Preface

The purpose of this book is to provide tools for a better understanding of the fundamental tradeoffs and interdependencies in wireless networks, with the goal of designing resource allocation strategies that exploit these interdependencies to achieve significant performance gains. Two facts prompted us to write it: First, future wireless applications will require a fundamental understanding of the design principles and control mechanisms in wireless networks. Second, the complexity of the network problems simply precludes the use of engineering common sense alone to identify good solutions, and so mathematics becomes the key avenue to cope with central technical problems in the design of wireless networks. In this book, two fields of mathematics play a central role: Perron-Frobenius theory for non-negative matrices and optimization theory.

This book is a revised and expanded version of the research monograph "Resource Allocation in Wireless Networks" that was published as Lecture Notes in Computer Sciences (LNCS 4000) in 2006. Although the general structure has remained unchanged to a large extent, the book contains numerous additional results and more detailed discussion. For instance, there is a more extensive treatment of general nonnegative matrices and interference functions that are described by an axiomatic model. Additional material on max-min fairness, proportional fairness, utility-based power control with QoS (quality of service) support and stochastic power control has been added. The power control problem with interference suppression at the receiver side has been included as well. Finally, the material has been extended to provide additional QoS-based power control approaches and powerful primal-dual network-centric power control algorithms.

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The main body of the book consists of three largely independent parts: mathematical framework, principles of resource allocation in wireless networks and algorithms. It ends with appendices that contain some supplementary results. Below, we briefly summarize the content of each part.

Mathematical Framework: Chaps. 1 and 2 deal with selected problems in the theory of nonnegative matrices and provide a theoretical basis for the resource allocation problem addressed in the subsequent parts of the book. It should be emphasized that our intent is *not* to provide a thorough treatment of this wide subject. Instead, we focus on problems that naturally appear in the design of resource allocation strategies for wireless networks. When developing such strategies, different characterizations of the Perron root of nonnegative matrices turn out to be vital to better understanding of fundamental tradeoffs between diverse optimization objectives. The Perron root can be viewed as a map from a convex parameter set into the set of positive reals. Chap. 1 is concerned with properties of this map and, in particular, with the question under which conditions it is a convex function of the parameter vector. In Chap. 2, we pose similar questions with regard to a positive solution to a system of linear equations with nonnegative coefficients. Applications that involve systems of linear equations with nonnegative coefficients are numerous, ranging from the physical and engineering sciences to other mathematical areas like graph theory and optimization. Such systems also occur in power control theory.

Principles of resource allocation in wireless networks: The second part of the book (Chap. 5) deals with the problem of resource allocation in wireless networks. The book addresses the problem of joint power control and link scheduling, which has been extensively investigated in the literature and is known to be notoriously difficult to solve, even in a centralized manner. Although we provide interesting insights into this problem, our main focus lies on the power control problem under fixed and adaptive (interference combating) receivers. In particular, a class of utility functions is identified for which the so-called utility-based power control problem can be converted into an equivalent convex optimization problem. The convexity property is a key ingredient in the development of powerful and efficient utility-based power control algorithms. In addition to the "pure" utility-based approach to the power control problem, we also consider other power control strategies for wireless networks. This includes QoS-based power control where given QoS requirements are required to be satisfied with a minimum total transmit power, max-min SIR power control where, roughly speaking, the objective is to optimize the performance of the "worst" link, and utility-based power control with QoS support which is a combination of utility-based and QoS-based power control approaches.

Algorithms: Chap. 6 presents distributed power control algorithms for a class of utility maximization problems in wireless networks with and without QoS support. We consider iterative optimization methods such as gradient projection algorithms as well as primal-dual algorithms that operate on the primal and dual variables of associated Lagrangian functions. Distributed implementation of the presented power control algorithms relies on the use of a so-called adjoint network to efficiently distribute some locally measurable quantities to other (logical) transmitters. This mitigates the problem of global coordination of the transmitters when carrying out power control iterations in distributed wireless networks.

The main purpose of the appendices is to make the book more understandable to readers who are not familiar with some basic concepts and results from linear algebra and convex analysis. They further introduces the notation and terminology used throughout the book. The treatment is mostly superficial and formal proofs are presented only for the most important results. The exception is App. A.4 (Perron–Frobenius theory) that presents selected results from the Perron–Frobenius theory of nonnegative but not necessarily irreducible matrices, and thus it is of fundamental importance to the remainder of the book. In addition to the key theorems such as the Perron–Frobenius theorem for irreducible matrices, we also provide proofs for some non-standard results that deal with the issue of reducibility. The presentation is limited to results used somewhere in the book.

This book is intended for post-graduate students, engineers and researchers working in the general area of design and analysis of wireless networks, with an especial interest in the problems of resource allocation, QoS control, medium access control, interference management. It can be used as a specialized textbook as well as a reference book. Courses based on parts of the material have been given by the authors at the Technische Universität Berlin. The prerequisites for reading this book are quite minimal. The book should be sufficiently self-contained, in the sense that it can be read without any supplementary material by anyone who has taken basic courses in calculus, linear algebra and probability.

The authors would like to emphasize that this book does not offer a comprehensive state of the art overview of the theory and practice of resource allocation in wireless networks. In addition to the authors' own work, the book contains a list of references that either were used to develop the presented theory or are known to the authors to deal with related research topics and are of sufficient relevance. The list is however by no means complete and undoubtedly subjective. Due to the rapid spread of wireless networking, the scarcity of wireless resources and growing expectations of users on service quality and connectivity, a great deal of important design principles have been developed over the past two decades. We hope that this book is an interesting contribution to this development and provides a sufficiently general theoretical framework for extensions, generalizations and improvements of existing resource allocation approaches and algorithms. In the light of time and space limitations, an inclusion of an exhaustive and precisely updated state of the art overview appears to be impossible.

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