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Challenges and Trends for Future Wireless Networks

Considering the increasing mobile data demands and the future wireless network technology innovations, this chapter briefly summarizes the challenges and technology trends for future wireless networks. The capacity surge and challenges in heterogeneous networks are introduced first in terms of the fifth-generation (5G) mobile communications system requirements. Then, the uneven traffic distribution characteristics in geography and time domains are described. Both the advantages and the challenges of small cell networks are introduced as key solutions to solve the capacity and coverage optimization problems in future networks. At last, the outline structure of this book is proposed as a guidance to readers.

1.1 Capacity Surge and Challenge in Heterogeneous Networks

The dramatic growth of mobile data services driven by Internet applications and smart devices has triggered the research innovation and study for the 5G mobile communications system. In order to promote the 5G technology development and the international cooperation, China has established the IMT-2020 (5G) promotion group in February 2013. And the key capabilities and requirements for 5G technology are proposed by IMT-2020 (5G) promotion group as shown in [1].

Future 5G systems must dramatically outperform the performance of 4G and previous generation systems, therefore 5G should support the key capabilities [1], including (1) User experienced data rate: 0.1~1 Gbps. (2) Connections density: 1 million connections per square kilometer. (3) End-to-end latency: millisecond level. (4) Traffic volume density: tens of Gbps per square kilometer. (5) Mobility: higher than 500 Km per hour. (6) Peak data rate: tens of Gbps.

Furthermore, the global mobile data traffic will be doubled every year with the popularization of intelligent terminal and data traffic growth in [2]. Therefore, the future wireless network is preparing for an astounding 1000 times increase of capacity in the next ten years. Therefore, finding innovative ways to improve the capacity is a critical issue for future wireless networks which has been paid much attention by researchers and engineers around the world. Obviously, the solution to this formidable challenge is a combination of increasing the efficiency of existing spectrum resources and utilizing more spectrum resources in the form of small cells, as well as adopting radically different ways of acquiring, deploying, operating and managing these resources. Heterogeneous network (HetNet), combined by a large number of low power small cells such as microcell, picocell, femtocell and relay nodes, is one of the most effective and low-cost solutions to satisfy the capacity enhancement challenge in 5G systems.

1.2 Uneven Traffic Distribution in Geography and Time Domains

Considering the dynamic changing feature of various services, the service demands are distributed unevenly at different locations (such as the urban city, suburban area, hotspot, etc.) at different time (fluctuation from day to night), due to the population density distribution pattern and commuters from home to work in [3]. And base stations are deployed by different densities in a large area according to the user’s demands base on the network planning and optimization technologies. Furthermore, different heterogeneous networks are usually overlapped with each other in the hot spot area. And wireless networks with different coverage types may be deployed hierarchically to fulfill the network capacity demand. Due to the flexible coverage capabilities, small cell can satisfy the uneven traffic demand in geography and time domains. Small cells deployed in urban hotspots and buildings can provide the capacity enhancement in a specific location. The scheme of switch on/off and resource re-allocation for small cells can solve the problem of uneven traffic distributions in different time domains.

1.3 Advantages and Challenges of Small Cell Networks

In terms of the capacity surge in urban areas and the unevenly distribution of traffics in geography and time domains, wireless networks are deployed by hierarchical networks with different coverage types and radio access technologies. Small cell is one of the novel technologies applied recently to provide both capacity enhancement and coverage optimization in hot spots. However, the densely deployed small cells which can enhance the network capacity are facing new challenges, such as the capacity boundary, inter-cell and intra-cell interference, network coverage limitation, and fairness among different small cell users.

1.3.1 Theoretical Analysis of Small Cell Capacity

The theoretical analysis of the signal to interference plus noise ratio (SINR) and the capacity in small cell networks are studied in [4]-[7]. The closed-form expression of capacity for both macrocell base station (MBS) and femtocell base station (FBS) in the coexisted networks scenario is described in [4]. An accurate and tractable model to characterize joint uplink-downlink rate coverage in a multi-tier HetNet is characterized in [5]. Furthermore, the key factors of SINR distribution for densely deployed HetNet are studied in [6] and results depict that it is quite different from the view that the network throughput increases linearly with the number of BSs in previous studies. The stability and performance of HetNet in the presence of flow-level dynamics are examined in [7] and results reveal that in the stationary traffic condition the maximum capacity can be achieved using a static resource split and traffic association rule.

1.3.2 Theoretical Analysis of Small Cell Coverage

Furthermore, the theoretical analysis of small cell coverage is studied in [8]-[13]. In [8], the coverage performance of the network is modeled as a cost function and analyzed under different deployment densities of small cells. The two-tier HetNet is studied in [9], where both macro tier and small cell tier operate on orthogonal frequency bands using a dynamic time division duplex (TDD) scheme. The association policy that leads to different associations in uplink and downlink and derive the load-aware coverage probability to maximize the per-tier or network-wide coverage probability is studied in [10]. The optimal bias factors to maximize the probability of coverage is studied in [11] for two cases, where the user is stationary or mobile in which the system is sensitive to handoffs. The problems of inter-cell interference and cell association are studied in [12] by analyzing and exploiting the inherent spatial cross-tier coverage correlation due to the co-channel interference for a two-tier network. Decentralized self-optimization network (SON) architecture of small cell cluster and distributed coverage optimization algorithm using game theory are studied in [13].

1.3.3 Resource Allocation

Uncoordinated densely deployed femtocells in a macrocell network pose unique challenges involving the cross-tier interference and resource management which may lead to significant performance degradation in coexisted macrocell and femtocell networks. Power control and sub-carrier allocation are critical issues in HetNets for the system performance enhancement, which has been investigated from different aspects recently in [14]. Existing research works have proposed many technologies to effectively achieve resource blocks (RBs) orthogonality among cells within HetNets, such as the cognitive radio resource management [15]. The resource allocation problem in both uplink and downlink for two-tier networks comprising the spectrum-sharing among femtocells and macrocells has been investigated in [16]. The reverse frequency allocation (RFA) scheme by dividing the cell service area into multiple regions and assigning frequencies to various cell entities to avoid the interference is studied in [17]. Both the mathematical formulation for the uplink resource allocation and the optimal exhaustive search algorithm are proposed in [18]. The cross-polarized complementary frequency allocation (CPCFA) strategy is proposed in [19] which utilizes the frequency and polarization diversities to mitigate the cross-tier interference among macrocell and femtocell networks.

1.3.4 Interference Management and Coordination

The unprecedentedly densely deployed small cell networks faces a critical challenge of the interference management and coordination among different cells [20]. A survey of different state-of-the-art approaches for the interference and resource management in orthogonal frequency division multiple access (OFDMA)-based femtocell networks is proposed in [21]. Moreover, a survey and qualitative comparison of existing cell association and power control schemes are provided to depict the limitations for interference management in 5G networks in [22]. Moreover, the interference management algorithm for fractional frequency reuse (FFR) wireless networks is studied in [23]. A semi-distributed (hierarchical) interference management scheme based on joint clustering and resource allocation for femtocells is proposed in [24]. Furthermore, the approach of finding the optimal strategy to develop and analyze limited feedback resource allocation algorithm is studied in [25]. And new algorithms are proposed in [26] to minimize the power consumption of an OFDM-based HetNet while satisfying all users' rate requirements, as well as considering the inter-cell interference. In addition, there are other interference coordination strategies including employing smaller and more specialized cells [27], interference cancelation [28], the joint analysis of resource partitioning and traffic offloading schemes [29]. The optimal configuration problem of enhanced inter-cell interference coordination (eICIC) parameters, such as the almost blank subframes (ABS) period ratio and range expansion (RE) bias, are solved by using subgradient methods in [30].

Besides, many recent works have studied the problem of cooperative interference management in small cell networks. A cooperative scheme for femtocell networks is modeled as a coalitional game in [31]. Another novel approach to allow small cells to cooperatively optimize their sum rates and satisfying their maximum transmit power constraints in an OFDMA two-tier small cell network, is studied in [32]. And the cooperative distributed radio resource management algorithms for time synchronization, carrier selection, and power control are discussed for the hyper-dense small cell deployment in [33].

1.4 Outline Structure of This Book

In terms of emerging challenges in small cells, this book will focus on the key technologies for the optimization of densely deployed small cells. Capacity analysis and coverage self-optimization technologies are proposed and verified with simulation results. Moreover, the interference mitigation technology is proposed to minimize the inter-cell and intra-cell interference among multi-tier small cell networks. The structure of this book is shown in Figure 1.1.

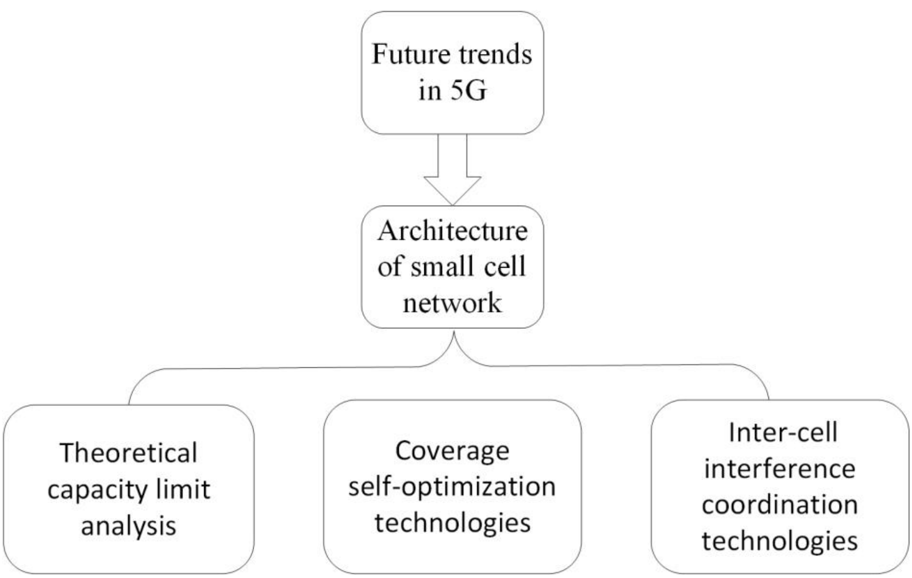

Figure 1.1 *Structure of the book.*

Chapter 1 introduces the future trends in wireless network. Small cell is a promising technology to meet the capacity enhancement demands in 5G wireless networks. However, there are other challenges unsolved, such as capacity limit, coverage self-optimization and interference management in small cells.

Chapter 2 analyzes the small cell network architecture with different frequency allocation schemes. And the small cell network capacity is analyzed with theoretical capacity limit in terms of both inter-cell and intra-cell interferences.

Chapter 3 proposes the coverage self-optimization technologies for the randomly deployed small cells in the indoor scenario.

Chapter 4 proposes the modified inter-cell interference coordination technologies to minimize the interference among macrocells and small cells.

Finally, a brief summary concludes this book and future research directions are described briefly in Chapter 5.

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