Full-Duplex Communications and Networks

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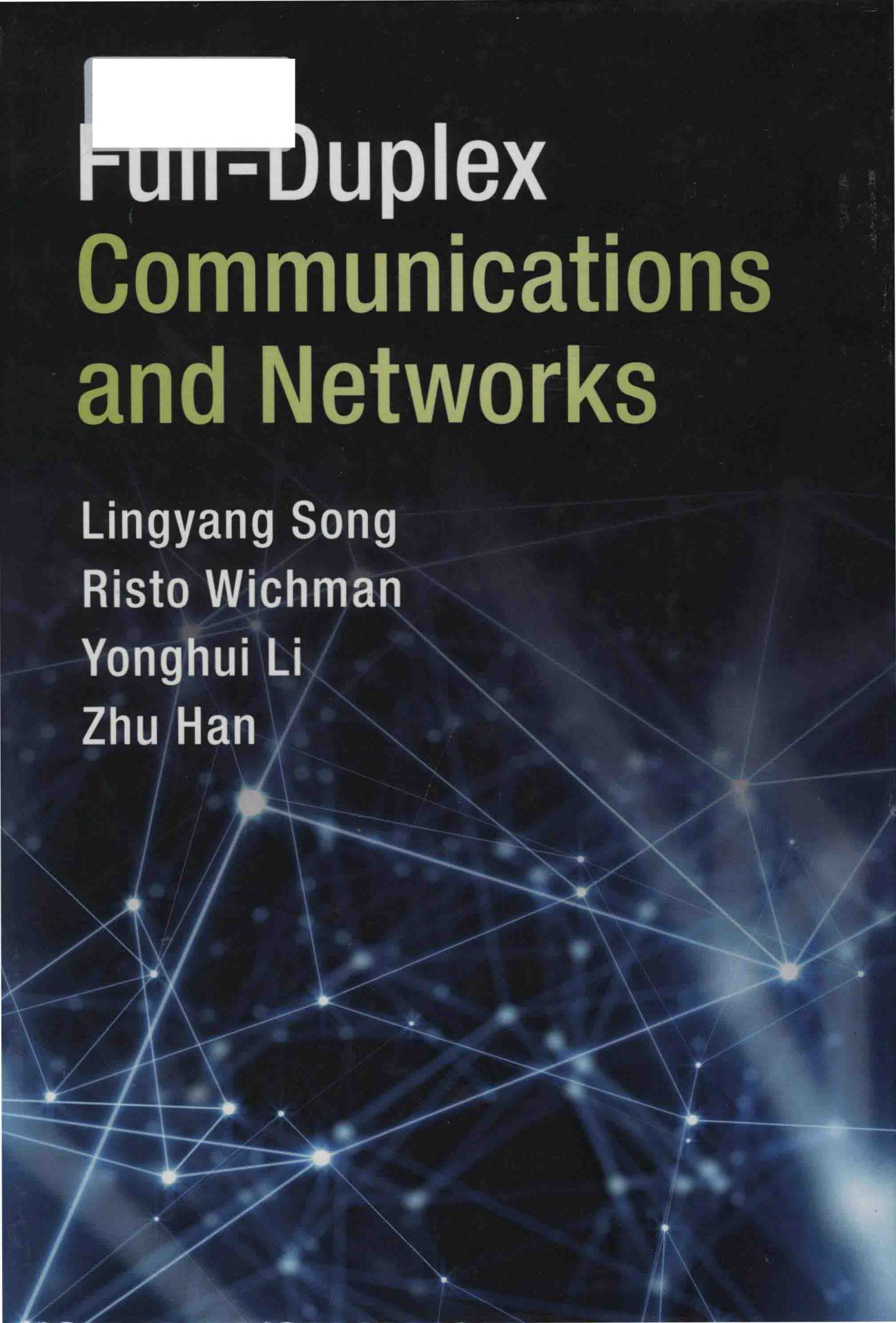

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Full-Duplex Communications and Networks

Learn about the key technologies and understand the state of the art in research for full-duplex communication networks and systems with this comprehensive and interdisciplinary guide. Incorporating physical, MAC, network, and application layer perspectives, it explains the fundamental theories on which full-duplex communications are built, and lays out the techniques needed for network design, analysis, and optimization. Techniques covered in detail include self-interference cancellation and signal processing algorithms, physical layer algorithms, transceiver design, resource allocation, networking and game theory for full-duplex systems. Potential applications and networking schemes are discussed, including full-duplex cognitive radio networks, cooperative networks, and heterogeneous networks.

The first book to focus exclusively on full-duplex communications, this is an indispensable reference for both researchers and practitioners designing the next generation of wireless networks.

Lingyang Song is Professor of Wireless Communications and Signal Processing in the School of Electrical Engineering and Computer Science at Peking University, China, and an IEEE Distinguished Lecturer. He is a coauthor of *Wireless Device-to-Device Communications and Networks* (Cambridge, 2015).

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To my wife, Tingting Li

—Lingyang Song

To my family

—Risto Wichman

To my three girls, Na Zou, Essie Li, and Eunice Li

—Yonghui Li

To my family

—Zhu Han

Preface

Overview

With more and more new multimedia-rich services being introduced and offered to a rapidly growing population of global subscribers, there is an ever-increasing demand for higher data rate wireless access, making more efficient use of this precious resource a crucial need. As a consequence, new wireless technologies such as Long Term Evolution (LTE) and LTE-Advanced have been introduced. These technologies are capable of providing high-speed, large-capacity, and guaranteed quality-of-service (QoS) mobile services. With the technological evolution of cellular networks, new techniques, such as small cells, have also been developed to further improve the network capacity by effectively reusing the limited radio spectrum. However, all existing wireless communication systems deploy half-duplex (HD) radios which transmit and receive the signals in two separate/orthogonal channels. They dissipate the precious resources by employing either time-division or frequency-division duplexing.

Full-duplex (FD) systems, where a node can send and receive signals at the same time and frequency resources, can offer the potential to double spectral efficiency; however, for many years it has been considered impractical. This is because the signal leakage from the local output to input, referred to as *self-interference*, may overwhelm the receiver, thus making it impossible to extract the desired signal. How to effectively eliminate self-interference has remained a long-standing challenge. Recently, there has been significant progress in self-interference cancellation in FD systems, which presents great potential for realizing FD communications for the next generation of cellular networks.

This book provides state-of-the-art research on FD communications and cellular networks covering the physical, MAC, network, and application layer perspectives. The book also includes fundamental theories based on which FD communications will be built. In addition to the self-interference cancellation signal processing algorithms, the book discusses physical layer algorithms, radio resource allocation and network protocols in the practical design and implementation of centralized and distributed FD wireless networks. Main applications such as FD cognitive radio networks, FD cooperative networks, and FD heterogeneous networks are explored.

The key features of this book are as follows:

- A unified view of FD communications and networking;
- A comprehensive review of the state-of-the-art research and key technologies of FD communications networks;
- Coverage of a wide range of techniques for design, analysis, optimization, and application of FD communications networks;
- An outline of the key research issues related to FD communications and networking.

To the best of the authors' knowledge, this is the first book on FD communications and networking. This book intends to provide background knowledge on FD communications, discuss the research challenges, review the existing literature on FD communications, and present techniques for analysis, design, optimization, and application of FD communications systems under given objectives and constraints.

Motivation and Objectives

Mobile data traffic, especially mobile video traffic, has dramatically increased in recent years with the emergence of smart phones, tablets, and various new devices and applications. It is therefore crucial to increase wireless network capacity to accommodate these bandwidth-consuming applications and services. FD communication is a promising concept to improve link efficiency, user experience, and resource utilization in cellular networks. However, design, analysis, and optimization of FD communications and networking require multidisciplinary knowledge, namely, knowledge of signal processing, communication theory, wireless communications and networking, artificial intelligence (e.g., for learning), decision theory, optimization, and economic theory. Therefore, a book containing the basic concepts/theories for addressing the research advances that enable FD communications for wireless networks, as well as the state-of-the-art research and development and related information, will be very useful for researchers and engineers. This is the primary motivation for writing this book.

There are three main objectives in writing this book:

1. The first is to provide a general introduction to FD-based wireless communications and networking from physical, MAC, networking layer requirements, and system design.
2. The second is to introduce the key techniques in enabling FD communications systems, and to present the related design, algorithms, analysis, and optimization problems in a comprehensive way.
3. The third is to present the state of the art of FD communications and networking schemes along with possible applications. This will include classifications of the different schemes and the technical details in each scheme.

The above objectives will be achieved as follows:

1. Starting with an introduction to wireless communications (including radio propagation and channel models), different wireless access technologies (e.g., cellular

wireless, WLAN, WMAN, and WPAN technologies) will be briefly reviewed. This will include their basic components, features, and potential applications. Then, advanced wireless communications technologies in the physical layer, such as cooperative communications, network coding, and cognitive radio, will be also discussed.

2. The requirements and main characteristics of FD communications will be discussed. Specifically, we will briefly describe the history, requirements, and physical-layer techniques, which enable interference cancellation, resource allocation, and possible applications.
3. Different self-interference cancellation and signal-processing techniques for FD communications will be discussed and analyzed. In this context, various cancellation methods, including antenna design, analog and digital methods, will be discussed.
4. Other physical-layer techniques are also critical for FD communications. To achieve FD transmission, the state-of-the art physical-layer approaches, such as channel estimation, synchronization, etc., should be adopted, and theoretical analysis on the performance limits will be investigated. FD system design issues will be explained in detail.
5. We will describe resource management techniques, which are required by FD communications systems for distributed spectrum sharing. Specifically, we will discuss methods for realizing efficient resource allocation, such as time, frequency, space, and device allocation, which can be developed based on optimization and game-theoretic models.
6. Game theory techniques will be discussed in the context of optimizing radio resources. Game theory is an attractive tool for modelling the spectrum-sharing problem in an FD communications network. The basics of different game theoretic models, namely, non-cooperative game, auction game, matching game and coalition game models, will be explained and modeled for FD communications and networks.
7. Then we discuss major research issues and possible extensions of FD communication and networks. Starting with FD MIMO networks, heterogeneous networks and cooperative networks, we then elaborate FD cognitive radio networks from physical to network layers: for example, FD-enabled WiFi, which realizes better co-existence of multiple distributed systems in the ISM bands.

Market and Readership

The reasons why this book is timely are based on the following observations:

- Boosts of mobile data traffic and scarcity of spectrum: Mobile data traffic has dramatically increased in recent years with the emergence of smart phones, tablets, and various new applications. It is hence crucial to increase network capacity to accommodate bandwidth-consuming applications and services. However, the frequency spectrum is the scarcest radio resource, and its efficient usage is crucial in the next generation of wireless communications systems. FD communication is a promising

concept to improve link efficiency, user experience and resource utilization in wireless networks. This new type of communication allows an additional communication dimension, and thus significantly improves network capacity and resource utilization.

- Interdisciplinary principles: Designing FD communications networks requires knowledge of multiple science and engineering disciplines to achieve the design objectives. These disciplines include traditional signal processing, wireless communications and networking, optimization and game theory, and network economics. Therefore, a unified treatment of this subject area is required.
- Emergence of FD-based wireless applications and services: Emerging wireless applications, a few of which are described below, can take advantage of FD communications:
  1. Future-generation cellular cooperative networks: Next-generation wireless networking is likely to include the features of device cooperation to enhance users' quality of experience (QoE). FD communication will facilitate provisioning of these future-generation wireless cooperative networks.
  2. FD cognitive radio networks: In traditional cognitive radio networks, secondary users (SUs) typically access the spectrum of primary users by a two-stage "listen-before-talk" protocol, i.e., SUs sense the spectrum holes in the first stage before transmitting in the second. With a FD radio, SUs can simultaneously sense and access the vacant spectrum. As a result, research topics such as spectrum-sensing algorithms, dynamic spectrum access, communication protocol design, etc., need to be redeveloped. Understanding the key concepts and design techniques for FD communications networks is fundamental for researchers, communications engineers, and application developers to implement the above FD-based applications.
- Integration of FD concepts in traditional wireless systems: FD communications techniques can be integrated into traditional wireless communications systems to achieve better flexibility of radio resource usage so that system performance can be improved: for example, load balancing/dynamic channel selection in traditional cellular wireless systems and WLANs, distributed subcarrier allocation in orthogonal frequency division multiplexing (OFDM) systems, etc.

The primary audience for this book consists of:

- Researchers and engineers interested in studying the new paradigm of FD communications overlaid with traditional cellular communications.
- Researchers and engineers interested in the state-of-the-art research on FD communications.
- Engineers in the field of LTE/LTE-Advanced for anticipating the emerging standards of FD communications.
- Graduate students interested in obtaining comprehensive information on design, evaluation, and applications of FD communications networks.

We sincerely hope this book can bring audiences new perspectives on the design of future communication and network systems, based on the new paradigm of full-duplex communications.

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