

Migrating to IPv6

A practical guide to
implementing IPv6
in mobile and
fixed networks

Marc Blanchet

Companion

Website



WILEY

Migrating to IPv6

A Practical Guide to Implementing IPv6 in Mobile and Fixed Networks

Marc Blanchet

Québec, Canada



John Wiley & Sons, Ltd

Contents

Foreword	xxiii
Preface	xxvii
1 IPv6 Rationale and Features	1
1.1 Internet Growth	1
1.1.1 IPv4 Addressing	1
1.1.2 IPv4 Address Space Utilization	3
1.1.3 Network Address Translation	5
1.1.4 HTTP Version 1.1 Virtual Hosting	7
1.1.5 Variable Length Subnet Mask	7
1.1.6 Classless IPv4	8
1.1.7 Provider-based Assignment and Aggregation of IPv4 Network Prefixes	8
1.1.8 Constrained Allocation Policy of IPv4 Addresses	9
1.1.9 Global Routing	9
1.1.10 Summary of Internet Growth	9
1.2 Real Issues and Trouble with IPv4	10
1.2.1 Deploying Voice over IP	10
1.2.2 Deploying IP Security	13
1.2.3 Deploying Application Security	13
1.2.4 Videoconferencing	14
1.2.5 A Simple Web Server at Home	15
1.2.6 Using Remote Procedure Calls	15
1.2.7 Remote Management of Applications and Servers	16
1.2.8 VPN Between Same Address Space	16
1.2.9 Deploying Services in the Home Network	17
1.2.10 Merging or Connecting Two Networks Together	18
1.2.11 Large Networks	18
1.2.12 Address Plans and Secondary Addresses	18
1.2.13 Provider VPN Address Collisions	19
1.2.14 Should IP Addresses be Free?	20
1.2.15 Summary	20
1.3 Architectural Considerations	20
1.3.1 Network Address Translator Variations	25
1.4 Paradigm Shift	26
1.5 IETF Work Towards IPv6	27

1.6	IPv6 Main Features	30
1.7	IPv6 Milestones	32
1.8	IPv6 Return on Investment	32
1.9	What Happened to IPv5?	33
1.10	Summary	34
1.11	References	34
1.12	Further Reading	36
2	I Can't Wait to Get my Hands Dirty!	37
2.1	Setup Description	37
2.2	Steps	38
2.2.1	Enabling IPv6 on N2 and N3	38
2.2.2	Two Nodes Talking Already!	40
2.2.3	Installing and Configuring the TSP Client on N2	40
2.2.4	Creating an IPv6 in IPv4 Tunnel with Freenet6	41
2.2.5	Testing IPv6 on N2	41
2.2.6	Requesting an IPv6 Prefix Delegation	41
2.3	Summary	42
2.4	References	42
2.5	Further Reading	42
3	IPv6 Datagram	43
3.1	Description of the IP Datagram	43
3.2	IPv4 Header	44
3.3	IPv6 Header	46
3.4	Header Fields	47
3.4.1	Version	47
3.4.2	Traffic Class	48
3.4.3	Flow Label	49
3.4.4	Payload Length	49
3.4.5	Hop Limit	49
3.4.6	Next Header	49
3.5	Extension Headers	50
3.5.1	Hop-by-Hop Option	51
3.5.2	Routing	52
3.5.3	Fragment	52
3.5.4	Destination Options	52
3.5.5	Authentication and Encapsulating Security Payload	52
3.5.6	No Next Header	52
3.5.7	Order of the Extension Headers	53
3.6	Datagram Size	53
3.6.1	Maximum Transmission Unit	54
3.6.2	Path MTU Discovery	54
3.6.3	Fragmentation	55
3.6.4	Jumbogram	56
3.6.5	Header Compression	57
3.7	Upper-layer Protocols	58
3.7.1	Checksum	58
3.7.2	Implications in Application Protocols	59
3.8	Summary	59
3.9	References	59

4	Addressing	61
4.1	Address Space	61
4.2	Format of an Address	62
4.2.1	Text Representation of Addresses	62
4.2.2	Text Representation of Prefixes	63
4.2.3	Addresses in URL	63
4.3	Unicast Addresses	64
4.3.1	Global Unicast Addresses	64
4.3.2	Scoped Addresses	66
4.3.3	Protocol Use Addresses	69
4.3.4	Unspecified Address	70
4.3.5	Loopback Address	71
4.4	Multicast Addressing	71
4.5	Anycast	74
4.6	Addressing Architecture	74
4.7	Summary	76
4.8	References	76
4.9	Further Reading	77
5	Configuring Node Addresses	79
5.1	Static Address Configuration	79
5.2	Address Auto-Configuration	79
5.2.1	Interface Identifier	80
5.2.2	Router Advertisements and Solicitations	81
5.3	Lifetime of Advertised Prefixes	84
5.4	Node Booting Process	87
5.5	DHCPv6	88
5.5.1	Basic Behavior	88
5.5.2	Initial Exchange	89
5.5.3	Data Exchange	90
5.5.4	DHCPv6 Prefix Delegation	92
5.5.5	Differences Between DHCPv4 and DHCPv6	92
5.5.6	Dual Stack DHCP Clients	93
5.5.7	Renumbering with DHCP	93
5.6	Node Addresses	93
5.7	Configuring Interfaces and Router Advertisements on Hosts and Routers	93
5.7.1	Network Example	94
5.7.2	FreeBSD	94
5.7.3	Linux	96
5.7.4	Solaris	98
5.7.5	Windows	99
5.7.6	Cisco	101
5.7.7	Hexago	104
5.7.8	Juniper	105
5.7.9	Debugging Autoconfiguration and Router Advertisements	107
5.8	Summary	107
5.9	Appendix	108
5.9.1	Router Advertisement and Solicitation Message Formats	108
5.9.2	DHCP Variables, Addresses and Ports	109
5.10	References	111
5.11	Further Reading	111

6	Link-layer Integration	113
6.1	Solicited-Node Multicast Address	113
6.2	Neighbor Solicitation and Advertisement	115
6.2.1	IPv4 Address Resolution Protocol	115
6.2.2	IPv6 Differences	115
6.2.3	Neighbor Solicitation Process	116
6.3	Duplicate Address Detection	117
6.4	Neighbor Cache	117
6.4.1	Neighbor Unreachability Detection	118
6.5	EUI-64 and Neighbor Discovery	118
6.6	IPv6 over Ethernet	119
6.6.1	Frame Identifier	119
6.6.2	Multicast	119
6.6.3	Ethernet MTU	121
6.7	Point-to-Point Links	122
6.8	Multi-link Subnets	124
6.9	Router Advertisements of the Link MTU	125
6.10	Managing Neighbors on Hosts and Routers	125
6.10.1	FreeBSD	126
6.10.2	Linux	126
6.10.3	Solaris	127
6.10.4	Windows	128
6.10.5	Cisco	128
6.10.6	Hexago	129
6.10.7	Juniper	129
6.11	Summary	129
6.12	References	129
6.13	Further Reading	130
7	Internet Control Message Protocol	131
7.1	ICMP	131
7.1.1	Error Messages	132
7.1.2	Informational Messages	135
7.2	Neighbor Discovery	136
7.3	Hop Limit Set to 255	136
7.4	Managing ICMP on Hosts and Routers	136
7.4.1	FreeBSD	136
7.4.2	Linux	137
7.4.3	Solaris	137
7.4.4	Windows	137
7.4.5	Cisco	137
7.4.6	Hexago	138
7.4.7	Juniper	138
7.5	Summary	138
7.6	References	138
8	Naming with DNS and Selecting an Address	139
8.1	Hostname To IPv6 Address with the AAAA Record	139
8.2	IPv6 Address To Hostname	140
8.3	Transport	141
8.4	DNS Server Discovery	143

8.5	Node Information Query	143
8.6	IP Address Selection	143
8.7	Configuring DNS and Address Selection on Hosts and Routers	144
8.7.1	Configuring a Unix Client	144
8.7.2	Configuring BIND	144
8.7.3	Troubleshooting with Dig	146
8.7.4	FreeBSD	146
8.7.5	Linux	146
8.7.6	Solaris	146
8.7.7	Windows	146
8.7.8	Cisco	147
8.7.9	Hexago	147
8.7.10	Juniper	148
8.8	Summary	148
8.9	References	148
8.10	Further Reading	149
9	Routing	151
9.1	Required Router Addresses	151
9.2	Source Routing with the Routing Header	151
9.3	Route Redirect	154
9.4	Static Routes	155
9.5	RIP	155
9.5.1	Changes	156
9.6	OSPF	157
9.6.1	Changes	157
9.6.2	Router ID	157
9.6.3	Link-State Database	157
9.7	IS-IS	158
9.7.1	Changes	158
9.7.2	Multi-topology	159
9.8	BGP	159
9.8.1	Changes	159
9.8.2	Router ID	160
9.8.3	Link-local Addresses for Peering	160
9.8.4	Site Scoped Prefixes in Routes	160
9.9	Tunneling IPv6	160
9.10	Renumbering Routers	162
9.11	Internet Routing	163
9.12	Multihoming	166
9.12.1	Provider Independent Address Space	166
9.12.2	Multiple Prefixes	167
9.12.3	Cross-tunnels at Site Exit Routers	168
9.12.4	Propagation using Router Renumbering and Advertisements	168
9.12.5	Multihoming Work Progress	170
9.13	Summary	171
9.14	References	171
9.15	Further Reading	172
10	Configuring Routing	173
10.1	Considerations on Using Autoconfiguration for Router Interfaces	173
10.2	FreeBSD	174

10.2.1	Forwarding	174
10.2.2	Static Routes	174
10.2.3	Route Redirect	175
10.2.4	RIP	175
10.2.5	Troubleshooting	176
10.3	Linux	176
10.3.1	Forwarding	176
10.3.2	Static Routes	176
10.3.3	Route Redirect	177
10.3.4	Troubleshooting	177
10.4	Solaris	177
10.4.1	Static Routes	177
10.4.2	Troubleshooting	177
10.5	Windows	178
10.5.1	Forwarding	178
10.5.2	Static Routes	178
10.5.3	Troubleshooting	178
10.6	Cisco	179
10.6.1	IPv6 Forwarding	179
10.6.2	Cisco Express Forwarding	179
10.6.3	Prefix Lists	180
10.6.4	Static Routes	180
10.6.5	Route Redirect	180
10.6.6	RIP	180
10.6.7	OSPF	181
10.6.8	IS-IS	182
10.6.9	BGP	183
10.6.10	Troubleshooting	184
10.7	Hexago	184
10.8	Juniper	184
10.8.1	Martian Routes	185
10.8.2	Router ID	185
10.8.3	Static Routes	185
10.8.4	RIP	186
10.8.5	OSPF	186
10.8.6	IS-IS	187
10.8.7	BGP	188
10.8.8	Troubleshooting	190
10.9	Quagga	190
10.9.1	Static Routes	191
10.9.2	RIP	191
10.9.3	OSPF	191
10.9.4	BGP	192
10.9.5	Troubleshooting	193
10.10	Summary	193
10.11	Further Reading	193
11	Mobility	195
11.1	Overview	196
11.1.1	MobileIP Terminology	197
11.1.2	Basic MobileIP Process	197

11.1.3	Triangle Routing	198
11.1.4	Route Optimization	200
11.1.5	Handoff	200
11.2	MobileIP	202
11.3	Applications are not Aware of Mobility	202
11.4	Mobile Node is at Home	202
11.5	Mobile Node is away from Home	203
11.5.1	Mobile Node Registering to the Home Agent	204
11.5.2	Mobile Node Registering to the Correspondent Nodes	204
11.5.3	Mobile Node Sending Packets	204
11.5.4	Correspondent Node Sending Packets to the Mobile Node	205
11.6	Mobile Node is Moving Again	206
11.7	Mobile Node Comes Back Home	207
11.8	Securing the Binding Update	207
11.8.1	Security Association with Home Agent	207
11.8.2	Return Routability Procedure with Correspondent Nodes	207
11.9	Correspondent Node is Not MobileIP Aware	209
11.9.1	Mobile Node Registering to the Correspondent Node	210
11.9.2	Mobile Node Sending Packets	210
11.9.3	Correspondent Node Sending Packets to the Mobile Node	211
11.10	Advanced Features	212
11.10.1	Fast Handoff	212
11.10.2	Home Agent is Not Reachable	213
11.10.3	Mobile Networks	214
11.11	MobileIP Messaging	215
11.11.1	Mobility Extension Header	215
11.11.2	Home Address Destination Option Extension Header	215
11.11.3	Type 2 Routing Header	215
11.11.4	ICMP Messages	215
11.11.5	Neighbor Discovery	217
11.12	Deployment Considerations	218
11.12.1	Enterprise Network with Mobile Nodes on Most Links	218
11.12.2	Security Considerations	219
11.12.3	IP Version Centric	219
11.12.4	Ubiquitous IP	219
11.13	Configuring Mobility	219
11.13.1	FreeBSD	219
11.13.2	Linux	221
11.13.3	Solaris	222
11.13.4	Windows	222
11.13.5	Hexago	222
11.14	Summary	223
11.15	References	223
11.16	Further Reading	224
12	Wireless IP	225
12.1	Characteristics of Wireless Links	225
12.2	Header Compression over Limited Bandwidth Link Layers	226
12.3	TCP Behavior over Wireless	228
12.4	3GPP	229
12.5	3GPP2	231

12.6	Summary	231
12.7	References	231
12.8	Further Reading	232
13	Security	233
13.1	IP Security (IPsec)	234
13.1.1	IPsec Transport and Tunnel Modes	234
13.1.2	Establishing a Security Association	235
13.1.3	AH Header	235
13.1.4	ESP Header	239
13.1.5	IPsec and IPv4 NAT	241
13.1.6	IPsec and IPv6	243
13.2	Secure Shell (SSH)	243
13.3	Filtering and Firewalls	244
13.3.1	ICMP Filtering	244
13.3.2	MobileIPv6	244
13.3.3	Network Address/Port Translation	244
13.4	Temporary Addresses	244
13.5	More Secure Protocols	245
13.6	Securing IPv6 on the Link	245
13.6.1	Threats and Trust Models for IPv6 on the Link	246
13.6.2	Secure Neighbor Discovery	246
13.7	Is IPv6 More Secure?	248
13.8	Configuring Security on Hosts and Routers	248
13.8.1	FreeBSD	248
13.8.2	Windows	250
13.8.3	Cisco	250
13.8.4	Juniper	251
13.9	Summary	253
13.10	References	253
14	Quality of Service	255
14.1	IPv5: Streaming Protocol	255
14.2	Diffserv	256
14.3	Integrated Services	256
14.3.1	RSVP	257
14.3.2	Flow Label	259
14.4	Network Address Translation	260
14.5	Hardware processing	260
14.6	Configuring QoS on Hosts and Routers	261
14.6.1	FreeBSD	261
14.6.2	Linux	262
14.6.3	Solaris	262
14.6.4	Cisco	262
14.7	Summary	262
14.8	References	262
15	Multicast and Anycast	265
15.1	Multicast Basics	265
15.2	Multicast Listener Discovery	267
15.2.1	Node Joining a Multicast Group	267
15.2.2	Node Leaving a Multicast Group	268

15.2.3	Router Verifying Group Membership	268
15.2.4	Electing a Router	269
15.2.5	Multicast Listener Discovery Version 2	269
15.3	Multicast Routing	270
15.4	Multicast Address Allocation	270
15.5	Unicast-based Multicast Addressing	271
15.6	Allocation of Multicast Addresses	271
15.7	Multicast Reserved Addresses	272
15.8	Anycast	273
15.9	Configuring Anycast and Multicast on Hosts and Routers	275
15.9.1	FreeBSD	275
15.9.2	Linux	275
15.9.3	Solaris	275
15.10	Summary	275
15.11	References	275
16	Deploying IPv6 in IPv4 Dominant Networks	277
16.1	Combined IPv4 and IPv6 Network	277
16.2	Tunneling IPv6 in IPv4	278
16.2.1	Encapsulation	278
16.2.2	Host to Router Encapsulation	279
16.2.3	Router to Router Encapsulation	280
16.2.4	Static Tunneling	281
16.2.5	6to4	283
16.2.6	ISATAP	290
16.2.7	IPv6 in IPv4 Tunneling Considerations	294
16.2.8	Encapsulating IPv6 in UDP IPv4	300
16.2.9	Tunnel Setup Protocol (TSP) Tunnel Broker	301
16.2.10	Teredo	317
16.3	Tunneling IPv6 in GRE-IPv4	325
16.3.1	Requirements	326
16.3.2	Limitations	326
16.3.3	Applicability	326
16.4	Comparing IPv6 in IPv4 Solutions	326
16.5	Configuring IPv6 in IPv4 Dominant Networks	326
16.5.1	Examples	326
16.5.2	FreeBSD	329
16.5.3	Linux	330
16.5.4	Solaris	331
16.5.5	Windows	333
16.5.6	Cisco	335
16.5.7	Hexago	336
16.5.8	Juniper	342
16.6	Summary	343
16.7	References	343
17	Deploying IPv6 Dominant Networks with IPv4 Support	345
17.1	Tunneling IPv4 in IPv6	345
17.1.1	IPv4 in IPv6 Encapsulation	345
17.1.2	IPv4 in IPv6 Static Tunnels	345

17.1.3	DSTM with DHCPv6	347
17.1.4	TSP Tunnel Broker	348
17.2	IP Packet and Transport Translation	350
17.3	Configuring IPv4 in IPv6 Dominant Networks	351
17.3.1	FreeBSD	351
17.3.2	Solaris	352
17.3.3	Cisco	353
17.3.4	Hexago	353
17.3.5	Juniper	354
17.4	Summary	355
17.5	References	355
18	Migrating with Application Level Gateways	357
18.1	Application Level Gateway	357
18.2	Application Specific Proxy	358
18.3	Considerations of Application Level Gateways	358
18.4	Summary	358
19	Transport Protocols	359
19.1	Checksum	359
19.2	Transmission Control Protocol (TCP)	360
19.2.1	Explicit Congestion Notification (ECN)	360
19.3	User Datagram Protocol (UDP)	362
19.4	Internet Control Message Protocol (ICMP)	363
19.5	Summary	363
19.6	References	363
20	Network Management	365
20.1	SNMP Transport	365
20.2	Management Information Base (MIB)	366
20.3	Other Management Tools	367
20.4	Authentication, Authorization and Accounting using RADIUS	367
20.5	Configuring SNMP on Hosts and Routers	368
20.5.1	Cisco	368
20.5.2	Hexago	368
20.5.3	Juniper	368
20.6	Summary	369
20.7	References	369
21	Porting Applications	371
21.1	Introduction	371
21.2	Considerations	371
21.2.1	IP Protocol Version Independence	372
21.2.2	Multiple Addresses	372
21.2.3	Scoped Addresses	372
21.2.4	Address Memory Space	372
21.2.5	URL and Text Representation of IP Addresses	372
21.3	Structures	373
21.3.1	Struct addrinfo	373
21.3.2	Struct sockaddr_in6	374

21.3.3	Struct sockaddr_storage	374
21.3.4	Definitions	374
21.4	Functions	375
21.4.1	Getaddrinfo	375
21.4.2	Getnameinfo	375
21.4.3	Macros	376
21.5	Change Table	376
21.6	Best Practice	377
21.7	Basic Example	377
21.8	Summary	380
21.9	References	380
21.10	Further Reading	380
22	Configuration and Usage of IPv6-enabled Open Source Software	381
22.1	Apache Web Server	381
22.2	Sendmail	382
22.3	Postfix	382
22.4	SSH	383
22.5	XFree86	383
22.6	MRTG	383
22.7	Dovecot	384
22.8	Summary	384
22.9	References	384
23	Best Current Practices and Case Studies	385
23.1	IPv6 Internet Address Space	385
23.2	IPv6 Address Policy	385
23.3	IPv6 Address Planning	387
23.3.1	Optimal Address Plans	387
23.3.2	Numbering Links	388
23.3.3	EUI-64 Considerations	388
23.3.4	Use of Unique Local Address Space	389
23.4	Incremental Deployment	389
23.5	DNS Considerations	390
23.5.1	Publishing the AAAA Record	390
23.5.2	Publishing Special IPv6 Addresses	390
23.5.3	TTL Use	391
23.6	Routing Considerations	391
23.6.1	Topologies	391
23.6.2	Policies	391
23.7	Security Considerations	391
23.7.1	End-to-End-Model	391
23.7.2	Policies	392
23.7.3	Transition Mechanisms	393
23.7.4	Special Addresses	393
23.8	Mail Considerations	393
23.9	Deploying IPv6 and Connecting to the IPv6 Internet	393
23.9.1	Connecting a Single Node	393
23.9.2	Connecting a Mobile Node	394
23.9.3	Connecting a Home Network	394
23.9.4	Connecting a Small Network	394

23.9.5	Enterprise and Military Networks	404
23.9.6	Provider Networks	406
23.9.7	Mobile Networks	406
23.9.8	IPv6-only Networks	406
23.10	Summary	407
23.11	References	407
23.12	Further Reading	407
24	Conclusion	409
25	Quick Reference	411
	Index	413

Migrating to IPv6

A practical guide to
implementing IPv6
in mobile and
fixed networks

Marc Blanchet, Québec, Canada

Understand IPv6, the protocol essential to future Internet growth.

Exhaustion of address space and global routing table growth necessitate important revisions to the current version of the Internet Protocol, IPv4. IP version 6 offers greater address space and additional features to support the evolving requirements of Internet applications. Deployed alongside current IPv4 networks, IPv6 will restore the full-fledged network necessary for Internet growth. *Migrating to IPv6* gives a comprehensive overview of IPv6 and related protocols, from the layers below IPv6 to the application and end-user layers. Author Marc Blanchet offers a direct and clear route to understanding the topic, taking a top-down approach and ordering topics by relevance. Tried and tested practical techniques and advice on implementation, applications and deployment provide 'how-to' information on everything you need to know to put the technology to work.

Migrating to IPv6:

- Provides a complete, up-to-date, in-depth, and accessible practical guide to IPv6.
- Demonstrates the theory with practical and generic examples and major implementation configurations, such as Windows, FreeBSD, Linux, Solaris, Cisco, Juniper and Hexago.
- Provides a comprehensive reference to key data structures and packet formats.
- Summarizes topics in tabular and graphical form to give fast access to information.
- Heavily illustrated with over 200 figures.
- Offers an accompanying website with extra coverage of specific topics, information on additional protocols and specifications, and updates on new features.

This text will give network engineers, managers and operators, software engineers, IT professionals and analysts a thorough understanding of IPv6.

"Marc's book is what every engineer on this planet is mandated to read to become the most advanced New Generation Internet engineer."

Latif Ladid, President, IPv6 Forum, Chair, European IPv6 Task Force

"This book is a thorough and logical engineer's walk through the universe of IPv6, ideal for those who need a good technical understanding of the future Internet protocol."

Brian E Carpenter, IETF Chair, Distinguished Engineer, Internet Standards & Technology, IBM

"This book will be an invaluable and reliable assistant if your task is to make IPv6 work in your network."

Geoff Huston, Author of the "ISP Survival Guide", Senior Internet Researcher,
Asia Pacific Network Information Centre

www.ipv6book.ca

Technically reviewed by Jun-ichiro "itojun" Hagino
Foreword by Vint Cerf

 **WILEY**
wiley.com

ISBN 0-471-49892-0



9 780471 498926