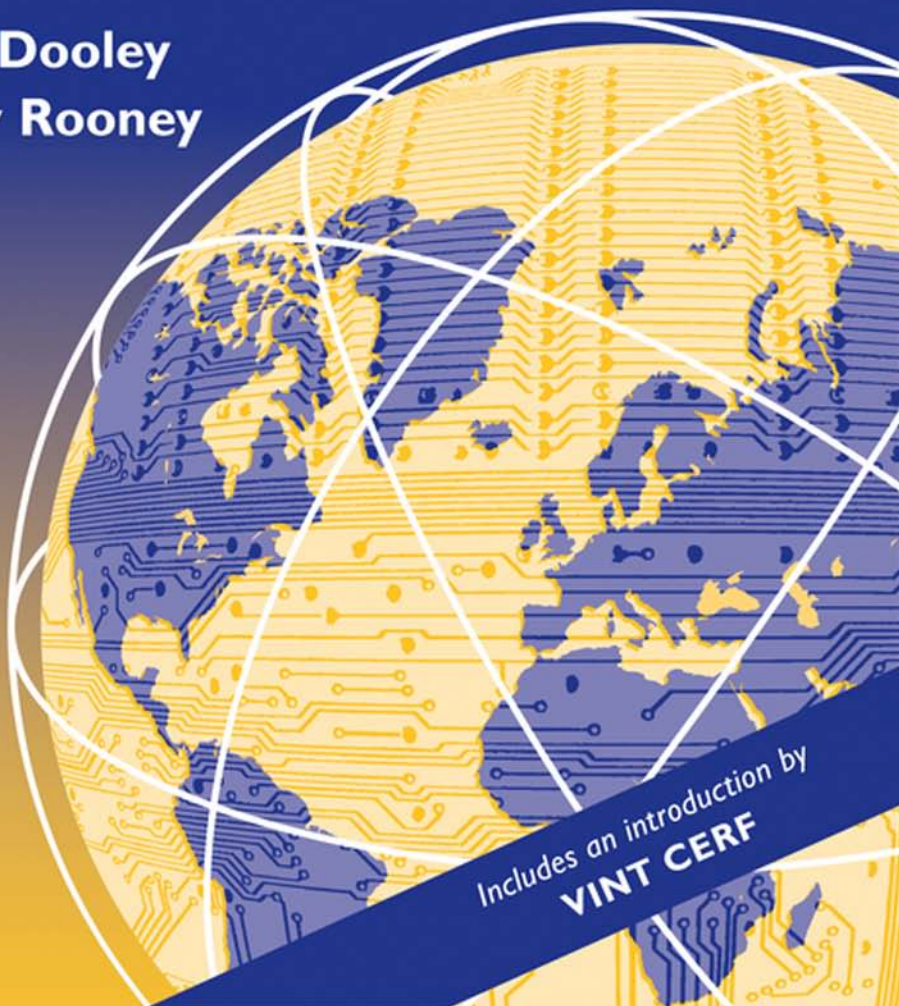


# IPv6 DEPLOYMENT AND MANAGEMENT

Michael Dooley  
Timothy Rooney



Includes an introduction by  
**VINT CERF**

 **IEEE**  
IEEE PRESS

 **IEEE Press**  
Series on  
Network  
Management  
Thomas Plevyak and  
Veli Sahin, Series Editors

**WILEY**



# *IPv6 DEPLOYMENT AND MANAGEMENT*

**IEEE Press**  
445 Hoes Lane  
Piscataway, NJ 08854

**IEEE Press Editorial Board 2013**  
John Anderson, *Editor in Chief*

Linda Shafer  
George W. Arnold  
Ekram Hossain  
Om P. Malik

Saeid Nahavandi  
David Jacobson  
Mary Lanzerotti

George Zobrist  
Tariq Samad  
Dmitry Goldgof

Kenneth Moore, *Director of IEEE Book and Information Services (BIS)*

---

# *IPv6 DEPLOYMENT AND MANAGEMENT*

**By**

**MICHAEL DOOLEY**

**TIMOTHY ROONEY**



**WILEY**

Copyright © 2013 by The Institute of Electrical and Electronics Engineers, Inc.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey. All rights reserved.  
Published simultaneously in Canada.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 750-4470, or on the web at [www.copyright.com](http://www.copyright.com). Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at <http://www.wiley.com/go/permission>.

**Limit of Liability/Disclaimer of Warranty:** While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Neither the publisher nor author shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

For general information on our other products and services or for technical support, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic formats. For more information about Wiley products, visit our web site at [www.wiley.com](http://www.wiley.com).

***Library of Congress Cataloging-in-Publication Data:***

Rooney, Tim.

IPv6 deployment and management / Timothy Rooney, Michael Dooley.  
pages cm

ISBN 978-1-118-38720-7 (pbk.)

1. TCP/IP (Computer network protocol)
  2. Internet addresses. I. Title.
- TK5105.585.R66 2013  
004.6'2068—dc23

2012041248

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

*Michael would like to dedicate this book to his parents*

*Timothy would like to dedicate this book  
in memory of his mother, Kathryn  
“Kitty” Rooney*





# CONTENTS

<i>ACKNOWLEDGMENTS</i>	<i>XI</i>
<i>INTRODUCTION</i>	<i>XIII</i>
<b>1</b> <i>IPv6 DEPLOYMENT DRIVERS</i>	<i>1</i>
1.1    The Internet: A Success Story	1
1.1.1    Supply-Side Issues	3
1.1.2    Internet at a Crossroads	6
1.1.3    Which Internet Are You On?	7
1.2    Emerging Applications	7
1.3    IPv6 Business Case	10
<b>2</b> <i>IPv6 OVERVIEW</i>	<i>13</i>
2.1    IPv6 Key Features	14
2.2    The IPv6 Header	14
2.2.1    IPv6 Extension Headers	15
2.3    IPv6 Addressing	17
2.3.1    Address Notation	18
2.3.2    Address Structure	19
2.3.3    IPv6 Address Allocations	20
2.3.4    Internet Control Message Protocol for IPv6 (ICMPv6)	27
2.3.5    IPv6 Ping	28
2.3.6    Multicast Listener Discovery	28
2.3.7    Multicast Router Discovery	31
2.3.8    Neighbor Discovery Protocol	31
2.3.9    Secure Neighbor Discovery (SEND)	33
2.3.10    Inverse Neighbor Discovery	33
2.3.11    Router Renumbering	34
2.3.12    Node Information Query	34
2.4    IPv6 Address Autoconfiguration	35
2.4.1    Modified EUI-64 Interface Identifiers	36
2.4.2    Duplicate Address Detection (DAD)	37
2.5    Mobile IPv6	38
2.6    Reserved Subnet Anycast Addresses	40
2.7    Required Host IPv6 Addresses	41
2.8    IPv6 Routing	41

<b>3</b>	<b><i>IPv4/IPv6 CO-EXISTENCE TECHNOLOGIES</i></b>	<b><i>43</i></b>
3.1	Dual Stack	44
3.1.1	Implementing Dual Stack	44
3.1.2	Which Address Is Used?	45
3.1.3	DNS Considerations	47
3.1.4	DHCP Considerations	48
3.2	Tunneling Approaches	49
3.2.1	Tunneling Scenarios for IPv6 Packets Over IPv4 Networks	49
3.2.2	Tunnel Types	51
3.2.3	Tunneling Scenario for IPv4 Packets Over IPv6 Networks	62
3.2.4	Tunneling Summary	63
3.3	Translation Approaches	63
3.3.1	IP/ICMP Translation	65
3.3.2	Bump in the Host (BIH)	72
3.3.3	Network Address Translation for IPv6/IPv4 (NAT64)	74
3.3.4	Other Translation Techniques	75
3.4	Application Support of IPv6	78
3.5	Service Provider IPv4/IPv6 Co-Existence	78
3.5.1	Reference Architecture	79
3.5.2	Deployment Approaches Overview	80
3.5.3	Routing Infrastructure Deployment Approaches	80
3.5.4	Comparison of Deployment Approaches	87
3.6	Addressing and DNS Considerations	87
<b>4</b>	<b><i>IPv6 READINESS ASSESSMENT</i></b>	<b><i>91</i></b>
4.1	Putting a Plan in Place	92
4.2	IP Network Inventory	93
4.2.1	IPv6 Readiness	93
4.2.2	Discovery	93
4.2.3	IPv6 Assessment	94
4.3	IPv6 to do List	106
4.4	IPv6 Readiness Assessment Summary	106
<b>5</b>	<b><i>IPv6 ADDRESS PLANNING</i></b>	<b><i>109</i></b>
5.1	Internet Registries	109
5.1.1	RIR Address Allocation Policies	111
5.1.2	Address Allocation Efficiency	112
5.2	IPv6 Address Planning	112
5.3	IPv6 Address Allocation Methods	113
5.3.1	Best-Fit Method	114
5.3.2	Sparse Allocation Method	116
5.3.3	Random Allocation	117
5.3.4	DHCPv6 Prefix Delegation	118
5.3.5	Unique Local Address Space	118
5.4	Defining Your IPv6 Address Plan	118
5.5	Multihoming and IP Address Space	122
5.6	IP Address Planning Summary	125

<b>6</b>	<b><i>IPv6 SECURITY PLANNING</i></b>	<b><i>127</i></b>
6.1	The Good News: IP Is IP	127
6.2	The Bad News: IPv6 Is Not IPv4	128
6.3	Update Your Security Policy	129
6.4	Network Perimeter Monitoring and Intrusion Prevention	129
6.4.1	IPv6 Address Filtering	130
6.4.2	ICMPv6 Messages	131
6.5	Extension Headers	132
6.6	Internal Network Protection	133
6.6.1	Network Reconnaissance	133
6.6.2	Network Access	134
6.6.3	DHCPv6	135
6.6.4	DNS	135
6.6.5	Anycast Addressing	136
6.6.6	Internal Network Filtering	136
6.7	Network Device Security Considerations	137
6.8	Mobile IPv6 Security	138
6.8.1	Mobility Extension Header	139
6.8.2	Mobile IPv6 Vulnerabilities	143
6.9	IPv4/IPv6 Coexistence Measures	144
6.9.1	Securing Tunneling Implementations	145
6.9.2	Securing Translation Implementations	146
6.10	Summary	148
<b>7</b>	<b><i>IPv6 NETWORK MANAGEMENT PLANNING</i></b>	<b><i>149</i></b>
7.1	Management Model	149
7.2	Network Management Scope	150
7.2.1	Network Inventory	150
7.2.2	IP Address Inventory	151
7.2.3	The Management Network	151
7.3	The Simple Network Management Protocol (SNMP)	152
7.3.1	Configuration Management	153
7.3.2	Fault Management	153
7.3.3	Accounting Management	154
7.3.4	Performance Management	154
7.4	Methods and Procedures	154
7.5	Summary	155
<b>8</b>	<b><i>MANAGING THE DEPLOYMENT</i></b>	<b><i>157</i></b>
8.1	Integrating Plans	157
8.2	Project Management	159
8.3	Testing Deployment	160
8.4	Production Deployment	161
<b>9</b>	<b><i>MANAGING THE IPv4/IPv6 NETWORK</i></b>	<b><i>163</i></b>
9.1	Common Network Management Tasks	163
9.2	Configuration Management	163

## **X CONTENTS**

9.2.1	Network Allocation-Related Tasks	164
9.2.2	Adding a New Device	166
9.2.3	Deletion Tasks	167
9.2.4	Address Renumbering or Movement Tasks	168
9.2.5	Block/Subnet Splits	171
9.2.6	Block/Subnet Joins	172
9.2.7	DHCPv6 Server Configuration	173
9.2.8	DNS Server Configuration	174
9.2.9	Prefix Renumbering	175
9.3	Fault Management	176
9.3.1	Fault Detection	176
9.3.2	Troubleshooting and Fault Resolution	177
9.4	Accounting Management	177
9.4.1	Inventory Assurance	177
9.4.2	Address Reclamation	180
9.5	Performance Management	181
9.5.1	Services Monitoring	181
9.5.2	Application Performance Management	182
9.5.3	Auditing and Reporting	182
9.6	Security Management	183
9.7	Disaster Recovery/Business Continuity	183
<b>10</b>	<b><i>IPv6 AND THE FUTURE INTERNET</i></b>	<b><i>185</i></b>
10.1	Technology Enablers	185
10.2	The Internet's Dark Side	187
10.3	The Internet's Bright Future	187
10.3.1	Living Smarter	187
10.3.2	Keeping Track	188
10.3.3	Extensible Healthcare	188
10.3.4	Public Safety	188
10.3.5	Credit Cards of the Future	188
10.3.6	Consumer Applications	188
10.4	Conclusion	189
	<b><i>APPENDIX</i></b>	<b><i>191</i></b>
	<b><i>BIBLIOGRAPHY</i></b>	<b><i>193</i></b>
	<b><i>INDEX</i></b>	<b><i>199</i></b>

---

# ACKNOWLEDGMENTS

We would both like to thank Vint Cerf for the introduction to this book; we are humbled and honored. We would also like to thank Thomas Plevyak, our series editor at IEEE Press, as well as Michael Vincent and Jeff Schmidt for their time spent reviewing drafts of this book and providing extremely useful feedback and comments.

From Michael: I would also like to thank my family, my wife Suzanne, my son Michael, and my daughter Kelly, for all their love and support and allowing me not to be distracted at home while I was working on this book. And I can't forget my puppy Bailey as well, who nudged me at every opportunity to pet her instead of letting me write. I would also like to thank the following individuals who are my friends and coworkers. I have had the pleasure to work with some of the best and brightest people in the world, and I am truly blessed. In no particular order, I thank Karen Pell, Steve Thompson, Greg Rabil, John Ramkowsky, Alex Drescher, Brian Hart (aka Billy Bond), Bob Lieber, David Cross, and Al Hilton. I would also like to acknowledge the original Quadritek leadership team that I had the privilege to work with as we helped to define and create the IP Address Management market back in the early years, specifically including Arun Kapur, Keith Larson, and Leah Kelly. And a special thanks to Joe D'Andrea whose leadership has had a profound impact on my life and my career.

From Timothy: I would also like to thank my family, my wife LeeAnn, and my daughters Maeve and Tess, for their love and support during the development of this book! I would also like to thank the following individuals with whom I have had the pleasure to work and from whom I have learned tremendously about communications technologies and IPv6: Greg Rabil, John Ramkowsky, Andy D'Ambrosio, Alex Drescher, David Cross, Marco Mecarelli, Brian Hart, Frank Jennings, and those I have worked with at BT Diamond IP, INS, and Lucent. From my formative time in the field of networking at Bell Laboratories, I thank John Marciszewski, Anthony Longhitano, Sampath Ramaswami, Maryclaire Brescia, Krishna Murti, Gaston Arredondo, Robert Schoenweisner, Tom Walker, Ray Pennotti, and especially Thomas Chu.



---

# *INTRODUCTION*

Nearly 14 years have passed since RFC2460 was published, specifying the IPv6 packet format. Authored by Steve Deering and Bob Hinden, this document represented nearly 8 years of debate beginning in the early 1990s over how the Internet's 32-bit IPv4 address space could be expanded. There were four proposals for what was called "IPng" for IP next generation. I won't catalog them here except to say they varied dramatically in their functionality. There was even a fifth proposal to adopt the OSI connectionless networking protocol format (CLNP) that provoked howls of outrage from many passionate engineers in the Internet Engineering Task Force (IETF) where this problem was near the top of the agenda.

After all the debate, the cochairs of the IPng Working Group, Deering and Hinden, recorded the results in December 1998 and submitted them as RFC 2460 to the Internet Engineering Steering Group (IESG) for release to the RFC editor. Many of us hoped there would be an immediate effort to implement this protocol. There was great concern that the rate of consumption of the Internet address space was accelerating during the period now known as the "dot-boom." New Internet companies were popping up like mushrooms after a spring rain. But at the same time that the IPng debates were taking place, another effort to restrain IPv4 address consumption, through reinterpretation of the bits of the address structure, was in full swing. The so-called classless interdomain routing system made much more efficient use of address space by allowing any bit boundary in the address structure to mark the dividing line between "network" and "host." In addition, the concept of autonomous system (AS) was introduced through which to associate indicators (masks) illustrating where this boundary lay. The Border Gateway Protocol was revised to take into account the masks marking network and host extents in the address format. Together with rules to guide very conservative IPv4 address allocations by the Regional Internet Registries, the rate of consumption of IPv4 address space was substantially curtailed. So much so that the pressure to implement IPv6 generally dissipated.

Network address translation (NAT) functionality was also introduced to allow multiple devices using private IP address numbering to share a single public address space. Port numbers were used in the NAT boxes to map to/from public addresses and the private addresses associated with individual devices in a local network. This practice attracted cable and telecommunications providers who were offering Internet service because they could now maximize the number of devices that could share one "public" IP address. This improved the absolute number of customers they could sign up to be subscribers to their Internet service.

These various practices actually stretched the use of IPv4 addresses until February 2011 when the Internet Assigned Numbers Authority (IANA), operating under the auspices of the Internet Corporation for Assigned Names and Numbers,