6–7
Session message (LDP), 191
SESSION objects (RSVP), 227, 229
SESSION_ATTRIBUTE objects (RSVP-TE), 232
Shortest Path First, 13
Shortest Path First algorithm. See SPF (Shortest Path First) algorithm
signaling protocols, 8
SLAs (service-level agreements), 11
soft state
RSVP, 229
RSVP-TE, 234
software upgrades, 17, 295–296
SONET (Synchronous Optical Network), 280
SONET/SDH (Synchronous Optical Network/Synchronous Digital Hierarchy), 7
APS, 9, 12
MPLS (versus), 17
speakers (BGP), 137, 141
internal/external, 144
RIBs, 148
RRs, 150
special locality, 29
SPF (Shortest Path First) algorithm, 13, 68, 105
LSPs, 111, 120
OSPF, 72
OSPF restarts, 85
RIBs, 73
zeroth LSP, 112
SRMflags (send routing message flags), 112
Cisco IS-IS restarts, 129
IS-IS restarts, 114
SSNflags (send sequence number flags), 112
SSO (stateful switchover), 15
capable components, 37
Cisco IOS architecture, 39–40
defensive techniques, 18
external view, 40
IP
control plane, 35–37
neighboring-node perspective, 40
MPLS
control plane, 59
neighboring-node perspective, 62
restartability, 16
starting routers, 115
IETF IS-IS restarts, 122–123
timers, 118
state transitions, 93
stateful components, 35–37, 57
stateful switchover. See SSO
stateless components, 35
states (BGP), 142–143
strides
address lookup, 27
patterns, 28
stub areas, 77
STYLE objects (RSVP), 229
Subsequent Address Family Identifier (SAFI) field, 153, 169, 173–174
SUGGESTED_LABEL objects (RSVP-TE), 239
SUMMARY_REFRESH messages (RSVP-TE), 235
supernets, 25
Suppress Adjacency Advertisement (SA) flags, 117
survivability. See fault tolerance
swapping (labels), 51
switching, 24
switching fabric (routers), 8
switchovers
fault control processor cards, 36
redundancy, 7
restartability, 15
SSO, 35–36
synchronizing databases, 114, 118
IETF IS-IS restarts, 119–120
OSPF, 70–71
timers, 118, 121
SSO, 35–36
Synchronous Optical Network/Synchronous Digital
Hierarchy. See SONET/SDH

T

T1 timers, 118
adjacency reacquisition, 119
restarting versus starting routers, 123
T2 timers, 118
adjacency reacquisitions, 119
database synchronization, 120
SPF computations, 121
start-capable routers, 122
T3 timers, 118
expiring before T2 timers, 121
IETF IS-IS restart routers, 118
inhibiting IIH transmissions, 119
Tag Forwarding Information Bases (TFIBs), 50
tail-end restarts (RSVP-TE), 244
TCP (Transmission Control Protocol), 189
TE (traffic engineering), 50, 225–226, 257
temporal locality, 29
TFIB (Tag Forwarding Information Bases), 50
tree-way handshakes, 109
timers
adjacencies, 110
Hello adjacencies, 190
IETF IS-IS restarts, 118
LDP, 206
LSP generation/flooding, 120–121
LSRefreshTime, 90
MaxAge, 77
MPLS Forwarding State Holding Timer, 205
refresh timers, 84
ResyncTimeout, 82
RouterDeadInterval timer, 88
TLVs (time length values)
FT ACK, 202
FT Protection, 202
FT Session, 201, 204
reason TLV, 90
restart TLV, 116–117
traffic engineering (TE), 50, 225–226, 257
traffic trunks, 226
traffic-engineered LSPs, 47
transit LSRs, 46, 51, 164
tries, 26, 28
tunnels
bypass tunnels, 284–285
MPLS-TE
establishing, 259–261
protecting, 262–263
reoptimizing, 262
RSVP, 231
VPNs, 255
demultiplexing, 255
signaling labels, 256
tuples (CIDR), 25
type 1 LSAs, 77–78
type 1/2 external paths (OSPF), 79
type 2 LSAs, 77
type 3 LSAs, 77
type 4 LSAs, 77
type 5 LSAs, 77
type 7 LSAs, 77

U–W

unavailability, 6. See also downtime; outages
Update messages (BGP), 141–144
distributing routing information, 171
path attributes, 146–147
Withdrawn Routes field, 171
VC labels, 165, 168
VCIs (virtual circuit identifiers), 45
Virtual Private LAN Service (VPLS), 275–277
virtual private networks. See VPNs
Virtual Private Wire Service (VPWS), 274–275
VPLS (Virtual Private LAN Service), 275–277
VPNs (virtual private networks)

backbones, 164
forwarding tables, 166
L2VPNs, 272–273
    control-plane failures, 274
    VPLS, 275–277
    VPWS, 274–275
L3VPNs, 265
    control-plane failures, 268–271
    IPv6 services, 268
    label distribution, 268
    PE-based, 265–266
    PE-to-PE tunnels, 267
    routing/forwarding tables, 266–267
MPLS, 164–165
    provider provisioned, 254
    tunnels, 168, 255
        demultiplexing, 255
        signaling labels, 256
VPWS (Virtual Private Wire Service), 274–275

wavelength-division multiplexing (WDM), 7, 279–280
well-known discretionary (BGP path attribute), 146
well-known mandatory (BGP path attribute), 146
    AS_PATH, 146
    NEXT_HOP, 147