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Green cell planning and deployment for small cell networks in smart cities☆

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ABSTRACT

In smart cities, cellular network plays a crucial role to support wireless access for numerous devices anywhere and anytime. The future 5G network aims to build the infrastructure from mobile internet to connected world. Small Cell is one of the most promising technologies of 5G to provide more connections and high data rate. In order to make the best use of small cell technology, smart cell planning should be implemented to guarantee connectivity and performance for all end nodes. It is particularly a challenging task to deploy dense small cells in the presence of dynamic traffic demands and severe co-channel interference. In this paper, we model various traffic patterns using stochastic geometry approach and propose an energy-efficient scheme to deploy and plan small cells according to the prevailing traffic pattern. The simulation results indicate that our scheme can meet dynamic traffic demands with optimized deployment of small cells and enhance the energy efficiency of the system without compromising on quality-of-service (QoS) requirements. In addition, our scheme can achieve very close performance compared with the leading optimization solver CPLEX and find solutions in much less computational times than CPLEX.

1. Introduction

Smart city is envisioned as a prospect to enable citizens to collect information and connect to the world more conveniently. With the extensively use of smart devices, such as smartphones, wearable devices, internet cameras and terminals on vehicles, the future wireless network is considered as internet of things (IoT) Hu et al. [11], Sheng et al. [16]. More and more cloud-based mobile applications are developed to provide citizens with abundant services. Until now, cellular network is still the key infrastructure to provide wireless access to the internet for all kinds of devices. However, the current cellular networks are incapable of supplying satisfactory and economical services considering dynamic traffic demands and huge energy cost.

According to descriptions of LTE and expectations of 5G network, future cellular networks are expected to be heterogeneous cellular networks Nakamura et al. [14]. Heterogeneous cellular network (HCN) is defined as a mixture of macrocells and small cells, e.g., picocells, femtocells and relays. Small cells can potentially enhance spectrum reuse and coverage while providing high data rate services and seamless connectivity Zhou et al. [19]. Meanwhile, small cell is also foreseen as a solution to achieve ecological

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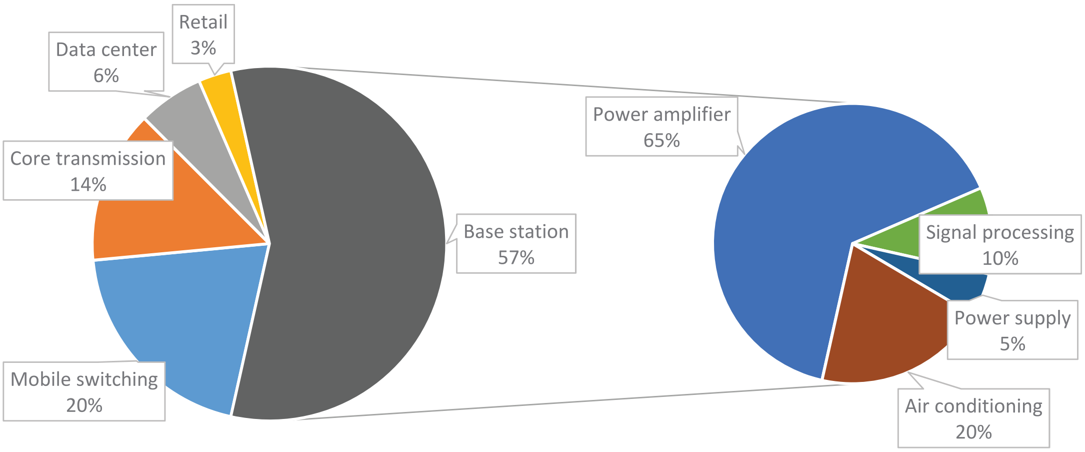

Fig. 1. Power consumption in cellular networks.

sustainability. However, when small cells become dense in a limited area, severe interference would happen due to spectrum reuse. Furthermore, if we consider all user equipments (UEs) in a given urban area, the distribution of UEs might fluctuate during one day, resulting in various traffic distributions. In this case, some base stations (BSs) might be overloaded while some might be idle. Traditional macro-only cellular networks are usually deployed in terms of the estimated highest traffic demand in a service area, which leads to unnecessary energy waste and extra expenditure Abdel˜Khalek et al. [2]. In consequence, energy-efficient techniques should be developed in order to satisfy various applications with better quality and lower cost. Numerous existing schemes on energy-efficient cellular networks focus on optimizing radio resource allocations Cao et al. [5], Le et al. [12], Ng et al. [15]. However, the improvements that they obtained are still minor compared with optimization of cell deployment and planning. The density of small cells, neither too dense nor too sparse, should correspond to the actual traffic demands.

It has been investigated that BSs consume most energy among all elements in a cellular network as illustrated in Fig. 1 De Domenico et al. [7]. Furthermore, the energy consumption of a BS can be divided into four parts roughly, which are the power amplifier, signal processing, power supply and air conditioning. The transmit power is only a small part of the power amplifier (PA) considering its transformation efficiency and all the rest energy consumption can be classified as circuit power consumption Chatzipapas et al. [6]. We assume all BSs have two working modes, namely, active mode and sleep mode. When a BS is turned into sleep mode, it only consumes very limited power to maintain basic operation in order to be waked up again timely. Therefore, turning BSs into sleep mode can reduce large amount of power consumption.

Cell deployment in traditional macro-only cellular networks usually lead to static deployments of BSs, which are mainly determined by the estimated highest traffic demands. Implementing them on small cell networks directly would result in severe energy waste and incur unnecessary costs. Recently, implementation of cell planning with sleep mode operations has attracted much attention. Among all elements that we need to consider in cell planning, geographical location of BSs, traffic load and radio propagation environment and energy consumption are the most important factors that we need to consider for implementation and evaluation Baumgartner and Bauschert [4]. For example, Wang et al. [17] aims to plan small cells by maximizing the number of traffic demand nodes with a limited budget. González-Brevis et al. [10] studies the combined problem of BS deployment and power allocation based on a TDMA protocol to avoid interference among the user equipments (UEs). Falconetti et al. [8] proves that the total energy consumption could be reduced by introducing the sleep mode while maintaining the performance of UEs. Rengarajan et al [3] achieves the energy-optimal density of base stations corresponding to a given user density based on stochastic geometry, which provides a lower bound of BS density for cell planning theoretically. However, we still need to find some practical way to guild the implementation of cell planning and deployment in real scenario, and the research on cell planning in the context of dense small cell networks under dynamic traffic demands is still limited.

To solve the emerging challenges, we propose a green cell planning scheme, which considers small cell planning and deployment jointly under dynamic traffic demands. Firstly, we build statistical traffic models for different traffic patterns based on stochastic geometry approach that adopts a non-parameterized statistical method. Then, for each traffic pattern, we devise a heuristic to update BS states and UE associations iteratively until we obtain a solution of BS states with minimum number of active small cell BSs (s-BSs). The final deployed set of s-BSs is the union of active s-BSs under all considered traffic patterns. We use Monte Carlo simulations to regenerate the traffic distributions for each traffic pattern so that more than one solution of BS states might be obtained for each traffic pattern. Finally, we select the optimal BS states for each considered traffic pattern to minimize the number of active s-BSs in the union. In this way, we obtain the optimal BS states for each traffic pattern and the final deployment plan with the