Preface

To meet the recent wireless traffic volume increment, 5G heterogeneous cellular networks have been investigated as the most powerful network architecture to enhance both spectrum and energy efficiency in a cost-effective way, where various kinds of small cells with different downlink powers coexist in the coverage of macrocells. These small cells can be pico cells, femtocells, remote radio heads, relays, and device-to-device communication pairs. These small cells can offload the traffic, extend the coverage, and better meet the subscribers' quality of experience (QoE). In summary, 5G heterogeneous cellular networks will counter the challenge of cost-effectively supporting a 1000-fold increase in traffic demand over the next decades.

However, these good opportunities provided by the 5G heterogeneous cellular networks always come with various technical challenges, for instance, both the inter- and the intra-tier interference damages the potential performance improvement. This is mainly due to the limited spectrum resources, thus leading to these underlying small cells fully sharing the licensed spectrum to the macrocells.

On the other hand, denser deployment of small cells means higher energy consumption, and backhaul and fronthaul expenditures. Therefore, the spectrum, energy, and cost efficiency problems are becoming more serious, in particular, in the ultra-dense deployment scenarios. This edited book will concentrate on the promising interference mitigation and energy management, with the aim to release the potential capabilities of the 5G heterogeneous cellular networks.

By now, extensive research has been poured on this topic, which can be viewed from the following aspects: first, theoretic performance limits of interference-limited systems have been analyzed in the framework of stochastic geometry and optimization theory. However, researchers prefer the advanced mathematical tools with features of characterizing the interaction and rational behaviors and distributed control schemes. Second, although there exist different interference mitigation technology, they should be further studied and applied to the 5G heterogeneous cellular networks. Meanwhile, there should exist a survey on the interference alignment, enhance inter-cell interference coordination, and interference cancellation. In addition, different energy management methodology should be jointly considered including the cell-zooming and cell range expansion to enhance the energy efficiency. Last but not the least, new network architectures and typical features are involved in the heterogeneous cellular networks, including cloud computing, cognitive radio, and software-defined networks and network virtualization. These will largely enhance the capabilities of 5G heterogeneous cellular networks.

The promising 5G featured technology has been widely studied to mitigate interference and save energy, thus improving both spectrum and energy efficiency. Researchers from academia, industry, and standardization communities are still working hard on these promising topics. Therefore, it is necessary to call for them to propose their novel ideas to contribute this book.

It is known that the energy efficient, green, and interference management should be explored and exploited for better understanding and design wireless networks. This book looks into discuss and address interference and energy management for the emerging 5G heterogeneous cellular networks, where we concentrate on building a overall picture on the topic, surveying the current research status, and providing novel mathematical frameworks, e.g., matching, game, and pricing.

This book is therefore both timely and apposite. The book will provide the novel and potential way to solve the encountered problems for wireless network researcher and engineer. It also will help various kinds of networking engineers for understanding and designing the suitable wireless networks.

TARGET AUDIENCE

Researchers, advanced-level students, technology developers, and engineers will find this text useful in furthering their research on Interference Mitigation and Energy Management in 5G Heterogeneous Cellular Networks. This text will assist wireless engineers in furthering their own research efforts and interests, where they will find useful and valuable guidance from the surveyed techniques, the specific technology applied to specific scenarios, and the mathematical frameworks.

CHAPTER OVERVIEW

After careful and rigorous review, finally we accepted 12 chapters according to the review results, and content, concentration, and objective of this book; and then we divide them into three sections according to their internal logic.

Section 1: Energy-Efficient Communications and Energy Management Techniques

In the section, we have three chapters, where the first two chapters (Chapter 1 and Chapter 2) concentrate on specific energy efficient technology from different perspectives, and Chapter 3 surveyed the current research status and the ongoing projects all over the world, finally the authors looked into the future research directions. In detail, Chapter 1 studied two kind of green communication techniques, including adding more sectors per site and deploying an overlay of small cells, which are key methods to enhance the RAN coverage and capacity. The impact of these two techniques on cellular network energy consumption was also investigated in Chapter 1 with the aim to find an energy efficient deployment strategy when trading-off the order of sectorisation with the intensity of small cell densification. In addition, Chapter 1 evaluated the amount of network energy efficiency improvement when various adaptive sectorisation schemes were implemented, where the conclusion was the strategy of adding more sectors was less energy efficient than directly deploying an overlay of small cells, even when adaptive sectorisation was implemented.

In Chapter 2, the authors studied caching to ultra-densely deployed small cells to save the energy consumption, where the authors investigated a NP-hard energy-efficient context-aware resource allocation problem and formulated it as a one-to-one matching. The preference lists in the matching were modeled

based on the optimum energy efficiency under specified matching and established by using an iterative power allocation algorithm based on nonlinear fractional programming and Lagrange dual decomposition. Some properties of the proposed Gale-Shapley algorithm were discussed and analyzed in detail. Moreover, the authors extended the algorithm to the matching with indifferent and incomplete preference lists in Chapter 2. In green communications, the network operator makes efforts to reduce energy consumption., where different research schemes about energy efficient communication techniques, the design of energy-aware network architectures and protocols, energy-friendly software, and renewable energy sources have been well studied recently. However developing an optimal energy management plan requires the understanding of the characteristics of 5G heterogeneous cellular networks that could be exploited to improve energy and resources efficiency. In Chapter 3, the authors presented a study about challenges in energy-efficient communications and communications technologies as enablers for green solutions and how this challenges could be extended to meet those of the 5G heterogeneous networks, in order to identify possible solutions to address the energy efficiency and interference mitigation issues. Chapter 3 surveyed the current research status and the ongoing projects allover the world, finally the authors looked into the future research directions.

Section 2: Enhanced Interference Management Technology with Featured Characteristics

In this section, we have five chapters, where Chapters 4, 5, 6, and 7 investigated the interference management schemes with featured characteristics of the full-duplex massive MIMO relay, the cognitive MIMO system, the combination of resource allocation and interference alignment, and game theory. Finally, Chapter 8 summarized the major challenges and solutions of interference management. Interference cancellation, avoidance and coordination were discussed in detail in Chapter 8.

Massive MIMO full-duplex relaying (MM-FDR) was studied in Chapter 4, where multiple source-destination pairs simultaneously communicated with the help of a common full-duplex relay. Different from the traditional MM-FDR protocol, a general model was formulated where sources and destinations were allowed to equip with multiple antennas. A low complexity hardware impairments aware transceiver scheme (named as HIA scheme) was presented to mitigate the distortion noises by exploiting the statistical knowledge of channels and antenna arrays at sources and destinations. The results showed that the HIA scheme can mitigate the ceiling effect appearing in traditional MM-FDR protocol when the numbers of antennas at sources and destinations can scale with that at the relay. In Chapter 5, the authors analyzed a typical scenario where the GEO satellite-terrestrial network and the 4G mobile communication network coexist heterogeneously. Besides, a multi-user cognitive system model was also proposed, where secondary satellite terminals interfered the primary MIMO 4G base stations. Meanwhile, DBF in 4G base station system was adopted to minimize the cognitive interference caused by multi-antennas and multi-users, where weight vector was only related to the azimuth of the interference, thus the proposed algorithm did not need real-time and repeat calculations, and had small complexity. Finally, the numerical simulation results verified that the proposed system and algorithm can effectively reduce interference between satellite-terrestrial network and terrestrial wireless network to a certain extent.

Chapter 6 and Chapter 7 are from the resource management perspective to manage the interference. However, different with the traditional resource allocation problems, the consistency of resource occupation and the diversity of interference of participants in interference alignment (IA) clusters bring about

the complexity in the combination of resource allocation and IA. Therefore, Chapter 6 gave a transformed conflict graph-based solution framework which considered the low complexity of chordal graph, where the selection criteria of IA clusters were determined by the influence of IA on the resource occupation and the interference. The simulation results showed that the proposed schemes can improve the network performance. Meanwhile, it is significant to study the self-organized distributed co-tiered interference mitigation and resource allocation. Game theory is an effective distributed approach towards handling the distributed co-tiered interference mitigation problem without a central controller. Chapter 7 was to address the application of game theory and distributed learning solutions for distributed co-tiered interference mitigation. Two potential game models for static and dynamic co-tiered interference mitigation were presented and discussed for small-cell networks with fixed loads and dynamic loads separately. In addition, two distributed learning algorithms were presented and results are discussed. Finally, some future research directions were given.

In addition to the listed interference management schemes, Chapter 8 summarized the major challenges and solutions of interference management. Interference cancellation, avoidance and coordination were discussed in detail, including enhanced intercell Interference Coordination(eICIC), Coordinated Multi-point Transmission (CoMP) et al. In addition, the future challenges of interference management had also been presented.

Section 3: Novel Mathematical Frameworks for Interference and Energy Management

We have four chapters in this section, where we provided novel mathematical frameworks, although there have exited the specific applications of matching in Chapter 2 and game in Chapter 7. In this section, a geometric programming formulation was first given, thus leading to the discussion of the necessity of self-organizing networks in the 5G era. Following that, we introduced two surveys of Stackelberg game and pricing methodology to meat the hierarchical architecture of Interference Mitigation and Energy Management in 5G Heterogeneous Cellular Networks.

In Chapter 9, the authors studied the high-speed moving scenario, such as high-speed railway (HSR). Which was a typical application scenario of 5G communication systems. Recently, the HSR has been rapidly developed in the world. Mobile relay stations (MRSs) which are mounted in a high-speed train (HST) is the popular system architecture for high-speed mobile communications. However, sharing spectrum between the macro cell and the MRS cell, interference exists in this hybrid system. Chapter 9 investigated the downlink of a multi-cellular decode and forward (DF) relayed OFDMA)system and formulated the problem to maximize the system sum rate of all cells subject to a total power constraint and a new proposed time delay constraint. An effective resource allocation scheme combined by a greedy sub-carriers allocation and geometric programming (GP) based power allocation algorithm was proposed to optimize subcarrier allocation and power allocation. Particularly, a rigid time delay constraint was introduced to accommodate the high speed mobile environment except for the common power constraint. Numerical experiments verified that the proposed resource allocation scheme outperforms the other traditional approaches and the necessity of introducing the time delay constraint. Although optimal solutions can be found in the convex optimization frameworks, there comes the novel challenges of distributed interference management and self adaptability with the overlaying macro cellular network since most

small cell base stations are user deployed and do not have centralized control on their configuration and operation. The purpose of Chapter 10 is to elaborate the concept of heterogeneous network and Self Organization Network (SON) in LTE-A. The various use cases of SON that can benefit the heterogeneous network has been discussed laying emphasis on interference management use case. Further the current trend of research in this field has been highlighted. It provides a holistic picture of the heterogeneous network and SON in LTE-A and upcoming mobile communication generations.

Chapters 11 and 12 considered the joint interference mitigation and energy management, where the concentration is to introduce the novel game and pricing techniques to facilitate the design of distributed schemes. Game theory has found an extensive application in wireless communication networks including cognitive radio networks, heterogeneous cellular networks, cooperative relay networks. Also, cognitive radio networks, green communications and heterogeneous cellular networks have attracted a wide attention on improve the spectrum efficiency and energy efficiency; therefore, the capacity, the coverage and the energy consumption. However, interference problem and energy consumption are critical for these networks. Introducing hierarchy among different decision-making players in cognitive, heterogeneous, green, cooperative cellular networks can both save energy and mitigate interference, thus enhance throughput. Stackelberg game suits to model, analyze and design the distributed algorithms in these hierarchical decision-making networking scenarios. In this chapter, we introduce basics of Stackelberg game and survey the extensive applications of Stackelberg game in cognitive, heterogeneous, cooperative cellular networks with the emphasis on resource management, green commutations design and interference management. Chapter 11 highlighted the potentials and applications with the promising vision of Stackelberg game theoretic framework for future cognitive green heterogeneous cellular networks.

Pricing theory and methodology from economic fields have found extensive applications in cognitive radio and multi-tier heterogeneous cellular networks. Conventional economic pricing applications in wireless communications are always related to the monetary revenue of network operators. In this chapter, the authors concentrate on different technical applications and research directions of pricing theory and methodology, where the authors investigate following technical applications and functions of pricing including cooperative incentive mechanism design, Pareto- and social optimality improvement, distributed algorithm design with the low signaling overhead. the authors first clarify different concepts of pricing, summarize the motivation, present a taxonomy according to these different technical applications. Then, the authors survey applications of pricing theory and methodology with understandings and observations in cognitive radio and multi-tier heterogeneous cellular networks. the authors emphasize some of the recent critical problems, such as the cooperation incentive, resource and interference management and economics of small cells. Finally, the authors conclude this chapter with the possible research directions and more potential network applications of pricing theory and methodology.

CONCLUSION

This comprehensive and timely publication aims to be an essential reference source, building on the available literature in the field of interference mitigation and energy management for wireless communication networks, and in particular, the readers will find useful and valuable guidance from the surveyed techniques, the specific technology applied to specific scenarios, and the mathematical frameworks.

The book will provide the novel and potential way to solve the encountered problems for wireless network researcher and engineer. It also will help various kinds of networking engineers for understanding and designing the suitable wireless networks.

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