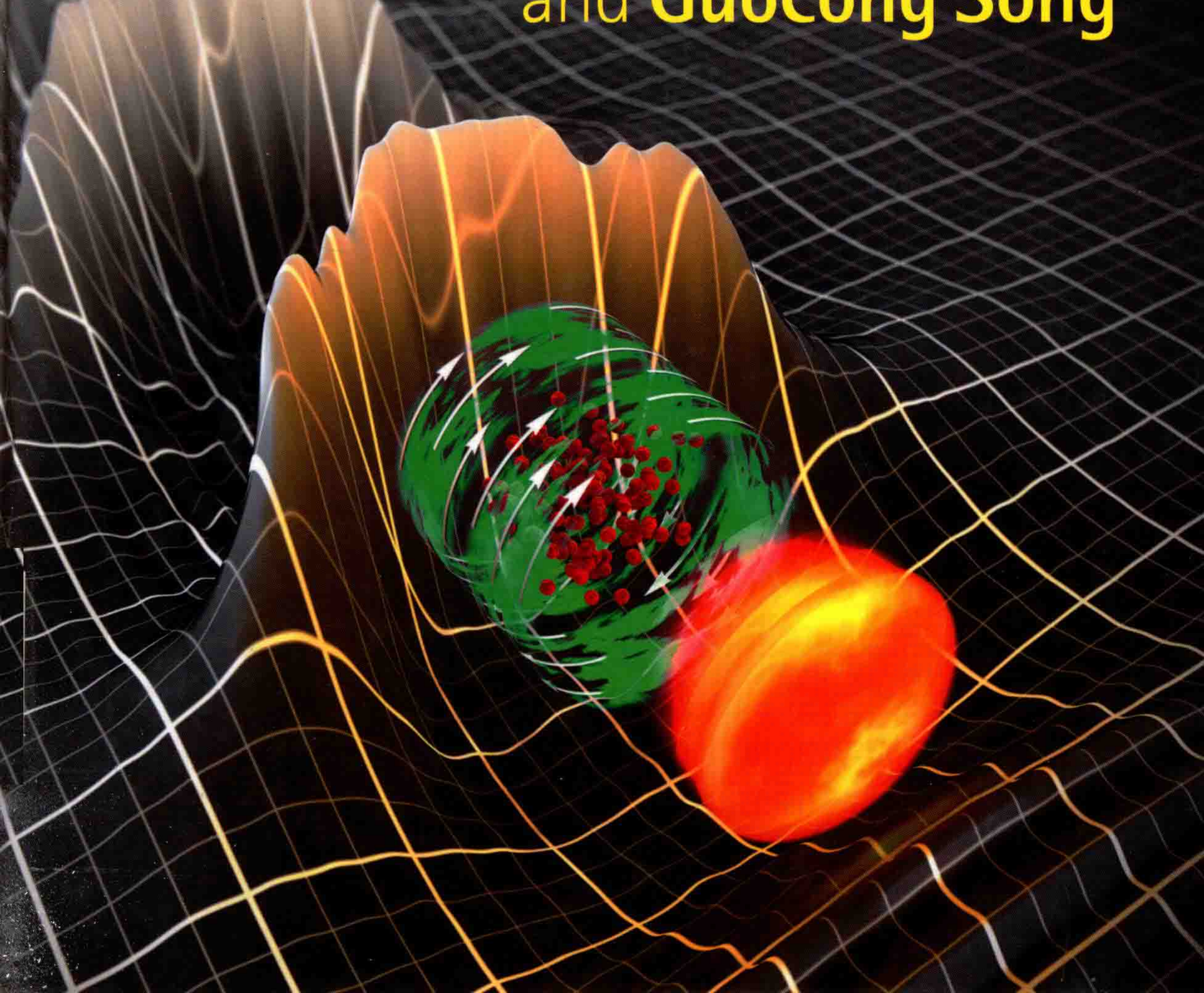
ENERGY AND SPECTRUM EFFICIENT WIRELESS NETWORK DESIGN

Guowang Miao
and Guocong Song



Energy and Spectrum Efficient Wireless Network Design

GUOWANG MIAO
KTH Royal Institute of Technology, Sweden

GUOCONG SONG
ShareThis, Palo Alto, California

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107039889

First published 2015

Printed in the United Kingdom by Clays, St Ives plc

A catalogue record for this publication is available from the British Library

Library of Congress Cataloguing in Publication data
Miao, Guowang.
Energy and spectrum efficient wireless network design / Guowang Miao, KTH Royal Institute of Technology, Sweden, Guocong Song, ShareThis, Palo Alto, California.
pages cm
ISBN 978-1-107-03988-9 (Hardback)
1. Wireless communication systems–Energy conservation. 2. Wireless communication systems–Energy consumption. 3. Radio frequency allocation. 4. Radio resource management (Wireless communications). 5. Engineering economy. I. Song, Guocong. II. Title.
TK5102.86.M53 2014
621.384–dc23 2014020418

ISBN 978-1-107-03988-9 Hardback

Energy and Spectrum Efficient Wireless Network Design

Covering the fundamental principles and state-of-the-art cross-layer techniques, this practical guide provides the tools needed to design MIMO- and OFDM-based wireless networks that are both energy- and spectrum-efficient. Technologies are introduced in parallel for both centralized and distributed wireless networks to give you a clear understanding of the similarities and differences between their energy- and spectrum-efficient designs, which is essential for achieving the highest network energy saving without losing performance. Cutting-edge green cellular network design technologies, enabling you to master resource management for next-generation wireless networks based on MIMO and OFDM, and detailed real-world implementation examples are provided to guide your engineering design in both theory and practice. Whether you are a graduate student, a researcher, or a practitioner in industry, this is an invaluable guide.

Guowang Miao is an Assistant Professor in the Department of Communications Systems at KTH Royal Institute of Technology, Sweden. After receiving his Ph.D. in electrical and computer engineering from Georgia Institute of Technology, USA, in 2009, he spent two years working in industry as a Senior Standard Engineer at Samsung Telecom America. His current research interests are in the design and optimization of wireless communications and networking.

Guocong Song is currently the Principal Research Engineering at ShareThis, Palo Alto, California. He has been working in wireless communications and networks for a decade, since receiving his Ph.D. in electrical and computer engineering from Georgia Institute of Technology. He received the 2010 IEEE Stephen O. Rice Prize for the best paper in the field of communications theory, and he is recently active in the area of data science and machine learning.

To

Ting Ren, Eileen Miao, and Ryan Miao

Wei and Lyra

Preface

This book provides a comprehensive introduction to the theory and practice of energy and spectrum efficient design for various types of wireless networks. The concepts and technologies are presented in a unified way for both centralized and distributed networks. The principles of the designs are stressed so that they can be applied in the broader context of wireless systems. The detailed derivations and proofs from first principles are provided. They are intended for the reader who desires a more in-depth understanding of the results. For the reader not interested in the detailed derivations, the concepts and theories are self contained and can be easily understood while skipping the derivations.

Energy and spectrum are two fundamental resources in wireless networks. A network design can always choose to optimize the utilization of one resource over the other. If one resource is redundant and the other is not, the design will need to optimize the network behavior towards better efficiency using that other resource. If both are adequate, then the system can be operated for the best user experience. If both are scarce, the design has to choose between them. Energy efficiency and spectrum efficiency are equally important and there is no clear advantage of one metric over the other. Which metric is more desired depends on network needs. This book presents a comprehensive yet rigorous discussion of the relationships between wireless channel state, energy efficiency, spectral efficiency, implementation, and network resource management in various wireless environments and their corresponding optimal designs.

The material in this book is structured into parallel discussions of energy and spectrum efficient designs, both of which are also discussed in parallell for centralized and distributed wireless networks. We hope this structure will facilitate the understanding of their similarities and distinctions.

The book is divided into four parts. In Part I, we introduce the basic concepts of wireless communications, e.g. wireless channel properties, performance metrics, conventional centralized and distributed radio resource management, that serve as the foundation to understand the book. The reader that is familiar with this background knowledge can skip this part and start from Part II directly. Part II introduces cross-layer designs for networks with central controllers and Part III for networks without central controllers. Both Parts II and III are focused on spectrum-efficient designs. Part II presents a generic framework for optimal opportunistic radio resource management in centralized networks by exploiting the multi-user diversity of time and frequency in wireless channels and regulating the resource allocation through network economics. Part III covers how to optimally exploit multi-user diversity in distributed wireless networks and shows how distributed random access can be designed to achieve spectrum efficiency comparable to that of ideal centralized schedulers. In Part IV, we present optimal energy-efficient transmission and resource management for both centralized and distributed wireless networks. For example, while the Shannon capacity results tell us the tightest spectrum efficiency upper bound of point-to-point communications, we introduce the tightest energy efficiency upper bounds, named energy efficiency capacity, for various types of channels. We also introduce energy-efficient centralized scheduling and distributed medium access control (MAC) and power control. The relationships between energy efficiency, spectral efficiency, and several other network performance metrics are rigorously examined. At the end of this part, we give a thorough discussion on energy-efficient cellular network designs and also on how to implement energy-efficient designs in practice.

This book is highly recommended for graduate-level courses as the primary or alternate textbook and professional tutorials in wireless networks and resource management. It provides material both to guide novice students as well as plenty of detailed in-depth material for graduate students pursuing research in the field. The book is also a useful reference for practicing engineers, academics, and industrial researchers. The only expected background of the reader is a basic understanding of probability, optimization, and digital communications. Background in wireless networks, radio resource management, and signal processing is helpful but not required, since we develop the related material in the text.

Acronyms

3GPP	3rd Generation Partnership Project
AD	adjustment
AM	amplitude modulation
AP	access point
APA	adaptive power allocation
AWGN	additive white Gaussian noise
BER	bit error rate
BS	base station
C/I	carrier to interference
CAD-MAC	channel-aware distributed medium access control
CCI	co-channel interference
CDF	cumulative distribution function
CDMA	code division multiple access
CIA-MAC	co-channel interference avoidance MAC
CoMP	coordinated multi-point transmission
CRC	cyclic redundancy check
CRS	contention resolution slot
CSI	channel state information
CSMA	carrier sense multiple access
CSMA/CA	carrier sense multiple access with collision avoidance
CSMA/CD	carrier sense multiple access with collision detection
CTS	clear to send
DOMRA	decentralized optimization for multi-channel random access
DSA	dynamic subcarrier assignment
EMMPA	energy-efficient MU-MIMO power allocation
ESPA	exhaustive search power allocation
EXP	exponential
FCC	Federal Communications Commission
FDM	frequency division multiplexing
FDMA	frequency division multiple access
FEC	forward error correction
FFR	fractional frequency reuse
FFT	fast Fourier transform
FM	frequency modulation

FPA	fixed power allocation
FS	frequency selective
HOL	head-of-line
ICR	interference to carrier ratio
ICT	information and communication technology
IFFT	inverse fast Fourier transform
LDPC	low density parity check
LLC	logical link control
LOS	line of sight
LS	least squares
LTE	long-term evolution
MAC	medium access control
MCS	modulation and coding scheme
MDU	maximum delay utility
MIMO	multiple-input multiple-output
M-LWDF	modified largest weighted delay first
MMSE	minimum mean squared error
M-QAM	M-ary quadrature amplitude modulation
MSC	maximum sum capacity
MT	mobile terminal
MU-MIMO	multiple user MIMO
OFDM	orthogonal frequency division multiplexing
OFDMA	orthogonal frequency division multiple access
OSI	open systems interconnect
PA	power amplifier
PAPR	peak to average power ratio
PC	personal computer
PDF	probability distribution function
PER	packet error rate
PF	proportional fair
PHY	physical
PSK	phase shift keying
QoS	quality of service
RF	radio frequency
RNC	radio network controller
RTS	request to send
SDMA	space division multiple access
SIMO	single-input multiple-output
SINR	signal to interference plus noise ratio
SNR	signal-to-noise ratio
TDD	time division duplex
TDMA	time division multiple access
WFQ	weighted fair queueing
WLAN	wireless local area networks

Contents