Computer Networks 79 (2015) 297–312

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Efficient eNB deployment strategy for heterogeneous cells in 4G LTE systems

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ARTICLE INFO

Article history:
Received 1 August 2014
Received in revised form 21 January 2015
Accepted 22 January 2015
Available online 31 January 2015

Keywords:
Base station deployment
Cell planning
Heterogeneous network (HetNet)
Long term evolution (LTE)
Network management

ABSTRACT

Base station deployment is an important issue in cellular communication systems because it determines the cost to construct and maintain a system and also the service quality to users. Conventional 2G and 3G systems assume that base stations are identical in the sense that they have the similar coverage range. For 4G systems, LTE introduces the concept of heterogeneous base stations (also called *eNBs*), which supports different sizes of coverage range. Given the user distribution and demands in a service area, the problem of deploying heterogeneous eNBs is NP-hard. Therefore, we propose a four-stage eNB deployment strategy to efficiently solve the problem. Our strategy first employs a geometric approach to provide the basic coverage to the service area. Then, it adaptively adjusts the cell range to satisfy the user demands under the power and bandwidth constraints on each eNB. Simulation results verify that the proposed strategy not only significantly saves the system cost, but also reduces the power consumption while balances the traffic loads of eNBs.

1. Introduction

The market of intelligent, hand-held communication devices such as mobile phones and tablet computers keeps growing year by year. Except for the basic voice communication, various wireless multimedia services with large bandwidth demand such as video streaming and teleconference services should be also supported by network operators. To follow this trend, ITU (International Telecommunication Union) defines IMT-A (International Mobile Telecommunications–Advanced) requirements for the current 4G communication systems [1]. Specifically, the target peak data rate (for total users) is 1 Gbps in the downlink and 500 Mbps in the uplink. Therefore, 3GPP (the third Generation Partnership Project) specifies *long term evolution (LTE)* and its advanced version, LTE-A, in order to meet the above IMT-A requirements [2].

For a cellular communication system, one critical issue is to determine the locations of base stations (BSs), also known as *BS deployment*, so as to provide the maximum service coverage with the minimum system cost. Existing 2G and 3G systems usually consider BSs with similar hardware characteristics such as antennas and power levels. A network operator may first predict where BSs should be located in theory or by simulations so that not only the service coverage is increased but also the interference between adjacent cells is reduced. Thus, BSs are often planned to be deployed in a regular fashion [3]. Then, BSs are practically deployed wherever the operator can acquire rights to purchase and install sites. However, because all cells have the similar coverage range, the above deployment may not work well when users request large traffic demands or some of them congregate in certain small regions (called *hotspots*, such as coffee shops or airports) [4].

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http://dx.doi.org/10.1016/j.comnet.2015.01.013
1389-1286/

In LTE, a BS is also called an *E-UTRAN NodeB* (or *eNB* shortly). Depending on their coverage range, LTE defines four types of eNBs (from large range to small range): *macro-cell*, *micro-cell*, *pico-cell*, and *femto-cell eNBs*. Only femto-cell eNBs can be user-installed, whereas other eNBs are operator-installed. Table 1 compares these four types of eNBs [5,6]. By allowing different types of eNBs to coexist in the same service area, LTE introduces the concept of *heterogeneous network (HetNet)* to address the above large user-demand and hotspot issues. In particular, macro-cell eNBs serve as the backbone to provide signal coverage in large geographic regions. Then, micro-cell and pico-cell eNBs can provide service to hotspots or fill those 'uncovered holes' left by macro-cells. Finally, users can install their own femto-cell eNBs to improve the signal quality.

The eNB deployment issue in LTE HetNets is also addressed in the literature, but most of relevant research discusses only the combination of large macro-cell and small femto-cell (or pico-cell) eNBs. This motivates us to study the *eNB deployment with the minimum cost (EDMC) problem*, where three types of operator-installed eNBs are considered (that is, macro-cell, micro-cell, and pico-cell eNBs). Given the distribution of LTE *user equipments (UEs)* and their traffic demands, the EDMC problem asks how to deploy different eNBs to meet the demands of all UEs such that the total system cost is minimized. The problem is NP-hard, so we develop an efficient four-stage strategy. Our idea is to first use large cells to provide basic coverage to every UE. Then, for each cell, our strategy checks whether the eNB has sufficient power and bandwidth resource to support all UEs in the cell. If not, the cell range is shrunk accordingly. Finally, small cells are added to strengthen the network deployment.

The contributions of this paper are threefold. First, the proposed EDMC problem considers all types of operator-installed eNBs, whereas many research efforts disregard micro-cell eNBs. Our EDMC solution thus helps support more flexible network deployment. In addition, we consider path loss, shadowing, multipath fading, and environmental noise, which can model LTE communication channels more realistically. Second, we develop an efficient eNB deployment strategy by considering not only the positions of UEs but also the power and bandwidth constraints on each eNB to meet UEs' traffic demands. Furthermore, several research issues of our strategy such as the fluctuations in UE density, impact of uplink transmission, and cell interference are also discussed in the paper. Third, we design four different scenarios of UE distributions in the simulations to evaluate the performance of our eNB deployment strategy. Experimental results demonstrate that our strategy can significantly save the overall system cost, reduce the power consumption of macro-cell eNBs, and deal out the load of each macro-cell eNB to its nearby small-cell eNBs.

Table 1
Comparison on LTE eNBs.

eNB	Transmission power	Cell size	Users supported
Macro-cell	20 W–160 W	>1 km	>micro-cell
Micro-cell	2 W–20 W	250 m–1 km	>pico-cell
Pico-cell	250 mW–2 W	100 m–300 m	32
Femto-cell	10 mW–200 mW	10 m–50 m	8

[Unit] m: meter, km: kilometer, W: watt, mW: milliwatt.
[Notice] The typical transmission power of a macro-cell eNB is 40 W.

The rest of this paper is organized as follows. The next section discusses the related work. Section 3 first addresses the eNB parameters and the fading and noise models used to describe an LTE communication channel. Then, the section formally defines the EDMC problem. Section 4 presents our eNB deployment strategy to the EDMC problem and Section 5 investigates some research issues in the proposed strategy. Experimental results are shown in Section 6. Finally, we give the conclusion and future work in Section 7.

2. Related work

BS deployment has been widely discussed in 2G and 3G communication systems. For 2G systems, many research efforts [7–10] consider two-phase BS deployment. In phase 1, they select a set of candidate locations to place macro-cell BSs in order to meet the given capacity demand such that the system cost can be reduced. Then, phase 2 aims at allocating frequency channels to BSs such that the interference between two adjacent cells can be eliminated while user QoS (quality of service) can be satisfied. On the other hand, 3G systems do not require the above phase 2 since all BSs share the same frequency spectrum. Therefore, 3G BS deployment [11–14] focuses on selecting the locations of BSs and adjusting their transmission power, with the consideration of cell interference. However, these studies only consider identical macro-cell BSs and thus their results may not be directly applied to wireless HetNets. Ting et al. [15] propose a multi-objective variable-length genetic algorithm to address BS deployment in a wireless HetNet containing both WiMAX and WiFi BSs, where the goal is to maximize the network coverage while minimizing the system cost. However, only two types of BSs are considered and the BS planning model aims at the map instead of the user distribution. The work of [16] proposes a *budgeted cell planning problem* for cellular networks with small cells, and its objective is to maximize the number of traffic demand nodes whose required rates are fully satisfied under the budget constraint. The problem is proven to be NP-hard and an approximation algorithm which yields an $(e-1)/2e$ fraction of the optimum is developed. Obviously, [16] has different objective with our work.

Several research efforts also investigate the LTE eNB deployment issue. By measuring the commercial GSM (Global System for Mobile Communications) live traffic to capture the spatial distribution of UEs, [17] can assess LTE downlink inter-cell interference and thus determine where to deploy macro-cell eNBs. However, it does not consider LTE HetNets. Both [18,19] discuss how to efficiently add femto-cell eNBs in existing LTE macro-cells in order to improve the service coverage and network capacity. As mentioned earlier, femto-cell eNB are usually user-installed for private usage. Some studies consider LTE HetNets with the coexistence of macro-cells and