Preface

Mobile communications have been instrumental in transforming our contemporary societies in the past decades. From the first-generation (1G) of analogue mobile phone system to the newest commercial fourth-generation (4G) long-term evolution (LTE) networks deployed widely across the global, mobile communications have fundamentally changed the ways as to how humans in the modern society access, exchange, and share information with each other. Currently, we are at an era of mobile Internet with explosive big data. The growing demand for mobile data traffic and the proliferation of applications requiring high data rates have raised a significant interest in the definition of new standards in the mobile market. This calls for next-generation mobile communication systems, which should have to respond to an avalanche of traffic, an explosion in the number of connected devices, and the large diversity of use cases and requirements.

Against the above backdrop, the fifth-generation (5G) mobile communications are fast emerging to tackle the challenges brought by an exponential increase in wireless data traffic. On top of the massive increase in data volumes and rates, a formidable challenge for the 5G networks to deal with is how to connect billions of smart devices such as surveillance cameras, smart-home/grid devices, connected sensors, etc. The primary goals of 5G networks are to support a 1000-fold gain in capacity, connections for at least 100 billion devices, and 10 Gb/s delivered to individual users. Furthermore, new 5G networks will be able to provide mass low-latency and ultrareliable connectivity between people, machines, and devices, which will ultimately usher in the era of the Internet of Things (IoT). To meet these enormous challenges, disruptive innovations and drastic improvements need to be made in the mobile network architecture design in both the physical and upper layers.

The International Telecommunications Union (ITU) has stipulated 2020 to be the target year of standardising future 5G mobile networks. Although the detailed technical approaches to implementing 5G mobile networks remain uncertain at the time of this writing, several breakthrough 5G techniques stand out such as massive MIMO and millimetre-wave (mmWave) communications. This book aims to be one of the first comprehensive books to reveal the enabling techniques underpinning next-generation 5G networks and to address the challenges and opportunities brought by 5G mobile communications. Specifically, the book is divided into three major parts: Part I Overview of 5G Networks, Part II Transmission and Design Techniques for 5G Networks, and Part III Networking Techniques and Applications for 5G Networks.

Part I of this book provides a comprehensive introduction to and overview of 5G networks. It consists of three chapters.

The chapter "An Overview of 5G Requirements" presents an overview of next-generation 5G mobile networks. To facilitate the study of 5G requirements and to provide guidance to 5G technical design, this chapter discusses several typical deployment scenarios including indoor hotspot, dense urban, urban macro, rural, and high-speed scenarios. It also presents high-level key capabilities and detailed technical requirements for 5G networks. Some technical performance metrics of 5G networks are also discussed.

The chapter "Spectrum Analysis and Regulations for 5G" discusses various aspects of 5G spectrum issues. It is expected that 5G requires much more bandwidth as well as more flexibility in spectrum usage and management. The suitable frequency ranges of 5G will include those bands below 6 GHz such as re-farmed 2G/3G spectrum, identified frequency bands for IMT, and also WRC-15 candidate bands. However, due to the scarcity of spectrum below 6 GHz, it is imperative to seek potential frequency ranges above 6 GHz. Controlled spectrum sharing is an important way of reusing spectrum to complement current licensed dedicated spectrum, which is still the foundation for the operation of 5G systems.

The chapter "Spectrum Sharing for 5G" first introduces spectrum sharing for 5G systems, which consists of multiple spectrum types with different scenarios. Then, spectrum sharing techniques mapped into different scenarios are introduced, i.e. coordination protocol, GLDB support, cognitive/DSA, and MAC-based coexistence. Besides, current applications of these techniques in real systems are described. Finally, spectrum sharing directions for 5G systems are analysed for different spectrum sharing techniques. It is concluded that licensed dedicated spectrum will continue to be the dominant spectrum usage method for 5G systems due to the possibility to control interference and guarantee coverage, while other spectrum sharing scenarios will act as complementary spectrum usage methods when beneficial.

Part II of this book presents new transmission and design techniques for 5G networks with a focus on physical-layer enabling techniques. It contains 11 chapters.

The chapter "Massive MIMO Communications" argues that every new network generation needs to make a leap in area data throughput, to manage the growing wireless data traffic. Massive MIMO technology can bring at least tenfold improvements in area throughput by increasing the spectral efficiency (bit/s/Hz/cell) while using the same bandwidth and density of base stations as in current networks. These extraordinary gains are achieved by equipping the base stations with arrays of a hundred antennas to enable spatial multiplexing of tens of user terminals.

This chapter explains the basic motivations and communication theory behind the massive MIMO technology and provides implementation-related design guidelines.

The chapter "Millimeter-Wave Mobile Communications" introduces key technologies of mmWave communications. Channel measurements show that mmWave signals suffer from much larger propagation losses and are suitable for small cell coverage. A hybrid network is presented where mmWave is used for capacity enhancement in hotspots, and a low-frequency network is applied for seamless coverage. Uniform air interface is a consequence to simplify the design between mmWave bands and low-frequency bands. Unified access and backhaul technique not only reduces the cost of backhaul but also can meet the requirement of 1000 times capacity enhancement over LTE systems.

The chapter "Non-Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access" introduces state-of-the-art NOMA techniques and evaluates the low density spreading (LDS)-based system, which is a strong candidate for the next generation of mobile networks due to its well-known advantages compared to state-of-the-art techniques based on orthogonal frequency division multiple access (OFDMA). Furthermore, the effect of LDS parameters such as density factor and maximum number of users at each time instance on the sum rate is evaluated. The effect of irregularity on the complexity is also discussed. Moreover, it is shown that the loss of achievable rates which is caused by modulation can be compensated by using a suitable channel coding scheme.

The chapter "New Multicarrier Modulations for 5G" presents recent advances in filter bank multicarrier (FBMC) techniques and compares them with the conventional cyclic prefix (CP)-OFDM approach, in the context of 5G. After a brief description of some adaptations of CP-OFDM, FBMC combined with offset-QAM is considered, pointing out the crucial issue of subchannel equalisation. Then, an alternative approach is proposed, FBMC combined with pulse amplitude modulation (PAM). FBMC-PAM is an attractive option whenever asynchronous access and high level of out-of-band rejection are required. Finally, the case of nonoverlapping emitted symbols is considered, and a CP-less OFDM scheme with frequency domain equaliser in the receiver is included in the performance comparison.

The chapter "Fundamentals of Faster-than-Nyquist Signaling" presents the fundamentals of Faster-than-Nyquist (FTN) signalling. As originally introduced, FTN increases the bit rate in the signalling bandwidth by packing symbols closer in time, at the cost of introducing intersymbol interference (ISI). The chapter begins with the Euclidean distance properties of bandwidth-efficient pulses at FTN rates and describes receivers that mitigate the severe ISI. The FTN achievable information rate is compared with the Nyquist information rate for practical pulses. It then discusses the FTN extension to multicarrier systems with not only time packing but also subcarrier, optimising both the time and frequency packing.

The chapter "Generalized Frequency Division Multiplexing: A Flexible Multi-Carrier Waveform for 5G" aims to develop a unified air interface that can be configured on-the-fly to address emerging 5G applications. Apart from an ever-increasing demand for data rates, 5G is facing new applications such as Tactile

Internet and the Internet of Things. Being aligned with the whole concept of software-defined networking, this chapter introduces the multicarrier waveform termed generalised frequency division multiplexing (GFDM) as the basis for realising such a flexible physical design.

The chapter "Spectrally Efficient Frequency Division Multiplexing for 5G" focuses on novel multicarrier communication techniques, which share the common goal of increasing spectrum efficiency in future communication systems. In particular, a technology termed spectrally efficient frequency division multiplexing (SEFDM) is described in detail outlining its benefits, challenges, and trade-offs when compared to the current state of the art. A decade of research has been devoted to examining SEFDM from different angles: mathematical modelling, algorithm optimisation, hardware implementation, and system experimentation. The aim of this chapter is to therefore give a taste of this technology, and in doing so, the chapter concludes by outlining a number of experimental test beds which have been developed for the purpose of evaluating the performance of SEFDM in practical scenarios.

The chapter "Full-Duplex Wireless Communications for 5G" introduces full-duplex (FD) wireless communications for 5G, which enables simultaneous transmission and reception over the same frequency band. In this way, the spectral efficiency can be improved significantly compared with half-duplex (HD). However, there exists severe self-interference (SI), signal leakage from the local transmitter to its own receiver. Three different classes of SI mitigation techniques are presented in this chapter, i.e. propagation-domain SI suppression, analogue-domain SI cancellation, and digital-domain SI cancellation. Furthermore, the system performance of several FD schemes in several different application scenarios is presented. Theoretically, the spectral efficiency of FD bidirectional and cooperative communications can be doubled, while for cognitive radio networks, the FD-based protocol can achieve much better sensing performance than the traditional HD-based cognitive radio schemes.

The chapter "Device-to-Device Communications over 5G Systems: Standardization, Challenges and Open Issues" introduces one of the key enabling technologies at the heart of the 5G systems, namely, device-to-device (D2D) communications. The potential of D2D communication paradigm holding the promise to overcome the limitations of conventional cellular systems with very high bit rates, low delay, and low power consumption is illustrated. Starting from an overview of D2D communication technology, this chapter will browse through the main aspects that characterise the proximity services, with a view on the standardisation process, the challenges, and the open issues.

The chapter "M2M Communications in 5G" provides an overview of machine-type communications (MTC) within the context of 5G networks. The Internet of Everything foresees a hyperconnected World where humans, things, and machines will need to coexist together. They will be interconnected and Internet-connected via communication networks. In specific, the authors review the key novel challenges of MTC: what is new with regard to human-type traffic (HTC). They then analyse existing communication technologies and how suitable they are for MTC. Finally, the authors identify key technology enablers being considered for the design of 5G networks and provide an outlook for the future.

The chapter "Design Techniques of 5G Mobile Devices in the Dark Silicon Era" is concerned with the design of the prospected 5G mobile communication system, which needs wide skills in wireless communication, analogue circuit design, embedded system, microwave technology, and so forth. System-level analyses, design space exploration, and performance trade-offs are some key steps that enable the design of low-cost, energy-efficient, ubiquitous, and flexible transceiver. This chapter provides comprehensive design techniques for 5G mobile communication in the dark silicon era using More than Moore technology (MtM).

Part III of this book focuses primarily on the networking and application layer techniques for 5G networks, which includes 12 chapters.

The chapter "Ultra-Dense Network Architecture and Technologies for 5G" presents the ultra-density network (UDN), which is the most promising way to meet the ultrahigh area capacity requirement for 5G. The content of this chapter includes characters of UDN scenarios, network architecture design, and key technologies like flexible networking, wireless backhauling, multi-RAT coordination, mobility management, interference management, and radio resource management.

The chapter "5G RAN Architecture: C-RAN with NGFI" describes cloud radio access networks (C-RAN), which are viewed as one of the key RAN architectures for 5G networks, with evolved architecture based on a newly designed fronthaul interface, dubbed the next-generation fronthaul interface (NGFI). The design principles and the challenges of NGFI are introduced. A prototype is further developed to verify the applicability of NGFI-based C-RAN.

The chapter "User-Centric Wireless Network for 5G" addresses the concept of user-centric wireless network for 5G from the perspective of fulfilling multiple user experience requirements in 5G. Four key technical directions are studied based on a gap analysis between LTE technology and 5G requirements, i.e. user-centric 5G access network architecture design, flexible functionality and deployment, smart user and traffic awareness and management, and high-efficient low-cost network operation. These key technologies work together with cross-layer and end-to-end solutions to provide the user-centric 5G ecosystem.

The chapter "Energy Harvesting Based Green Heterogeneous Wireless Access for 5G" is concerned with the issues of energy harvesting for future 5G cellular systems. A feasible and efficient method to tackle this issue is to let the communication systems harvest energy from renewable energy sources instead of fossil fuels. However, by employing the energy harvesting (EH) technique, the instability of renewable energy resources introduces new challenges on the design of the upcoming 5G systems. This chapter focuses on uplink access schemes and power allocations for EH-based heterogeneous networks. First, a heterogeneous access model incorporating EH-based mobile users is proposed and followed by a throughput maximisation framework. Then, by classifying transmission policies into two main categories (i.e. single-channel vs. multichannel scenarios), the proposed framework is concretised under various practical conditions, including the availability of central control, causality of harvested energy, channel state information, and others.

The chapter "Resource Management in Sustainable Green HetNets with Renewable Energy Sources" investigates the energy sustainability performance of a green HetNet where the small cell base stations (SBSs) are powered by green energy. Specifically, we first develop an analytical framework to study the energy sustainability of each SBS. Then, we propose a distributed admission control strategy at SBSs striking a balance between resource utilisation and energy sustainability. Extensive simulations validate the analytical framework and demonstrate that relaxing the admission control criteria can improve resource utilisation when the energy is abundant, but may significantly degrade resource utilisation instead when the energy comes short due to poor sustainability performance.

The chapter "Resource Allocation for Cooperative D2D Communication Networks" studies various resource allocation policies for cooperative device-to-device (D2D) communications in systems operating under OFDMA or cognitive radio architectures. A variety of system models are explored, wherein additional features, such as, packet storage, energy harvesting, and cognitive radio capabilities, are incorporated at the user devices so as to enable cooperative D2D communications. Computationally efficient solutions are provided for multiple resource optimisation problems including power allocation, subcarrier allocation, subcarrier pairing, and relay selection. Simulation results demonstrate that the sum-throughput performance can be improved whenever the user devices are equipped with cooperative D2D capabilities.

The chapter "Fog Computing and Its Applications in 5G" explains the emergence of fog computing as a promising, practical, and efficient solution tailored to serving mobile traffics. Fog computing deploys highly virtualised computing and communication facilities at the proximity of mobile users. Dedicated to serving the mobile users, fog computing explores the predictable service demand patterns of mobile users and typically provides desirable localised services accordingly. It can provide mobile users with the demanded services via low-latency and short-distance local connections. The authors introduce the main features of fog computing and describe its concept, architecture, and design goals. Lastly, they discuss the potential research issues from the perspective of 5G networking.

The chapter "A Conceptual 5G Vehicular Networking Architecture" shows how 5G communication systems will help to enable connected future cars to implement automated functions in short term and fully autonomous operation in long term. The authors review the well-known existing communication technologies for connected cars and analyse their shortcomings. Towards this end, they outline the innovation areas that 5G aims to address in order to mitigate the limitations of the current technologies.

The chapter "Communications Protocol Design for 5G Vehicular Networks" provides an overview on existing standards in vehicular networking and highlights new emerging trends towards an integrated infrastructure based on the interworking of heterogeneous technologies. Next-generation mobile vehicular networks are first characterised by providing an insight on relevant stable standards in wireless communication technologies, with a special focus on heterogeneous vehicular networks. Furthermore, the chapter discusses a general framework supporting opportunistic networking scheme and outlines novel application and use cases based on social- and context-awareness paradigms.

The chapter "Next-Generation High-Efficiency WLAN" centres around the topic of next-generation high-efficiency WLAN technology. With the increasing demands for WLAN and the deployment of carrier-WiFi networks, the number of WiFi public hotspots worldwide is expected to increase dramatically. To face this huge increase in the number of densely deployed WiFi networks, and the massive amount of data to be supported by these networks in indoor and outdoor environments, it is necessary to improve the current WiFi standard and define specifications for high-efficiency wireless local area networks (HEWs). This chapter introduces emerging HEW technology, including its typical use cases, environments, and potential techniques that can be applied for HEWs. The typical HEW use cases are first given, followed by an analysis of the main requirements from these use cases and environments. Then, potential techniques, including enhanced medium access and spatial frequency reuse, are presented and discussed.

The chapter "Shaping 5G for the Tactile Internet" investigates the topic of the Tactile Internet, which is expected to have a massive impact on business and society. It has the potential to revolutionise almost every segment of the society by enabling wireless control and remote operation in a range of scenarios. The next-generation (5G) mobile communication networks will play an important role in realising the Tactile Internet. This chapter investigates the interesting area of 5G and Tactile Internet intersection. Key requirements for the Tactile Internet, from a networking perspective, have been identified, after introducing exciting Tactile Internet applications. The chapter covers several technical issues and challenges in shaping 5G networks for realising the vision of the Tactile Internet. The most important challenge would be to ensure tight and scalable integration of various technological solutions into a single network.

We would like to thank all the authors who submitted their research work to this book. We would also like to acknowledge the contribution of many experts who have participated in the review process and offered comments and suggestions to the authors to improve their works. We would also like to express our sincere appreciation to the editors from Springer for their support and assistance during the development of this book.

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http://www.springer.com/978-3-319-34206-1

5G Mobile Communications
Xiang, W.; Zheng, K.; Shen, X.S. (Eds.)
2017, XV, 691 p. 273 illus., 226 illus. in color.,
Hardcover
ISBN: 978-3-319-34206-1