Preface

Wireless networks and services are vital elements of daily life around the world. Presently, there are close to 4.8 billion mobile subscribers and more than 8 billion mobile connections (including machine-to-machine) in the world, and the numbers are increasing at a very rapid pace. The revenue generated worldwide in 2015 for providing mobile services exceeded US$1 trillion. It is expected that by 2020, there will be more than 50 billion mobile connections; hence, there is a need to provide the required resources for this anticipated phenomenal growth. However, the resources (e.g., frequency spectrum, energy) are limited, which calls for innovative approaches to improving efficiencies, managing complexities, providing quality, and ensuring availability and security. It is of the utmost importance to meet the requirements of new services in a cost-effective and efficient manner; their proliferation depends on it.

The conventional approach is to formulate resource allocation in wireless networks as optimization problems that aim to maximize the goodput (e.g., throughput) of networks or users while minimizing their badput (e.g., energy consumption, interference). Many existing resource allocation schemes assume exact parameter values and side information to achieve their objectives. However, their performance is sensitive to the accuracy and availability of parameter values and other ancillary information.

Such assumptions in many instances are unrealistic due to the ever increasing number of wireless devices in the neighborhood and their mobility, as well as the nonlinear and time-varying nature of propagation of electromagnetic waves, and in some cases result in significant and unacceptable degradation of the quality of service experienced by users. To deal with the undesirable side effects of such simplifying and unrealistic assumptions, there is a need to introduce robustness into resource allocation schemes that would be efficient and fair, with acceptable complexity, cost, and overhead.

The nominal (i.e., no uncertainty) optimization problems in many cases are not easy to solve in a straightforward manner because they are nondeterministic polynomial-time and nonconvex. Introducing robustness in such problems is nor-

mally done by way of introducing additional constraints that at times are stochastic and nonlinear, which aggravates the problem even further. It is in this light that developing practical schemes for the robust allocation of resources in wireless networks is a formidable challenge.

This book represents an attempt to present the state of the art in current research on this topic and to show that, in general, many existing techniques and methods in robust allocation will be usable in future wireless networks. Another objective of this book is to demonstrate that there is an urgent need to devise alternative schemes to improve performance and avoid some of the very serious obstacles and limitations pointed out in the literature. The book contains five chapters, which are described briefly in what follows.

In Chapter 1, we explain why robust optimization theory is important in wireless networks and how, in general, it can be applied for allocating resources in such networks. We begin the chapter by presenting fundamental notions of wireless communications relevant to the book and describe different types of resource allocation problems, namely, network-centric (cooperative) and user-centric (competitive) approaches. The objective of the cooperative approach is to maximize the total network utility, whereas in the competitive approach, the goal of each user is to maximize its own utility. We also show how to map a nominal (i.e., nonrobust) optimization problem into its robust counterpart. Finally, we explain the implementation issues pertaining to robust optimization problems.

In Chapter 2, we cover robust cooperative transmit power allocation in wireless networks, where the uncertain parameters are channel gains between secondary users and primary access points. The objective of secondary users is to use the frequency spectrum that belongs to the primary network subject to keep their interference to the primary network below a given threshold while maximizing their own social utility. We present the system model and formulate the robust resource allocation problem using the concept of uncertainty region within which all instances of uncertain parameter values are assumed to be confined. We also show that by properly defining the uncertainty region, the computational complexity of solving robust problems can be reduced to the level of nonrobust problems, develop algorithms for trading off between throughput reduction and robustness, and devise schemes to reduce signaling in robust solutions for distributed approaches.

In Chapter 3, we study robust noncooperative resource allocation where each user competes with other users over utilizing the resources to maximize its own utility. In doing so, we present a game-theoretic formulation of the problem and discuss its solution where greedy, noncooperative, and rational users utilize the available but noisy and uncertain side information to achieve their objectives. To tackle uncertainty and improve the utility of each user, we apply worst-case robust optimization in noncooperative games and present their analysis for allocating resources in wireless networks. Specifically, via variational inequalities, we present a systematic approach to securing the conditions for the existence and uniqueness of the games' equilibria, derive the gap between the utility values of nonrobust and robust games, and present distributed algorithms for solving such games.

In Chapter 4, we present a taxonomy of relaxation methods for solving nonconvex and intractable robust optimization problems for allocating resources in wireless networks and provide several examples of such problems in existing and future wireless networks. We also show how such problems can be solved. In particular, we present cases in which uncertainty in channel state information (CSI) is assumed to be within a given region, when only statistics of uncertainty in CSI are available, or when no CSI is available to users, and we discuss the relevance of each case in future wireless networks.

In Chapter 5, we present a brief overview of important features of future wireless networks that will affect resource allocation; then we identify important problems in robust resource allocation in such networks that can be tackled using the material in Chapters 1, 2, 3, and 4.

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