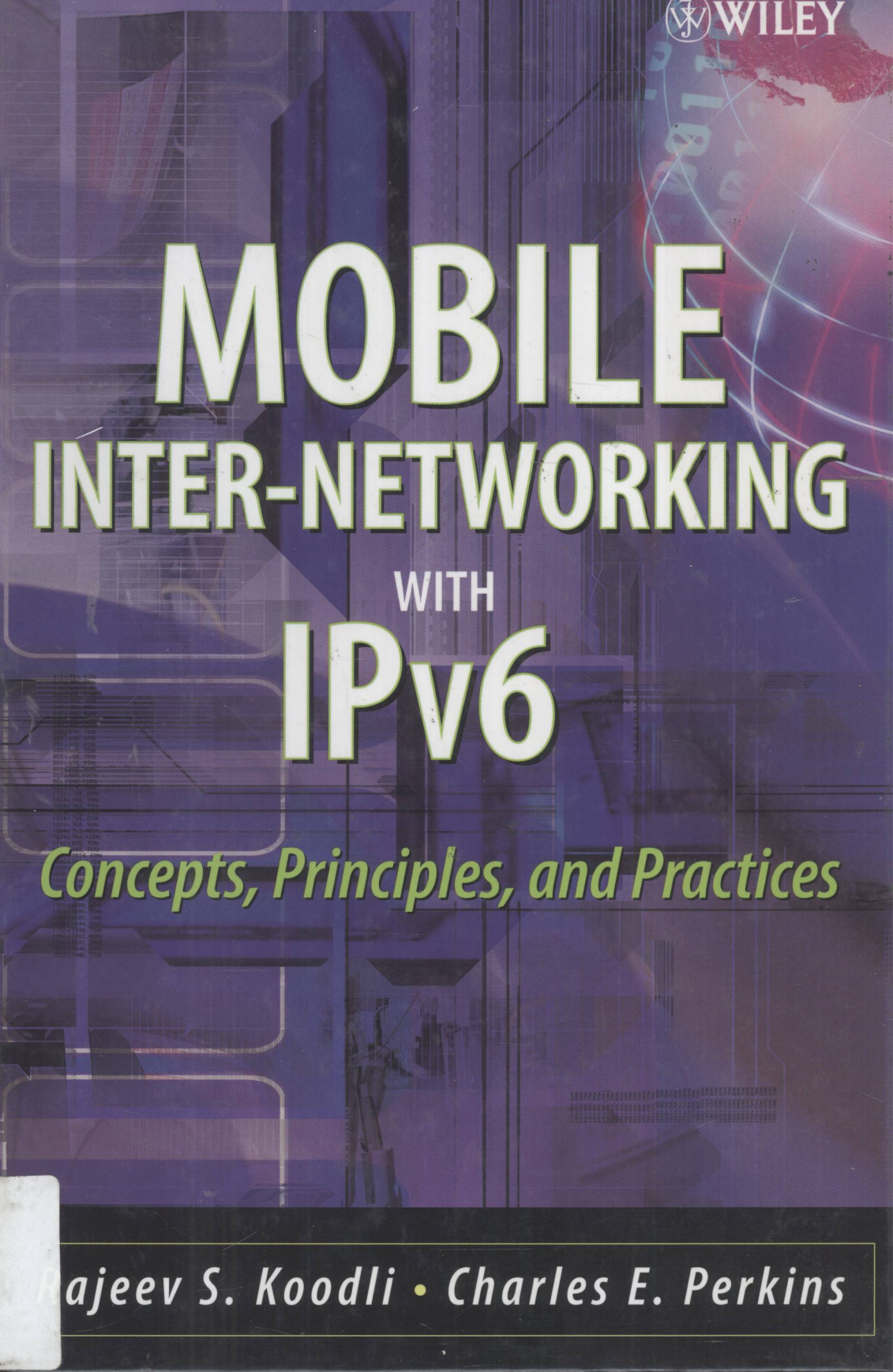
WILEY
MOBILE
INTER-NETWORKING
WITH
IPv6
Concepts, Principles, and Practices
Rajeev S. Koodli • Charles E. Perkins

MOBILE INTER-NETWORKING WITH IPv6

Concepts, Principles, and Practices

RAJEEV S. KOODLI and CHARLES E. PERKINS

WILEY-INTERSCIENCE
A John Wiley & Sons, Inc., Publication

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

Library of Congress Cataloging-in-Publication Data:

Koodli, Rajeev S., 1968–
Mobile inter-networking with IPv6 : concepts, principles, and practices /
Rajeev S. Koodli and Charles E. Perkins. — 1st ed.
p. cm.
"A Wiley-Interscience publication."
Includes bibliographical references and index.
ISBN 978-0-471-68165-6
1. Mobile communication systems. 2. TCP/IP (Computer network protocol) 3. Internetworking (Telecommunication) I. Perkins, Charles E., 1951– II. Title.
TK6570.M6K66 2007
621.3845'6—dc22 2006052808

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

MOBILE INTER-NETWORKING WITH IPv6

THE WILEY BICENTENNIAL–KNOWLEDGE FOR GENERATIONS

Each generation has its unique needs and aspirations. When Charles Wiley first opened his small printing shop in lower Manhattan in 1807, it was a generation of boundless potential searching for an identity. And we were there, helping to define a new American literary tradition. Over half a century later, in the midst of the Second Industrial Revolution, it was a generation focused on building the future. Once again, we were there, supplying the critical scientific, technical, and engineering knowledge that helped frame the world. Throughout the 20th Century, and into the new millennium, nations began to reach out beyond their own borders and a new international community was born. Wiley was there, expanding its operations around the world to enable a global exchange of ideas, opinions, and know-how.

For 200 years, Wiley has been an integral part of each generation's journey, enabling the flow of information and understanding necessary to meet their needs and fulfill their aspirations. Today, bold new technologies are changing the way we live and learn. Wiley will be there, providing you the must-have knowledge you need to imagine new worlds, new possibilities, and new opportunities.

Generations come and go, but you can always count on Wiley to provide you the knowledge you need, when and where you need it!

William J. Pesce

WILLIAM J. PESCE
PRESIDENT AND CHIEF EXECUTIVE OFFICER

Peter Booth Wiley

PETER BOOTH WILEY
CHAIRMAN OF THE BOARD

Preface

Internet access and mobility continue to change our perception of communications and computing. We are becoming more dependent on both, as can be seen by the continued proliferation of mobile telephones, personal digital assistants (PDAs), and laptop computers. Improvements in miniaturization and higher-speed communications media are creating an ever-increasing population of users for these electronic gadgets. To a certain extent, the basic applications remain very familiar: messaging, voice communications, e-mail, and Web access. More recently, we have seen that imaging and music are becoming important features in mobile communication. Image processing and rich video are not far behind.

Consumers want access to these applications wherever they go, and they naturally want to interconnect their gadgets for any of myriad reasons. The image should be easily tagged and shared with a group, and perhaps should be backed up locally on a home disk. The message should be transferred into an e-mail folder. The e-mail headers should be read aloud into the earphones hooked up to the mobile telephone. These are very natural requirements, yet far from universally satisfied. The inevitability of mobile computing and mobile Internet access will soon cause these features to be taken for granted.

Underneath the shiny personalized faceplates and the high-resolution LCD displays, there is a wholly different world of engineering to make these separate, mobile devices able to communicate on behalf of the users' applications. The genius of the Internet allows every device in the world to be separately addressable, and thus separately managed for the purpose of establishing communications pathways for the applications. In recent years, the Internet protocols for basic packet delivery have

been devised to handle the requirements of global mobility and application transparency. After all, the user doesn't want to worry about whether things will break just because the computer or telephone or communications device is operating in a different location. Up until now, unfortunately, we have had to worry about this far too much. The purpose of *Mobile IP* is to eliminate this source of bewilderment and worry.

This book provides the reader with a thorough understanding of how Mobile IP works, particularly in the context of the new Internet Protocol standard known as *IP version 6* (IPv6). Mobile IPv6, although functionally similar to Mobile IPv4 (which was explained in a previous publication), is quite different in detail due in part to conformance with IPv6 specifications and to experience gained over the years. For instance, "Route-Optimized" communication between mobile nodes and their correspondents is now an integral part of the Mobile IPv6 specification, not a separate protocol. Mobile IPv6 is specified as the mobility protocol for the *CDMA* cellular packet systems and is being specified as the mobility protocol for the *WiMax* networks.

While Mobile IPv6 is designed to provide basic mobility support on the Internet, there are some newer protocols known as *Fast Handover*, *Context Transfer*, and *Hierarchical Mobile IP* or *Regionalized Registration*. These protocols enable better performance for real-time applications such as voice and video, for which the connectionless aspect of base IP operation is typically insufficient for an enjoyable user experience. These protocols are gaining increasing importance as more and more communication, spearheaded by Voice over IP (VoIP), becomes dependent on the Internet Protocol.

Part IV of the book investigates how IP mobility is used in practice. We look at the adoption of Mobile IPv6 in CDMA cellular systems. We also investigate mobility in enterprises, where Virtual Private Networks (VPNs) and access enforcement devices such as firewalls end up interacting with mobility protocols.

Part V describes some experimental work, such as performance of VoIP over WLAN during handovers, multi-access networks and VoIP handovers, as well as emerging topics such as *Location Privacy*. This part is intended to expose the readers to experimentation involving mobility and to provide a glimpse of research one could envision.

Many chapters in this book have *Exercises* to encourage readers to pursue further the topics covered in the book. All chapters contain *References*, some of which may still be "works in progress" reflecting the nature of standardization in the *Internet Engineering Task Force* (IETF), the organization that specifies Internet standards such as TCP/IP, http, and SIP.

In order to take full advantage of the information in this book, you should be familiar with TCP/IP protocols, including IP, the *Internet Protocol*, and TCP, the *Transmission Control Protocol*). Rich Stevens' book "TCP/IP Illustrated Vol 1: The Protocols" and Douglas Comer's "Internetworking with TCP/IP" both provide excellent introductions to the topic. The book is otherwise self-contained, so that familiarity with Mobile IPv4 is not a requirement.

This book is designed to be useful for students interested in mobile networking with insights into communication protocols and details of operations. Engineers

reading this book will be able to implement Mobile IPv6 more effectively, having a clear understanding of the system impact of mobility. Experts may find it as a useful reference.

As you read the book, you will notice many italicized terms, some of which have conventional meanings which may be different from the expected ones (for example, *home agent*). These terms are defined in the Glossary, so please be sure that you understand their meaning before continuing.

We used LaTeX to write this book. It is a great tool, but it has a mind of its own! At times, it generously introduces extra space in exactly those places where you least wish for it. We have tried our best to "hand craft" around such tantrums, but there are a few places where we just had to let it go. We hope that our readers will be kind and understanding if there is any inconvenience.

Finally, a few comments on the *packet header*, which we will frequently encounter in this book. Any communication protocol must be able to define the syntax and semantics for communication. Such definitions must be clear and unambiguous. This is especially important for Internet communication protocols that traverse individual subnetworks. IP is a packet-based protocol, which basically means that communication takes place without dedicating a "circuit" for the sole use of a particular communication, but instead by using small chunks of *datagrams* or *packets*, a stream of which could be used to constitute a *session* or a *connection*. A header in IP defines fields which are essential for the IP software in the communicating end-points to understand how to process each packet. A packet header is shown in Internet Standards using ASCII pictures! In this book, we use the same ASCII notation (while admittedly sacrificing the aesthetics) to be consistent with the protocol specifications that readers will encounter in these standards.

R. S. KOODLI AND C. E. PERKINS

Mountain View, California

Acknowledgments

Many intelligent people have made major contributions to Mobile IPv6 and its companion protocols including Network Mobility, Fast Handovers, Hierarchical Mobility and so on. Thanks are due to all of them, especially to the long-suffering participants of the Mobile IP working group of the IETF. In addition to learning a lot and enjoying many good conversations during the years of development, we appreciate the many benefits and improvements that have resulted from the group effort. In these acknowledgments, we would like to mention specifically some people whose personal interactions have enriched our experience of developing the protocols and writing this book.

Our research colleagues in Nokia Research Center, in Mountain View, California played a very important part in helping to shape the way we understood the promise and potential of Mobile IPv6 by way of numerous prototype implementations from a very early version all the way to the eventual standard. We shared the joys and the pain of Connectathons, TAHI test suites, ETSI interoperability events, and countless internal demonstrations for various product managers and research associates. Our hearty thanks go to Vijay Devarapalli, Jari Malinen, T.J. Kniveton, and Meghana Patil nee Sahasrabudhe, as well as our fond hopes of working together again in the future. Thanks also to Hannu Flinck, who worked tirelessly and endured great stress to obtain funding for our many projects, apart from contributing to implementation. We also acknowledge the support of the head of our laboratory, Reijo Juvonen, especially for bearing with us on this seemingly never-ending (book) project. By extension, we wish also to give thanks to Nokia for supporting our research efforts. Our team at Mountain View was responsible for a long stream of Internet Drafts, protocol

enhancements, testbeds, demonstrations, RFCs, and published papers on the subject. From an outsider's point of view, it may have appeared like we had a team of twenty top researchers to have accomplished all we did.

Thanks to Pekka Nikander, who collaborated in the creation of the BAKE (Binding Authorization Key Establishment), which was one of the first protocols that could scale to the numbers needed for IPv6 and essentially offered us the confidence that the job could in fact really be done. Thanks to Basavaraj Patil, who as co-chair of the Mobile IPv6 working group and valued colleague within Nokia, never failed in his encouragement for us and assistance at numerous times. Thanks also to Francis Dupont, a long-time contributor to Mobile IPv6, who also supported the idea of inline mobility management signaling and produced a draft on the topic.

This book has benefitted immensely from the meticulous proofreading by the Wiley production staff, and Cedric Westphal, our longtime trusted colleague at Nokia. We are grateful to both of them.

No list of acknowledgments would be complete without mentioning the kind understanding and support we have derived from our families. Charlie would like to acknowledge his love and thanks to Diane, Greg and Phil! It was not so long ago that the boys were Gregory Russell and Philip Austin. Some day, you two might read and understand this book, at least as a historical artifact and maybe as a step along the way to a much better technological future.

Rajeev would like to dearly thank Vidya for her endurance and astute sense of knowing when to ask "How is it going?", and mother Ramaa Koodli for her persistence in asking "When are you finishing?". Rohan and Krithi have brought unfailing joy and cheer in life. You two already understand mobility, beginning with all the photos and videos you have taken on the phone, so perhaps you will take this book for granted!

K. P.

Acronyms

AAA	Authentication Authorization and Accounting
AH	Authentication Header
AP	Access Point
ARP	Address Resolution Protocol
BAck	Biding Acknowledgement
BCE	Binding Cache Entry
BS	Base Station
BSS	Basic Service Set (in Wireless LAN)
BU	Binding Update
CoA	Care-of Address
CN	Correspondent Node
CDMA	Code Division Multiple Access
DAD	Duplicate Address Detection
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
EAP	Extensible Authentication Protocol
ESP	Encapsulating Security Payload

FBU	Fast Binding Update
GGSN	GPRS Gateway Support Node
GPRS	General Packet Radio System
GSM	Global System for Mobile Communication
HA	Home Agent
HoA	Home Address
ICMP	Internet Control Message Protocol
IETF	Internet Engineering Task Force
IID	Interface Identifier
IKE	Internet Key Exchange (protocol)
IMS	IP Multimedia Subsystem
IP	Internet Protocol
IPsec	IP security
IPv6	Internet Protocol version 6
MAC	Media Access Control
MAP	Mobility Anchor Point
MN	Mobile Node
MH	Mobility Header
MR	Mobile Router
MS	Mobile Station
NAR	New Access Router
NAT	Network Address Translator
NEMO	Network Mobility
ND	Neighbor Discovery
PAR	Previous Access Router
PDSN	Packet Data Serving Node
QoS	Quality of Service
RFC	Request For Comments (an IETF protocol specification)
RO	Route Optimization
RTP	Real-time Transport Protocol
SA	Security Association
SAD	Security Association Database
SCTP	Stream Control Transmission Protocol
SGSN	Serving Gateway Support Node

SIP	Session Initiation Protocol
SPD	Security Policy Database
SPI	Security Parameter Index
SSID	Service Set Identifier
SSL	Secure Socket Layer
TCP	Transmission Control Protocol
TLS	Transport Layer Security
UDP	Unreliable Datagram Protocol
URI	Universal Resource Identifier
URL	Universal Resource Locator
VPN	Virtual Private Network
VoIP	Voice over IP
WLAN	Wireless LAN

Part I

Introduction and Background

As the Internet continues to shape and reshape our lives, there is a parallel phenomenon taking place in wireless (cellular) communication which is equally (if not more) influential. Personal and mobile voice communication has proved to be a major paradigm in the history of human communication. As both the Internet and mobile telephony continue their dramatic advances, their confluence is already emerging in image sharing, instant messaging and even some rudimentary forms of voice communication. However, it is only fair to recognize that this trend is in its infancy, and also perhaps has been affected by the existing Internet and cellular deployment limitations and deficiencies. The following few functionalities are considered necessary in the Mobile Internet:

- An ability to readily provide addressing support for billions of devices without severely restricting the spectrum of applications (and without burdening the network infrastructure itself)
- Easily support movement of users on the Internet from one network (e.g., Wireless Local Area Network (WLAN)) to another (e.g., 3G cellular)
- Provide adequate support for security

Perhaps there are others, but the above are arguably essential for a Mobile Internet.

In this part of the book, we provide a preliminary introduction to our main subject of Internet Protocol (IP) Mobility. We introduce the reader to the underlying problems in mobility on the Internet. We recognize that users value *persistence* of their communication, as well as the ability of their peers to reliably *reach* them in spite of mobility on the Internet. We will walk the reader through the events that take

place as a device connected to the Internet disconnects and plugs back into the Internet.

We will provide background on *IPv6*, the protocol designed primarily to provide an abundance of IP addresses for billions of devices, a large portion of which are going to mobile devices accessing the Internet. IPv6 is crucial for the evolution of the current Internet into a Mobile Internet. We also provide background on Internet Protocol security, or *IPsec*, which is a suite of protocols designed to provide comprehensive security at the IP layer. IP mobility protocols are obliged to make use of IPsec in order to protect messages that require adequate authorization. Chapters 2 and 3 present information which is immediately relevant for the rest of this book. We suggest that readers requiring additional information on these topics consult other references. On the other hand, those already familiar with these topics may still find the chapters refreshing.

Contents