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Cellular networks planning: A workload balancing perspective

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ABSTRACT

Cell planning has been a long-standing problem since the very starting commercialization of mobile communications, of which power coverage and capacity coverage are two major objectives. In this paper, we develop a novel cell planning scheme that is effective and efficient for both the conventional cellular systems and the arising heterogeneous networks, e.g., the long term evolution advanced (LTE-A) one. The key idea of our proposal is that we redesign the service regions of base stations (BSs) in a traffic-balanced way, making each BS serve a subregion of ALMOST equal throughput requirement. For a given connected polygonal region to be served by a cellular system, we first divide it into compact and connected subregions based on an infinite optimization formulation while keeping the traffic demands of all subregions as equal as possible. Each subregion will be served by a BS located in it. To avoid yielding ill-shaped subregion that is difficult to be covered by a practical BS, a penalty term is introduced to the objective function and it is required that areas of subregions should not differ too much from each other. Then we select the BS from all candidate sites in each subregion to minimize the total power consumption. By using the proposed dividing and selecting algorithms, we update the boundary of each subregion and the location of each BS in an iterative manner until convergence. Numerical results show that our proposal performs quite well for both randomly generated scenarios and real city environment. The proposed cell planning method provides quality of service (QoS) guaranteed performance with lower capital expenditure and operating expenditure.

1. Introduction

Over recent years, mobile data consumption has experienced a record growth among the world's operators as subscribers use more smart phones and mobile devices, like tablets. Investigations have discovered over 100% annual growth in mobile data traffic starting from about 2008, and predicted that the data demands would continue increasing exponentially, which projects a factor of 1000 increase from 2007 to 2016 [1]. In order to handle the crazily increasing data rate of mobile communication services, heterogeneous networks (HetNets) are introduced and deemed as a cost-effective way to keep up with the increasing traffic demands of user equipments [2–6], where different kinds of access points coexist in a cellular system. To be more specific, various types of low power nodes are deployed throughout macro base stations (BSs), including micro BSs, pico BSs, home BSs, and relays. In HetNets, the overlaid macro BSs provide the basic wide coverage while low power BSs are deployed to cover dead zones and traffic hot zones.

Denser and denser low power BSs do improve the throughput of the cellular system, but they also lead to a complex network architecture which requires more complex coordination strategies. As a result, advanced signal processing techniques, such as Coordinated Multiple Point (CoMP) transmission and reception, Inter-cell Interference coordination (ICIC), are rising as promising solutions to improve the performance of HetNets. CoMP for the long term evolution

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advanced (LTE-A) was proposed to improve the coverage of high data rates together with the cell-edge throughput and/or system capacity. The concept of cell defined in LTE also applies to such a coordinated scenario. CoMP implies dynamic coordination among multiple geographically separated transmission, and has been accepted by the 3rd Generation Partnership Project (3GPP) LTE-A work [7]. ICIC has gained much interest in 3GPP's LTE standardization of a new air interface. In the physical layer of LTE-A, interference can be predicted and avoided on a frequency basis. Such schemes are based on cell wise usage restrictions or resource preferences [8].

In the past years, screening conditions for selecting BSs are quite harsh because of the large size and the high cost of BSs, and radio planning engineers usually concern more about the power coverage issue, which requires that all users in the service region should be provided with strong enough signal strength or high enough signal-to-interference-plus-noise ratio (SINR) so as that they can demodulate symbols correctly [9]. Besides, due to the reason that the traffic load is not as heavy as today, it is reasonable to configure all BSs in the cellular system with almost the maximum throughput margin, though the traffic demand always varies in temporal and spatial domain. With the explosive growth in data demands, the capacity provided by the BSs in hot zones can hardly meet users' rate requirements, which leads to more and more low power BSs overlaying in an existing cellular system, as well as more and more advanced signal processing techniques required to address the unavoidable interference problems, just as the HetNets do currently. In other words, HetNets and the related issues are undoubtedly logical from the viewpoint of conventional cell planning to deal with the ever increasing data demand of mobile communications.

On the other hand, with the advances of radio and material technology, both the size and cost of a BS are reduced dramatically during the past decades, which indicates that more candidate sites can be acquired to deploy macro BSs for a given service region. E.g., many places where low power BSs are deployed can also be used to lay macro BSs in cellular networks nowadays. That is to say, the deployment of macro BSs can be potentially re-designed without changing the infrastructure of an existing cellular network and without increasing sites requisition cost. Besides, BS's utilization rate is usually low because the average network load is usually far lower than that in peak hours and hot zones; while the BS' processing power cannot be shared with other BSs [10]. This stimulates us with an idea to plan the macro BSs in an ALMOST optimal way: if the traffic load of each BS in a cellular system is near equal, obviously, the minimum number of BSs are required for a region with given traffic demands. Moreover, with such a planning model of macro BSs, the number of low power BSs for hot zones can also be reduced, as well as the pressure of developing complex signal processing techniques to address the interference between different kinds of BSs. In brief, the benefit of planning macro BSs in an optimal way is great, at least in theory. However, is it possible to divide a region into multiple subregions with equal traffic? Furthermore, even though such a division exists, is the shape of each subregion reasonable to deploy a BS in practice? In this work, we will answer these questions. Our research results show that both of the two questions have a 'Yes' answer. We will also show that our proposed planning paradigm is fruitful for improving the quality of service and the energy efficiency of a cellular network.

Last but not the least, planning macro BSs in an ALMOST optimal way also coincides with the concept of Centralized processing, Cooperative radio, Cloud, and Clean (Green) infrastructure Radio Access Network (C-RAN). C-RAN is believed to solve five main challenges of today's RAN: large number of BS and associated high power consumption, rapid increasing capital expenditure (CAPEX)/ operating expenditure(OPEX) of RAN, explosive network capacity need with falling average revenue per user (ARPUs), dynamic mobile network load and low BS utilization rate, and growing internet service pressure on operator's core network. C-RAN is a natural evolution of the distributed base transceiver station (BTS), which is composed of the baseband Unit(BBU) and remote radio heads (RRHs) [10]. In C-RAN architecture, the BBU pool can evaluate the current situation of whole network in terms of traffic demand, system performance level, target system performance level, criticality of user, energy status at the time of day and many other similar factors to decide whether the activation of the respective small cell RRH is needed or not. This dynamic approach enables the network topology to change based on current demand levels and performance expectations [11].

The key idea of our proposal is as follows. Given a region and the distribution of traffic demand nodes in the service region, we first estimate how many BSs are required to cover the region by considering the practical capacity supported by a BS and reserving sufficient margin to address the constant traffic variations in practical mobile networks. Then we divide the region into subregions according to the candidate sites for deploying BSs to guarantee that at least one candidate site falls into each subregion. Each subregion covers (near) equal traffic demand nodes. Third, we relocate the position of the BS in each subregion to minimize the power consumption by testing all candidate sites in this subregion, as well as re-partition the whole region until the consumed power of the cellular system is minimized. In this way, we balance the traffic capacities of macro BSs and decrease power consumptions simultaneously. Our proposed planning scheme is verified by numerical results and a practical cellular system.

The remainder of this paper is organized as follows. In Section 2, we discuss the relationship between our work and prior ones. In Section 3, we give a brief introduction of our cell planning strategy. In Section 4, we develop efficient algorithms to carry out the proposed cell planning scheme. Numerical results are reported with discussions in Section 5. Conclusions are drawn in Section 6.

2. Related work

Basically, our proposed cell planning scheme is to balance the workload of a cellular system in traffic demand aspects. Workload balancing has been researched widely in the literature. It is a way to balance the workload among various servers [12] and machines in order to optimize factors like resource utilization, fairness, waiting/processing delays, or throughput [13]. Equitable location problem on a plane has been studied in the Operational Research field, which is generally designed to locate M facilities on a unit square so