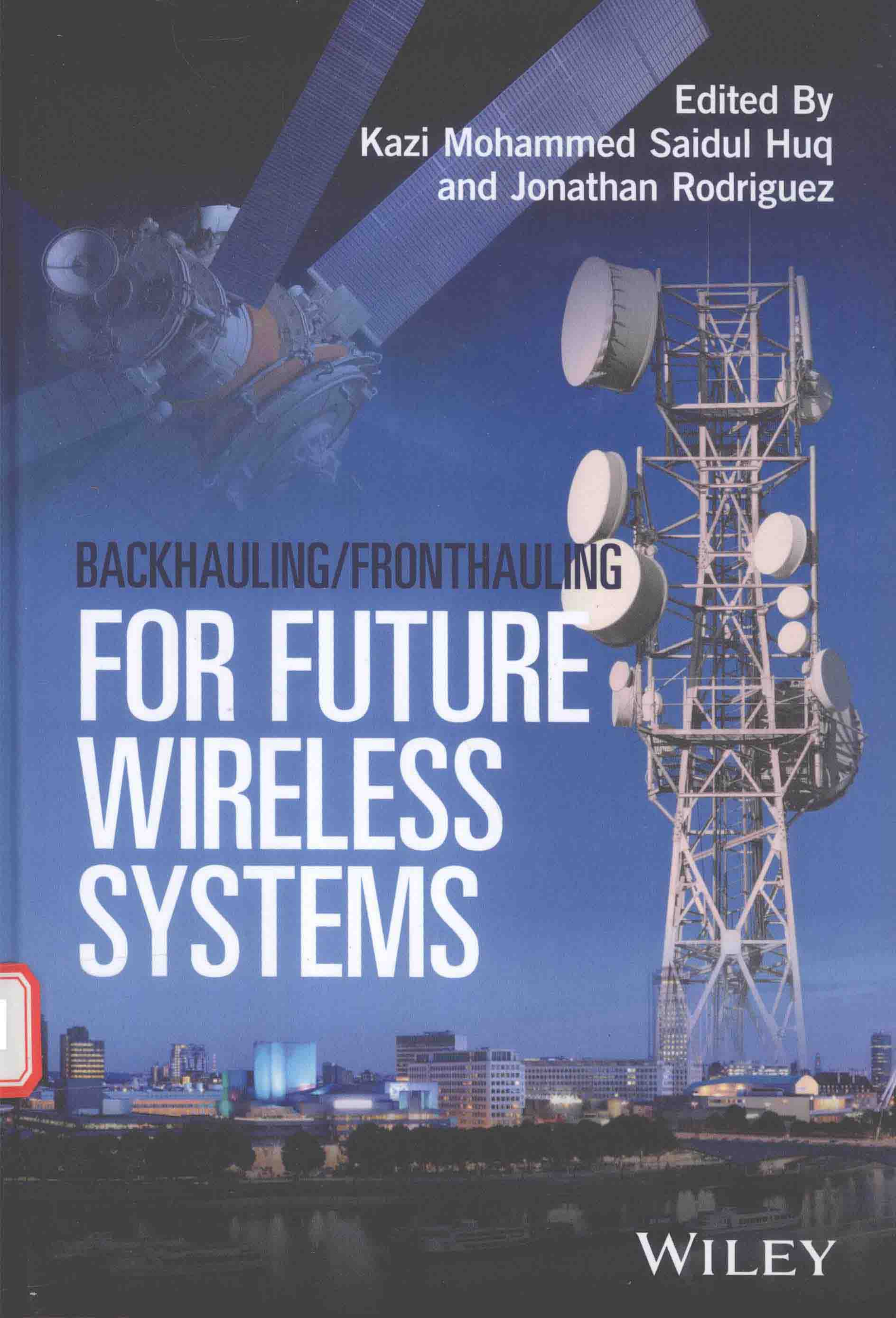

Edited By
Kazi Mohammed Saidul Huq
and Jonathan Rodriguez

BACKHAULING/FRONTHAULING FOR FUTURE WIRELESS SYSTEMS

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Preface

In a mobile communication system, the segment that connects the core to the access networks is termed the 'backhaul'. The edges of any telecommunication network are connected through backhauling. The importance of backhaul research is spurred by the need for increasing data capacity and coverage to cater for the ever-growing population of electronic devices – smartphones, tablets and laptops – which is foreseen to hit unprecedented levels by 2020. The backhaul is anticipated to play a critical role in handling large volumes of traffic, its handling capability driven by stringent demands from both mobile broadband and the introduction of heterogeneous networks (HetNets). Backhaul technology has been extensively investigated for legacy mobile systems, but is still a topic that will dominate the research arena for next generation mobile systems; it is clear that without proper backhauling, the benefits introduced by any new radio access network technologies and protocols would be overshadowed.

Traditionally, the backhaul segment connects the RAN (radio access network) to the rest of the network where the baseband processing takes place at the cell site. However, with the onset of next generation networks, the notion of 'fronthaul access' is also gaining momentum. The future technology roadmap points towards SDN (software-defined networks) and network virtualization as means of effectively sharing resources on demand between different mobile operators, thus taking a step towards reducing the operational and capital expenditure in future networks. Moreover, the baseband processing will be centralized, allowing the operators to completely manage interference through coordinated resource-management strategies. In fact, 3GPP are today visualizing a C-RAN (cloud-RAN) architecture, where the evolved base stations are connected to the C-RAN unit through communication hauls, to what is referred to as the 'fronthaul network'. Traditionally, fibre-optic technology is used to roll out the deployment of base stations; however, this comes along with inherent limitations, including cost and lack of availability at many small sites. This provides the impetus for radio solutions that can handle large volumes of traffic on the fronthaul access, triggering the research community at large to find alternative and advanced solutions that can supersede fibre.

The current work on backhaul and fronthaul technology is fragmented, and still in its infancy. There are still giant steps to be taken towards developing concrete solutions to provide a modern communication haul for next generation networks, which is also commonly referred to as 5G. This book aims to be the first of its kind to hinge together the related discussions on the fronthaul and backhaul access under the umbrella of 5G networks, which we will often refer to as the 'communication haul'. We aim to discuss these pivotal building blocks of the communication infrastructure and provide a view of where it all started, where we are now in terms of LTE/LTE-A networking and the future challenges that lie ahead for 5G. In addition, this book presents a comprehensive analysis of different types of backhaul/fronthaul technologies while introducing innovative protocol architectures.

In the compilation of this book, the editors have drawn on their vast experience in international research and being at the forefront of the communication haul research arena and standardization. This book aims to be the first to talk openly about next generation communication hauls, and will hopefully serve as a useful reference not only for postgraduate students to learn more about this evolving field, but also to stimulate mobile communication researchers towards taking further innovative strides in this field and marking their legacy in the 5G arena.

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Acknowledgements

This book is the first of its kind tackling the research challenge on the communication haul for legacy and emerging mobile communication networks, and the authors hope that it will serve as a source of inspiration for researchers to drive new breakthroughs on this topic. The inspiration for this book stems from the editors' vast experience at the forefront of European research on backhaul/fronthaul architecture for future wireless systems, including the E-COOP project (UID/EEA/50008/2013), an interdisciplinary research initiative funded by the Instituto de Telecomunicações (Portugal). However, this work would not be complete if it weren't for those who contributed along the way. The editors would first like to thank all the collaborators that have contributed with chapters toward the compilation of this book, providing complementary ideas towards building a complete vision of the communication haul. Moreover, a heartfelt acknowledgement is due to the members of the 4TELL Research Group at the Instituto de Telecomunicações who contributed with useful suggestions and revisions. Furthermore, the editors would like to acknowledge the Fundação para a Ciência e a Tecnologia (FCT-Portugal) for the grant (reference number: SFRH/BPD/110104/2015) that supported this work.

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Introduction: The Communication Haul Challenge

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1.1 Introduction

Nowadays, the mobile Internet is a pervasive phenomenon that is changing social trends and playing a pivotal role in creating a digital economy. This, in part, is driven by advancements in semiconductor technology, which are enabling faster and more energy-compliant devices, such as smartphones, tablets and sensor devices, among others. However, a truly smart digital world is still in its infancy and the current trends are set to continue, leading to an unprecedented rise in mobile data traffic and intelligent devices. In fact, according to an Ericsson report [1], a typical laptop will generate 11 GB, a tablet 3.1 GB and a smartphone 2 GB per month by the end of 2018. These figures represent the changing communication paradigm, where the end user will not only receive data but generate data; in other words, the end user will become a 'prosumer' running data-hungry applications, for example, high-definition wireless video streaming, machine-to-machine communication, health-monitoring applications and social networking. Therefore, existing technology requires a radical engineering design upgrade in order to compete with ever-growing user expectations and to accommodate the foreseen increase in traffic. The change will be driven by market expectations, and the new technology being considered is fifth generation (5G) communications [2].

Experts anticipate that 5G will deliver and meet the expectations of a new era in wireless connectivity, and will play a key role in enabling this so-called digital world.

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In contrast to legacy fourth generation (4G) systems, the widely accepted consensus on the 5G requirement includes [3, 4]:

- Capacity: 1000x increase in area capacity;
- Latency: Less than 1 millisecond (ms) round trip time (RTT) latency;
- Energy: 100x improvement in energy efficiency in terms of Joules/bit;
- Cost: 10–100x reduction in cost of deployment;
- Mobility: Mobility support and always-on connectivity of users that have high throughput requirements.

To achieve these targets, all the key mobile stakeholders, such as operators, vendors and the mobile research community, are contriving to reengineer the mobile architecture in order to support higher-speed data connectivity.

Small-cell technology is an emerging deployment that is providing promising results in terms of delivering fast connectivity due to the small distance between the base station (BS) and the end user, whilst reducing energy consumption. Market use cases of small cells such as the indoor femto cell have already become a success story, so the question is, can we extrapolate the femto cell paradigm to the outdoor world? In fact, current trends are suggesting that this is the way forward, with multi-tier heterogeneous networks being a new design addition to the LTE-Advanced standard [5, 6]. Here, multi-tier radio networks (small-cell tiers) play a pivotal role, coupled with network coexistence approaches to reduce the interference between tiers. Moreover, mobile technology will continue to evolve in this direction with the hyper-dense deployment of small cells providing hotspot islands of high data connectivity coverage zones. This context will ask new questions from the research community in terms of how to tunnel this traffic from the local serving base station towards the core network. Typically, in legacy networks, the segment of the network that interconnects the BS to the RAN (radio access network) to the EPC (evolved packet core) is called the *backhaul*. Fibre optic lines or microwave links have fulfilled this role, with limitations in terms of deployment cost and limited coverage area. However, mobile technology is heading towards an era of virtualization and software-defined networking, where radio resources are allocated from a common pool to different providers, and their management is centralized. This new era is, in fact, reflecting parallels in the cloud computing world, with the onset of cloud services. Emerging mobile networks are heading towards a C-RAN (cloud radio access network) approach [7, 8], where RRUs (remote radio units) and a centralized processing RAN core work in synergy to provide coordinated scheduling, or, in other words, interference management. This paradigm is changing the perception of the communication haul in the network, from backhauling to incorporating both a back and fronthaul segment. In this context, the backhaul dictates how the information is parried from the base stations to the core network, whilst the fronthaul refers to the connectivity segment between the C-RAN core network and the small cell. Figure 1.1 shows definitions of

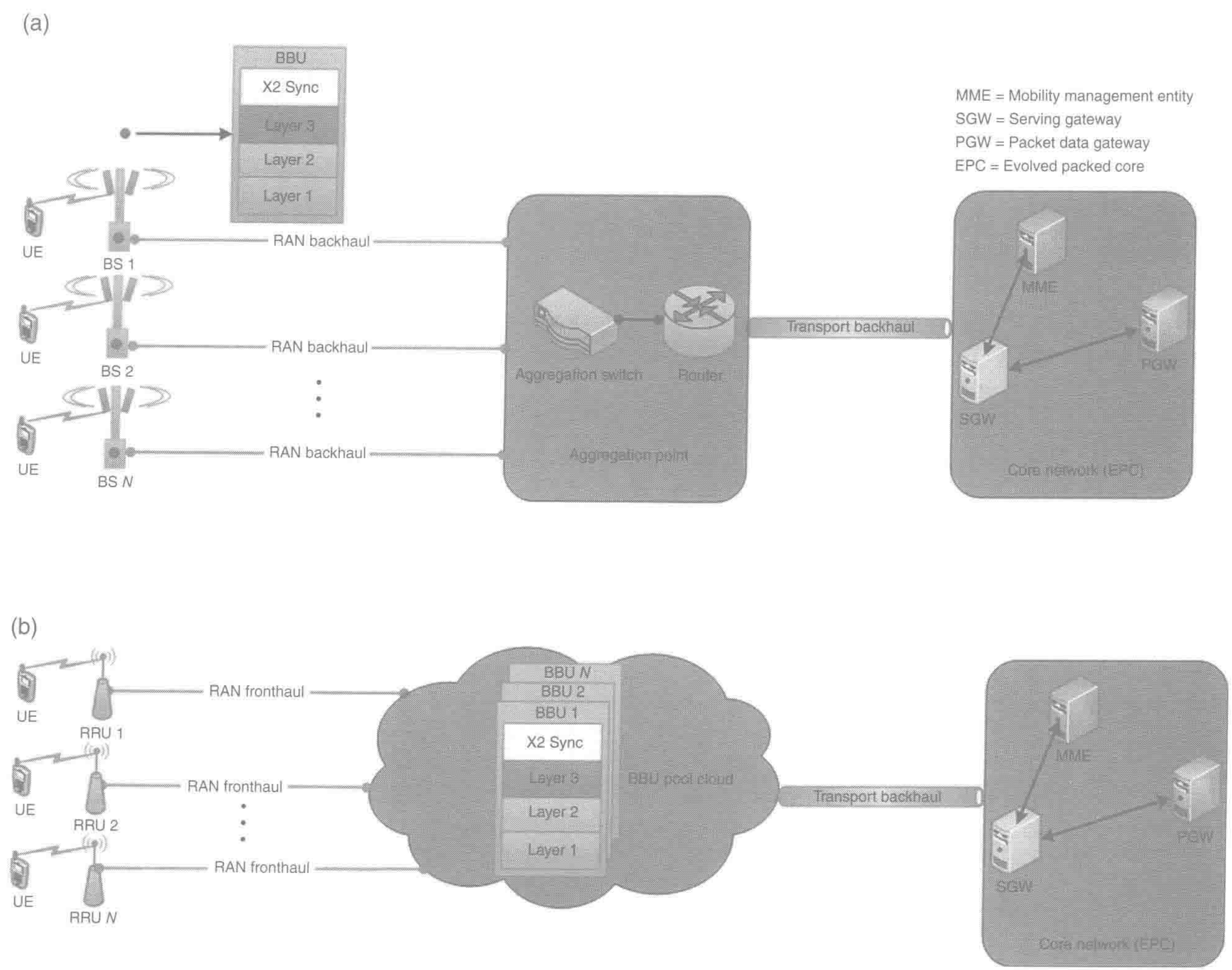

Figure 1.1 Communication haul segments of (a) legacy and (b) emerging C-RAN mobile network

the backhaul and fronthaul segments pertaining to legacy and emerging C-RAN architectures.

The future enhanced communication haul (be it backhaul or fronthaul) for 5G is expected to be deployed around 2020 in order to support the exponential growth in wireless data that is forecast over the next decade. Therefore, there is substantial market interest in the development of ground-breaking backhaul and fronthaul solutions that can not only enhance today's networks, but also provide a coherent interference management approach in emerging technologies such as C-RAN and beyond. This communication haul challenge provided the inspiration for this book and its title: *Backhauling/Fronthauling for Future Wireless Systems.*

The book intends to bring together all mobile stakeholders, from academia and industry, to identify and promote technical challenges and recent results related to smart backhaul/fronthaul research for future communication systems such as 5G. It provides an overview of current approaches to backhauling legacy communication systems and explains the rationale for deploying future smart and efficient backhauling/fronthauling infrastructure from architectural, technical and business points of view using real-life applications and use cases. The book is intended to inspire researchers, operators and manufacturers to render ground-breaking ideas in the newly emerging discipline of smart backhauling/fronthauling over future, ultra-dense wireless systems. Moreover, detailed security challenges are presented to analyse the performance of smart backhauling/fronthauling for future wireless. It is clear that smart backhauling/fronthauling deployment can offer a palette of interesting colours capable of painting new business opportunities for mobile stakeholders for next generation wireless communication systems. This is the first book of its kind on smart backhauling/fronthauling for future wireless systems which updates the research community on the communication haul roadmap, reflecting current and emerging features emanating from the 3GPP group.

To guide the reader through this adventure, the book has the following layout. In Chapter 2, a reference architecture for the future radio communication haul is presented from a 5G perspective. 5G networks are anticipated to obtain Shannon-level and beyond throughput and almost zero latency. However, there are several challenges to solve if 5G is to outperform legacy mobile platforms; one of these is the design of the communication 'haul'. Traditionally, the backhaul segment connects the radio access network (RAN) to the rest of the network where the baseband processing takes place at the cell site. However, in this chapter, we will use the concept of 'fronthaul access,' which is recently gaining significant interest since it has the potential to support remote baseband processing based on adopting a cloud radio access network (C-RAN) architecture that aims to mitigate (or coordinate) interference in operator-deployed infrastructures; this eases significantly the requirements in interference-aware transceivers. To do this, we provide a reference architecture that also includes a network and protocol architecture and proposes a so-called 'cloud resource optimizer'. This integrated solution will be the enabler for

RAN-as-a-Service, not only paving the way for effective radio resource management, but opening up new business opportunities for virtual mobile service providers.

Emerging channel transmission approaches and the possibility of using higher frequency bands, such as massive MIMO and millimetre-wave (mmWave), respectively, are of paramount importance for future wireless systems and for the communication haul. Chapter 3 introduces the fundamentals with regard to massive MIMO and mmWave communication, and their suitability for small-cell backhauling and fronthauling. Furthermore, a performance analysis model for wireless backhauling of small cells with massive MIMO and mmWave communication is outlined. Using this model, some numerical results on the performance of massive-MIMO- and/or mmWave-based wireless backhaul networks are presented.

C-RAN promises considerable benefits compared to decentralized network architectures. Centralizing the baseband processing enables smaller radio access points as well as cooperative signal processing and ease of upgrade and maintenance. Further, by realizing the processing not on dedicated hardware, but on dynamic and flexible general-purpose processors, cloud-based networks enable load balancing between processing elements to enhance energy and cost efficiency. However, centralization also places challenging requirements on the fronthaul network in terms of latency and data rate. This is especially critical if a heterogeneous fronthaul is considered, consisting not only of dedicated fibre but also of, for example, mmWave links. A flexible centralization approach can relax these requirements by adaptively assigning different parts of the processing chain either to the centralized baseband processors or the base stations based on the load situation, user scenario and the availability of the fronthaul links. This not only reduces the requirements in terms of latency and data rate, but also couples the data rate to the actual user traffic. In Chapter 4, a comprehensive overview of different decentralization approaches is given, and we analyse their specific requirements in terms of latency and data rate. Furthermore, we demonstrate the performance of flexible centralization and provide design guidelines on how to set up the fronthaul network to avoid over- or under-dimensioning.

Heterogeneous backhaul deployment using different wired and wireless technologies is a potential solution to meet the demand in small-cell and ultra-dense networks. Therefore, it is of cardinal importance to evaluate and compare the performance characteristics of various backhaul technologies in order to understand their effect on the network aggregate performance and provide guidelines for system design. In Chapter 5, the authors propose relevant backhaul models and study the delay performance of various backhaul technologies with different capabilities and characteristics, including fibre, xDSL, mmWave and sub-6 GHz. Using these models, the authors aim to optimize the base station (BS) association so as to minimize the mean network packet delay in a macro-cell network overlaid with small cells. Furthermore, the authors model and analyse the backhaul deployment cost and show that there exists an optimal gateway density that minimizes the mean backhaul cost