Preface

Introduction

Mobile and wireless communication systems are a prominent communications technology with profound economical and social impacts in practically all parts of the world. The current state of wireless communication systems allows for a much wider scope of applications than what it used to be originally, that is, to be a mobile extension of the public switched telephone network. The convergence of mobile systems and the Internet has become a reality as new radio access technologies emerged with improved coverage, capacity, and latency. While the desire to develop and establish a truly mobile Internet dates back to the mid-1990s, it is only now that a significant increase in the volume of data is being witnessed by most cellular operators, not only in Europe and Japan, but also throughout North and Latin Americas. This book is about some of the underlying technological breakthroughs that allowed the evolution to the current state of development in wireless technology.

The focus of the book is on the two lower layers of the ISO/OSI layered model, that is, the physical and data link layers, including the link and media access control sublayers. These two layers are of specific importance in wireless systems, as opposed to many of its wired counterparts. This is fundamentally due to spectrum shortage, the broadcast nature of interference, and time variability of the wireless channel. As a consequence, much of the improvements in coverage, capacity, and latency of modern wireless systems are due to new approaches for tackling old problems in high-capacity radio communications in these two lower layers.

Intended Audience and Usage

This book is intended for researchers in the field of wireless communications, more specifically to the ones involved with the design and optimization of current and emerging wireless access technologies for mobile communications. Graduate students working in subjects such as radio resource management, OFDM, and MIMO, as well as in third-generation systems and beyond, will benefit from the state-of-the-art concepts, methods, examples, and case studies presented. Every chapter, in addition to having a clear ambition to address the state of the art of the corresponding subject, discusses basic concepts in the introductory sections and gives references for the interested reader to deepen his/her understanding. All chapters can be used independently as a complement to a graduate-level "advanced" wireless communications course, where each chapter can be subject to a directed study or a seminar. The book may also be of interest to the practitioner or to engineers involved in standardization efforts. The attention to technical details from standards is given in several chapters when performance results and case studies are presented. The idea is to demonstrate how advanced concepts can be adapted to be applicable in more realistic scenarios. Finally, almost every chapter of the book sheds light, directly or indirectly, on the subject of performance evaluation of wireless systems by means of system and link-level simulations. As the complexity of wireless systems grows, efficient and correct methods for modeling and performance simulations of these systems are becoming a fundamental discipline on their own.

Organization of the Book

Part I – Resource Allocation

Radio resource allocation (also known as radio resource management or RRM) has its roots in frequency reuse planning of first-generation cellular systems. Its fundamental goal is to increase spectrum efficiency. More efficient utilization of the radio spectrum plays such an important role because spectrum is simultaneously a very scarce and widely shared resource.

In the evolution of second- and third-generation systems, RRM became a discipline on its own, encompassing a variety of techniques such as power control, frequency hopping, dynamic channel allocation, and more advanced multi-antenna concepts, such as beamforming solutions as well as various transmit diversity schemes. Then, the emergence of packet-switched data services in third-generation systems and beyond has demanded a new set of RRM techniques able to handle mixed services scenarios. These included concepts borrowed from wired data networks, such as packet scheduling and congestion control, but that were reformulated and adapted to the wireless environment. More recently, highly configurable emerging radio access technologies, such as orthogonal frequency division multiplexing (OFDM)-based multiple access, have widened the scope of RRM. By means of advanced optimization approaches, radio resource allocation in time and frequency is now possible with fine granularity, increasing the efficiency potential of spectrum usage to unprecedented levels. This is mainly due to a clever exploitation of the multiuser diversity made available by these emerging systems.

Chapter 1 deals with power control. Transmission power is one fundamental resource whose optimization impacts directly on coverage and capacity. Power control has been a key technique since second-generation systems to achieve energy efficiency and interference management. This chapter focuses mostly on the latter. A basic introduction to some fundamentals in wireless communications is included. Basic propagation phenomena and modeling are first discussed. Then, a review about the fundamentals of power control is given along with classical algorithms, including analysis of convergence. A new approach to power control, based on game theory, is then presented, appropriated to emerging systems where multiple services with different quality-of-service (QoS) demands coexist. In particular a class of "opportunistic" distributed power control algorithms is derived for elastic data services, making it relevant to reconsider the supremacy of adaptive modulation and coding in current wireless systems. Finally a discussion about the use of channel prediction methods to improve the performance of existing algorithms is presented.

Chapter 2 presents an overview of RRM for the commercially most successful mobile communication system to date, that is, GSM, along with its packet-switched counterpart, EDGE. RRM has played a key role in the long-lasting life of GSM, which, dating back to more than 25 years now, is still able to cope with the majority of worldwide voice traffic. The chapter begins with a review on the fundamentals of the GSM/EDGE technology according to the respective 3GPP standards. Then, several RRM techniques are described as applied to GSM/EDGE along with performance results, using a detailed and realistic simulation model. These include power control, dynamic channel allocation, spatial division multiple access (SDMA), and management of multiple services by interference balancing. A discussion about large-scale modeling and simulation of wireless systems is also presented, including traffic modeling of data services.

Chapter 3 is a practitioner-oriented tutorial on HSPA deployment and optimization. HSPA is the key access technology currently behind the mobile broadband Internet expansion. The chapter serves a dual scope. First, a review about the HSPA standard is given. Both HSDPA and HSUPA are presented in aspects such as protocol stack, network architecture, channel structure, and physical layer procedures. A description of radio resource management fundamentals in HSPA is presented including aspects such as power allocation, mobility management, and related protocol aspects. Then the author describes several field results and real case studies leading to optimized broadband experience via HSPA. The chapter ends with suggestive guidelines for planning and dimensioning HSPA networks for the residential market.

Chapter 4 builds on the previous chapter to propose and analyze advanced congestion control mechanisms for HSPA, as well as for WCDMA (wideband code division multiple access) systems. While the baseline WCDMA/HSPA system can bring significant capacity improvements over GSM/EDGE, the growing demand for data services may rapidly press its spectrum efficiency to the limit. Quality-of-service management by means of congestion control is then proposed for dealing with multiple services competing for radio resources. Congestion control functions, in the form of admission control, load control, and packet scheduling, are responsible for keeping the network load at controlled levels and maintaining stability while ensuring QoS levels. Basic concepts and new methods are discussed and results showing the capacity benefits of employing congestion control demonstrate a significant impact. The proposed methods are shown to be fully automatic and scalable, able to cope with many services under different network loads. Case studies for WCDMA and HSPA are presented using realistic simulation scenarios composed of services such as World Wide Web access and voice-over-IP.

Chapter 5 addresses state-of-the-art OFDMA systems and corresponding resource allocation aspects. As previously mentioned, OFDMA opens up a new breed of RRM techniques due to the high flexibility and granularity with which frequency and time radio resources (i.e., subcarriers and time slots) can be allocated to multiple users. Advanced optimization techniques can then be employed to map radio resources to active connections in such a way as to fulfill network-level objectives such as maximization of the overall capacity or satisfaction of QoS levels. The chapter begins by establishing the system-level scenarios for RRM in OFDMA and their differences. Then a review of the key optimization and algorithmic approaches suitable for these problems is given. A new scheduling approach for OFDMA is proposed, based on the maximization of the user satisfaction ratio. A case study for 3GPP's long-term evolution (LTE) system is presented to illustrate the performance of the proposed methods and concepts. Finally, a new method for power allocation for OFDMA is presented along with results showing superior performance as compared to existing approaches.

Finally (for Part I), *Chapter 6* looks to the near future of wireless systems by dealing with the topic of multi-access networks. In this case, multiple radio access technologies cooperate to increase coverage and capacity. By means of a common core network infrastructure, complementary features of different radio access technologies can be combined to increase return of investment of existing networks while attending new demands for coverage and capacity. The chapter begins with a conceptual review about multi-access networks and the involved fundamental tradeoffs. Then, concepts and methods for common radio resource management are exposed. These methods can be seen as an extension of conventional RRM methods for the multi-access case. Typical CRRM procedures include access selection and inter-system (or vertical) handovers. A case study involving a UMTS (Universal Mobile Telecommunication System) and a wireless local area (WLAN) joint network is explained and illustrated with simulation results.

Part II – Transceiver Architectures

The significant improvements at the physical layer have been instrumental for the increase of the wireless link capacity over the last decade. OFDM itself, already a popular modulation mechanism in fixed digital subscriber lines, has been combined with the use of multiple antennas at both ends of wireless links, in the so-called multiple input multiple output (MIMO) schemes. MIMO has changed the way wireless engineers face the fundamental capacity limits of the wireless channel by exploiting fading variability in favor of it. This fact also illustrates the major challenge – How can a wireless system be designed that allows for a practical implementation in the presence of such potentially fast fading propagation channels between and among the multitude of employed antennas? The main aspect to take into consideration is how to make such a system design both observable and controllable – the former important in order to generate the appropriate amount of radio network measurements and the associated signaling and the latter significant in the sense of keeping the interference levels under control on a system level.

The understanding and modeling of MIMO propagation channels have reached a rather mature level during the last decade; a remaining problem is, however, the computational complexity associated with using any of the available detailed MIMO models in system (or even link-) level simulations. There are also still many aspects to understand when it comes to including also antenna design – and modeling aspects for any realistic MIMO application – this is in particular the case on the user equipment side, mainly due to the fundamental restrictions originating from the size (in wavelengths) of handheld or portable devices.

Chapter 7 deals with a basic concept when analyzing wireless links by explaining the way wireless links can be modeled and have their performance efficiently evaluated. Modeling and simulating wireless systems is a complex task which starts with a good assessment of the physical layer behavior. The chapter discusses two main aspects. First, the authors discuss the approaches for dividing complex wireless system simulations into two independent, more tractable parts, namely link and system-level simulations. Then they focus on how to design reliable link-level simulators. Besides that, a software development framework is proposed for flexible and modular construction of link-level simulators. Several case studies are presented, involving the modeling and simulation of actual mobile systems, to illustrate the concepts.

Chapter 8 presents an overview of techniques related to the problem of equalization for wireless systems. The hereby desired recovery of coded symbols transmitted through a propagation channel is treated for the SISO scenario as well as for the SIMO (beamforming) case. Techniques for channel identification and tracking are discussed together with means to handle time-dispersive channels using either time- or frequency-domain techniques. Furthermore, case studies exemplify typical equalization solutions for wireless systems in use today. Finally, the chapter discusses the concept of – and principles for – turbo-equalization, that is, equalization structures that achieve near-optimal performance by jointly performing equalization and decoding.

Chapter 9 treats channel estimation for OFDM-based systems. Since the granularity in the time and frequency-domains are rather high, the concepts of frequency-domain interpolation and time-domain filtering are required for a practical implementation of a channel estimation algorithm. These concepts become very important for allowing as low a density as possible of the reference or pilot signals dedicated for aiding the channel estimation over the frequency band of interest and over time as the channel changes. As mandated by the OFDM systems currently emerging from ongoing standardization efforts (in, e.g., 3GPP LTE), good channel estimation performance and robustness as well as the associated system design aspects – like the desire to reduce the signaling overhead – becomes highly relevant for MIMO applications. Such aspects are discussed in that chapter and different channel estimators are evaluated and compared by means of simulations.

Chapter 10 brings the discussions in Chapter 9 further toward an application of channel estimation methods and the related channel state information and channel quality indicators to the problem of adapting modulation scheme and coding rate for a MIMO-OFDM system. This is commonly known as the problem of link-adaptation, and the problem to address is how to best select transmission parameters (like transmit antennas, bit rates, transmit power) for a certain estimated channel realization in order to optimally utilize the available system resources (like spectral efficiency or ultimately even energy consumption). The chapter outlines and discusses the different gains that can be achieved – diversity and multiplexing – and the relation between them. Furthermore, some hybrid MIMO transmission schemes are suggested and evaluated for various numbers of employed transmit antennas.

In *Chapter 11* the authors present an innovative space–time–frequency multiple-access (STFMA) MIMO wireless communication system combining space-domain and frequency-domain spreading by means of linear precoding, along with a time-domain block-spreading CDMA strategy. Precoding across space (transmit antennas) and frequency (subcarriers) provides robustness against deep channel fades while providing space and frequency diversities, while block-spreading enables multiple accessing. They utilize a tensorial algebra-based decomposition to model the received signal in the STFMA system. Thanks to the powerful identifiability properties of this tensor decomposition, blind signal detection based on multiuser detection is possible.

Chapter 12 finally addresses the problem of how to reduce the overhead signaling that is typically present for MIMO transmit schemes employing closed-loop channel state information feedback. The techniques that are discussed are mainly based on the concept of transmitter precoding, that is, the feedback from the user equipment consists of an index in a pre-designed transmit codebook, known at both transmitter and receiver sides; the codebook design is also described in the chapter in the form of illustrative examples. The transmitter then applies the so-indicated codebook vector of antenna weights, and this process is updated regularly. Clearly, the performance of closed-loop precoding schemes will suffer from high-speed terminals since the selected codebook index then quickly becomes outdated, and a possible remedy is then to switch to an open-loop transmit scheme, where mainly the modulation and coding rates are updated regularly and the potential additional transmit weights are designed to primarily generate diversity gains. Examples are provided, where the performance of different transmit schemes are compared by means of simulation studies.

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