Interference Management in Wireless Networks

Fundamental Bounds and the Role of Cooperation

Learn about an information-theoretic approach to managing interference in future-generation wireless networks. Focusing on cooperative schemes motivated by coordinated multi-point (CoMP) technology, the book develops a robust theoretical framework for interference management that uses recent advancements in backhaul design, and practical pre-coding schemes based on local cooperation, to deliver the increased speed and reliability promised by interference alignment. Gain insight into how simple, zero-forcing pre-coding schemes are optimal in locally connected interference networks, and discover how significant rate gains can be obtained by making cell association decisions and allocating backhaul resources based on centralized (cloud) processing and knowledge of network topology. Providing a link between information-theoretic analyses and interference management schemes that are easy to implement, this is an invaluable resource for researchers, graduate students, and practicing engineers in wireless communications.

Venugopal V. Veeravalli is the Henry Magnuski Professor in the Department of Electrical and Computer Engineering at the University of Illinois at Urbana-Champaign, and a Fellow of the IEEE.

Aly El Gamal is an Assistant Professor in the Department of Electrical and Computer Engineering at Purdue University.

This is a concise, rigorous and authoritative introduction to the information-theoretic analysis of interference management in wireless systems. It provides a principled and comprehensive reference for students and researchers with a background in communication and information theory.

Professor Osvaldo Simeone, *King's College London*

Veeravalli and El Gamal have successfully captured in this book a most productive decade of fundamental research breakthroughs in our understanding of interference management and, especially, the role of cooperation in wireless networks. The topics covered are not only some of the most exciting directions for future wireless networks, but also they showcase some of the most elegant insights that information theory has to offer.

Professor Syed Jafar, *University of California, Irvine*

With new wireless networks becoming dramatically more complex to optimize, especially from an interference point of view, the availability of solid theoretical tools allowing to study the fundamental radio access performance of future mobile systems is a great plus to engineers and researchers alike. Up to my knowledge, this book is among the very first to give a solid and comprehensive analytical perspective in this area.

David Gesbert, *EURECOM*

The book stands out with its comprehensive treatment of fundamental information-theoretic tools for interference management and with detailed descriptions of algorithms that implement these tools. The book is thus very valuable for everyone who wants to understand how to design good practical interference management systems.

Michèle Wigger, *Telecom Paris-Tech*

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CAMBRIDGE
UNIVERSITY PRESS

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One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre,
New Delhi – 110025, India

79 Anson Road, #06-04/06, Singapore 079906

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/9781107165007
DOI: 10.1017/9781316691410

First published 2018

Printed in the United States of America by Sheridan Books, Inc.

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

Library of Congress Cataloging-in-Publication Data
Names: Veeravalli, Venugopal V., 1963– author. | Gamal, Aly El, 1985– author.
Title: Interference management in wireless networks : fundamental bounds and the role of cooperation / Venugopal V. Veeravalli, University of Illinois, Urbana-Champaign, Aly El Gamal, Purdue University.
Description: Cambridge, United Kingdom ; New York, NY, USA : Cambridge University Press, [2017] | Includes bibliographical references and index.
Identifiers: LCCN 2017038711 | ISBN 9781107165007 (hardback)
Subjects: LCSH: Radio–Interference. | Wireless communication systems–Management.
Classification: LCC TK7867.2.V44 2017 | DDC 621.388/1–dc23
LC record available at https://lccn.loc.gov/2017038711

ISBN 978-1-107-16500-7 Hardback

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Preface

Efficient interference management is the key to meeting the ever increasing demand for wireless data services in wireless networks. In this book, an information-theoretic framework for interference management is presented, along with a discussion of practically implementable schemes for interference management that approach provable bounds on performance and are applicable in large cellular networks.

A particular focus of the book is on exploiting recent technological advancements in the wireless infrastructure that enable cooperative transmission and reception. Our theoretical framework highlights the potential of this technology to deliver the rate gains promised by interference alignment, while using simple zero-forcing schemes that are easier to implement in practice. The schemes that we present rely on local cooperation, and they are shown to be optimal in locally connected interference networks, where the path loss effect allows us to neglect connections between transmitters and receivers that are far away from each other. It is also shown that cooperative communication can be used to deliver significant rate gains using simple zero-forcing with no or minimal extra load on the backhaul, by selecting cell associations and allocation of backhaul resources based on centralized processing and knowledge of the network topology. The insights obtained are also extended to dynamic interference networks that capture the effect of deep fading conditions.

This book is organized as follows:

- In Chapter 1, we provide a high-level introduction to interference management in wireless networks, including a historical perspective on wireless cellular networks, and we motivate the need for a fundamental information-theoretic understanding of this problem.
- In Chapter 2, we provide a detailed overview of the state of the art in determining the information-theoretic sum capacity of the interference channel. Determining the capacity even in the simplest setting with two users with one antenna at each of their transmitters and receivers is still an open problem, but exact results can be obtained in certain low-interference regimes that may arise in practice.
- In Chapter 3, we take an alternative approach to characterizing the rate of communication on an interference channel, based on a *degrees of freedom* (DoF) analysis, which is more analytically tractable. The DoF approach corresponds to analyzing the limiting normalized capacity as the signal-to-noise ratio goes to infinity, and the DoF measure emphasizes the loss in rate that results from the users interfering

with each other over the effect of channel noise. We also describe in Chapter 3 the important technique of interference alignment, which is justified through a DoF analysis. We follow this up with a study of iterative algorithms for approaching the interference alignment solutions for interference management in Chapter 4.

- In Chapter 5, we initiate the discussion of cooperative communication in large interference networks, and analyze the DoF of fully connected interference networks where each message can be available at more than one transmitter, as in coordinated multi-point (CoMP) transmission; this is particularly useful in locally connected networks where each of the transmitters is only connected to a set of neighboring receivers, as we show through the DoF analysis in Chapter 6. Further advantages from CoMP transmission can be gained by relaxing the cooperation constraint to one where the average number of transmitters per message cannot exceed a set value, as we show in Chapter 7. We study the dual problem of cooperative reception schemes for cellular uplink in Chapter 8, and show that similar gains in DoF with cooperation can be obtained in the uplink as in the downlink.
- In Chapter 9, we study dynamic interference networks, where we alter our interference network model to take into account deep fading conditions that can result in random link erasures. In Chapter 10, we discuss recent advances and open problems in the context of modern applications that are anticipated for upcoming generations of wireless networks.
- The book has two appendices: In Appendix A, we summarize some useful results from information theory, and in Appendix B we summarize some results in algebraic geometry.

The main audience for this book is researchers in wireless communication and information theory, with a focus on future generation cellular networks. The material in this book should be accessible to engineers working in the industry as special attention is given to bridging the gap between information-theoretic analyses and practical coding schemes.

Acknowledgments

Some of the material in Chapters 2, 5, and 6 is based on joint work with Sreekanth Annapureddy; some of the material in Chapters 4 and 5 is based on joint work with Craig Wilson; some of the material in Chapter 7 is based on joint work with Meghana Bande; some of the material in Chapter 8 is based on joint work with Manik Singhal; and some of the material in Chapter 9 is based on joint work with Yasemin Karacora and Tolunay Seyfi. We are grateful to Sreekanth Annapureddy, Craig Wilson, Meghana Bande, Manik Singhal, Yasemin Karacora, and Tolunay Seyfi for their contributions.

Our research on interference management in wireless networks over the last decade, which has led to this book, has been funded by the U.S. National Science Foundation through several grants, and also by Motorola, Intel, and Huawei, and we are grateful for this support.

Venugopal Veeravalli dedicates this book to his wife Starla Carpenter for her love and support over the years. Aly El Gamal dedicates this book to his family of seven electrical engineers, and Ali and Omar.