Wireless Device-to-Device Communications and Networks

Covering the fundamental theory together with the state of the art in research and development, this practical guide provides the techniques needed to design, analyze, and optimize device-to-device (D2D) communications in wireless networking.

With an ever-increasing demand for higher-data-rate wireless access, D2D communication is set to become a key feature supported by next-generation cellular networks. This book introduces D2D-based wireless communications from the physical-, MAC-, network-, and application-layer perspectives, providing all the key background information before moving on to discuss real-world applications as well as potential future developments. Key topics are discussed in detail, such as dynamic resource sharing (e.g., of spectrum and power) between cellular and ad-hoc D2D communications to accommodate larger volumes of traffic and provide better service to users. Readers will understand the practical challenges of resource management, optimization, security, standardization, and network topology, and learn how the design principles are applied in practice.

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Dedications

To my family, Zhu Han

To Suprova Hossain and Nirvoy Lalon, Ekram Hossain

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Preface

Now that more and more new mobile multimedia-rich services are becoming available to mobile users, there is an ever-increasing demand for higher-data-rate wireless access. Therefore, new wireless technologies such as Long Term Evolution Advanced (LTE-A) and WiMAX have been introduced, which are capable of providing high-speed, large-capacity, and guaranteed-quality-of-service (QoS) mobile services. Apart from the new technologies, new techniques such as small-cell networks and heterogeneous networks (HetNets) have also been developed, which are able to improve network capacity by reducing cell size and effectively controlling the interference. However, all these attempts still rely on a centralized network topology, which entails mobile devices communicating with a base station or access point. Such a centralized network topology is inherently limited by the capabilities of the base station and access point, which could be congested due to the presence of a large number of communicating devices. Also, the base station and access point might not have complete information about transmission parameters among devices, which is required in order to achieve the optimal network performance. To mitigate this problem, the concept of device-to-device (D2D) communications has been introduced to allow local peer-to-peer transmission among mobile devices offloading traffic from the base station and access point. Also, it is crucial to increase the wireless network capacity to accommodate the bandwidth-consuming mobile applications and services. Device-to-device communications is a promising concept to improve user experience and resource utilization in cellular networks, operating in both licensed and unlicensed spectrum bands.

The D2D communications can underlay or overlay a cellular network, using the same resources to improve the system throughput. Specifically, besides cellular operation, where user equipment (UE) is served by the network via the evolved NodeBs (eNBs) in the LTE architecture, UEs may communicate with each other directly over the D2D links. The UE in D2D connections still has to be loosely controlled by the eNBs in a network-controlled manner, thus continuing cellular operation. The eNBs can control the resources used for the cellular and D2D links. The eNBs can also set constraints on the transmission parameters (e.g., transmit power and communication duration) of D2D transmitters to limit the interference experienced at the cellular receivers.

Numerous researchers and wireless engineers have postulated that D2D communications will become a key feature supported by next-generation cellular networks. D2D communication has the following advantages. One can

- extend coverage,
- offload in cellular networks,
- improve energy efficiency,
- increase throughput and spectrum efficiency, and
- create new services such as social/vehicular ad-hoc networking services, etc.

The design, analysis, and optimization of D2D communications and networking require multidisciplinary knowledge, namely knowledge of wireless communications and networking, signal processing, 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 D2D communications in cellular networks as well as the state of the art of research and development and related information will be very useful for researchers and engineers.

This book summarizes the state of the art of research on D2D communications coexisting with cellular networks from physical-, MAC-, network-, and application-layer perspectives. The key features of this book are as follows:

- a unified view of D2D communications and networking,
- a comprehensive review of the state-of-the-art research and key technologies for D2D communications networks,
- coverage of a wide range of techniques for design, analysis, optimization, and applications of D2D communications networks,
- outlining the key research issues related to D2D communications and networking, and
- Standardization activities on D2D communications.

This book is divided into five parts: Part I (Introduction), Part II (Techniques for modeling and analysis of D2D communications), Part III (Resource management, cross-layer design, and security for D2D communications), Part IV (Applications of D2D communications), and Part V (Standardization of D2D communications). Part I contains Chapter 1, which provides an introduction to D2D communications. The topics include the different methods for configuration or access, device synchronization and discovery, spectrum sharing and resource management, power control, and D2D local area networks. Also, a simulation scenario for D2D communications is described.

In Part II, which consists of Chapters 2 and 3, different techniques that can be applied to the problem of design, analysis, and optimization of D2D communications are introduced. In particular, the optimization techniques which are useful to obtain the optimal resource-management schemes for D2D communications are discussed in Chapter 2. Major variations of optimization techniques (e.g., unconstrained and constrained optimization, nonlinear optimization, combinatorial optimization) are presented. Also, stochastic optimization based on dynamic programming, the Markov decision process (MDP), and stochastic programming are discussed. In Chapter 3, the

game-theory techniques are discussed. The basics of different game-theoretic models, namely noncooperative game, repeated game, cooperative game (i.e., bargaining game, coalition game), and evolutionary game models as well as the basics of matching theory and auction theory are presented.

Part III, which consists of Chapters 4–8, deals with radio-resource management, cross-layer design, and security for D2D communications. Chapter 4 presents a framework for mode selection for D2D communications that is based on a coalitional game. Also, a model for joint mode selection and resource allocation is developed. Chapter 5 focuses on interference coordination for D2D communications. A network-assisted power control scheme that considers both interference reduction and power saving is proposed. Chapter 6 introduces methods for subcarrier allocation and time-domain scheduling for D2D communications. Chapter 7 provides an overview of cross-layer design concepts and discusses the challenges in adopting these concepts to develop new protocols. Several examples of cross-layer design are also illustrated. Chapter 8 studies the security issues that arise during the neighbor-discovery phase and data-transmission phase of D2D communications. The concept of physical-layer security is discussed as a method for secure D2D communications.

Part IV, which consists of Chapters 9–11, deals with several application scenarios of D2D communications. In particular, applications of D2D communications in the context of vehicular ad-hoc networks (VANETs) are discussed in Chapter 9. In Chapter 10, application of D2D communications for cooperative content delivery in mobile social networks is discussed. Chapter 11 deals with the paradigm of machine-to-machine (M2M) communications, noting that D2D communications can be considered as a type of M2M communication when the D2D users are in close mutual proximity.

Part V consists of Chapter 12, which introduces the motivation, requirements, and application scenarios for using D2D communications over LTE/LTE-A networks. Also, this chapter introduces the key methods and system parameters to evaluate the performance of D2D communications (at both link and system levels) by computer simulations.

Since each chapter in this book is quite independent, skipping any chapter in this book will not affect your ability to follow the rest of the book.

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