A Two-Phase Heuristic for Base Station Placement in Long Term Evolution (LTE) Networks with Cell Heterogeneity

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ABSTRACT

In cellular networks, base station placement is a critical issue because it determines the construction cost and service quality. Existing placement approaches for 2G and 3G networks usually consider homogeneous base stations, where they have similar coverage areas and hardware features. Recently, the burgeoning LTE technology allows different types of base stations to collaboratively provide service in the same network. This characteristic motivates us to address the problem of placing heterogeneous base stations to serve user devices such that the overall cost is minimized while user demands are stratified. The problem is NP-hard, and thus we develop an efficient two-phase heuristic which first employs a geometric idea to provide coverage to all user devices and then adjusts the cell range to meet the power and bandwidth constraints of each base station. Experimental results show that our two-phase heuristic can reduce the construction cost and energy consumption of base stations.

Categories and Subject Descriptors

C.2.1 [**Computer-communication Networks**]: Network Architecture and Design—*centralized networks, wireless communication*

General Terms

Algorithms, Design

Keywords

base station placement, cell heterogeneity, long term evolution (LTE), network construction, wireless network

1. INTRODUCTION

For a cellular network, one critical issue is to determine the locations to set up base stations (BSs), also called *BS placement*, to support the maximum service coverage with the minimum construction cost. Most 2G and 3G networks assume BSs with similar hardware features such as antennas and power levels. Therefore, they are usually placed in a regular manner to expand the coverage range while reducing the interference between BSs [1]. Nevertheless, such BS placement may not perform well when user devices are sparsely distributed or congregate in some hotspots like airports and coffee shops [2].

The emerging LTE technology employs heterogeneous BSs to address the above issue. In fact, many research efforts [3, 4, 5] have shown the superiority of heterogeneous wireless networks in providing flexible network service and better system performance. According to their coverage sizes, four kinds of BSs are defined in LTE (from larger to smaller): macro-cell BS, micro-cell BS, pico-cell BS, and femto-cell BS. Most BSs are operator-installed but femto-cell BSs are consumer-installed. By adaptively placing different BSs, the problems of sparse users and hotspots can be alleviated. Specifically, macro-cell BSs serve as the network backbone to provide signal coverage in large geographic areas. Then, micro-cell and pico-cell BSs can serve hotspots or fill those *uncovered holes* left by macro-cells. Finally, consumers can install their femto-cell BSs to improve the signal quality.

However, the placement of heterogeneous BSs in LTE networks has not been intensively investigated in the literature. Most studies consider the placement of either only macro-cell BSs or the combination of macro-cell and pico/femto-cell BSs. This motivates us to investigate the problem of placing all kinds of operator-installed BSs to cover user devices while satisfying their demands, under the power and bandwidth constraints of each BS. It has been shown in [6] that such a heterogeneous BS placement problem is NP-hard. Therefore, we propose an efficient heuristic which contains two phases. In the first phase, we employ the geometric approaches to determine the locations of macro-cell and micro-cell BSs so that all user devices can be covered. Then, in the second phase we check whether each BS has sufficient resource to serve the user devices in its cell and shrink its coverage if necessary. Through simulations, we demonstrate the effectiveness of our two-phase heuristic in terms of saving the construction cost and BSs' energy consumption.

We outline this paper as follows: Section 2 studies the related work. In Section 3, we formulate the LTE heterogeneous BS placement problem. Then, Section 4 details our two-phase BS placement heuristic to the problem. Section 5

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presents the simulation results. We finally make a conclusion and give future work in Section 6.

2. RELATED WORK

Many BS placement methods have been proposed for 2G and 3G networks. In 2G networks, two-stage BS placement [7, 8, 9] is usually considered. Specifically, these studies select a set of sites to place macro-cell BSs to satisfy the given user demand so that the total cost is reduced in the first stage. Then, they allocate frequency channels to BSs so as to alleviate their interference in the second stage. On the other hand, in 3G networks BSs share the same communication spectrum, so the above stage 2 is not necessary. In this case, 3G BS placement schemes [10, 11, 12] mainly aim at selecting the BSs' sites and adjusting their transmission power in order to minimize the cell interference. Apparently, the above studies assume only macro-cell BSs. The work of [6] considers a wireless heterogeneous network with WiMAX and WiFi, and it develops a genetic algorithm to place BSs to maximize the network coverage and minimize the overall cost. However, its BS placement model focuses on the map instead of the distribution of user devices.

LTE heterogeneous BS placement is also investigated in the literature. The studies of [13] and [14] suggest tactically adding femto-cells to an LTE network (with only macro-cells) to enhance service coverage and network bandwidth. However, femto-cell BSs are consumer-installed for private use. Given the locations of macro-cell BSs, [15] employs the *CRE (cell range expansion)* and *TDM-ICIC (time domain multiplexing inter-cell interference coordination)* technology to decide the positions, transmission power, and antenna tilt of pico-cell BSs. In this way, these pico-cell BSs may balance macro-cell BSs' loads and mitigate their interference. The work of [16] calculates the sites of macro-cell and pico-cell BSs in the service area so that the total cost can be decreased while user demands are guaranteed. As can be seen easily, these studies use quite small pico/femto-cells to enhance the LTE network. On the contrary, our work seeks to use larger micro-cells to save the construction cost while reducing the energy consumed by macro-cell BSs.

3. PROBLEM DEFINITION

We are given the locations and bandwidth demands of user devices in a service area. The network operator plans to place macro-cell, micro-cell, and pico-cell BSs to serve these user devices, where the propagation of wireless communication is modeled by the *log-distance path loss model* (suggested by the LTE specification [17]). In particular, the path-loss effect of a macro-cell is determined by

$$\Phi_{ma} = 128.1 + 37.6 \cdot \log 10 D(\mathrm{BS}_i, u_j),$$

where $D(\mathrm{BS}_i, u_j)$ indicates the distance from BS_i to a user device u_j (measured in km). In addition, the path-loss effect of a micro/pico-cell is calculated by

$$\Phi_{mi} = \Phi_{pi} = 140.7 + 36.7 \cdot \log 10 D(\mathrm{BS}_i, \mathrm{UE}_j).$$

On the other hand, to calculate the environmental noise, we employ the *AWGN (additive white Gaussian noise)* model.

Each kind of BS has its maximum thresholds of communication distance, transmission power, and supported bandwidth. Then, our objective is to compute the locations to set up BSs so that not only the total cost is minimized but also the bandwidth demand of every user device is satisfied.

4. TWO-PHASE BS PLACEMENT HEURISTIC

Given the positions and demands of user devices, our heuristic has two phases to place heterogeneous LTE BSs. In the *covering phase*, we use both macro-cells and micro-cells to provide basic coverage to the service area. Then, in the *adjusting phase*, we check if every BS has enough resource such as power and bandwidth to meet the demands of all user devices in its cell. If not, we decrease its cell coverage and add pico-cells to serve these uncovered user devices.

4.1 The Covering Phase

In the covering phase, we try to use fewer macro-cells and micro-cells to cover all user devices in the service area. To do so, we can find where most user devices congregate and place cells accordingly. K-means is a popular geometric solution to group nodes based on their congregating degree [18], so we employ it in this phase. However, the original K-means scheme cannot be directly applied due to two reasons. First, it requires only a single K value. Second, it does not take heterogeneous cells into account. Therefore, we develop a 'modified' K-means approach by considering two inputs, K_{ma} and K_{mi}, which indicate the expected number of macro-cells and micro-cells to be placed in the service area, respectively. Then, our modified K-means approach has the following steps:

1. We randomly divide user devices into $K_{ma}+K_{mi}$ groups. For each group, we place a BS on its centroid.
2. Each user device then recomputes its new group. In particular, for each BS_i, a user device u_j computes its 'weighted' distance to that BS by $D_w(\mathrm{BS}_i, u_j) = D(\mathrm{BS}_i, u_j) \times w$, where w is a predefined weight. If BS_i is a macro-cell BS, we set $w = 1/R_{ma}$, where R_{ma} is a macro-cell's radius. Otherwise, we set $w = 1/R_{mi}$, where R_{mi} is a micro-cell's radius. Then, u_j chooses the BS such that $D_w(\mathrm{BS}_i, u_j)$ is minimized and joins that BS's group.
3. For each group, we recompute its new centroid and move the BS accordingly.
4. The above two steps are repeated until all BSs need not be moved.

The remaining issue is how to estimate the values of K_{ma} and K_{mi}. Here, we borrow the idea from the *agglomerative hierarchical clustering (AHC)* method [19] to do the estimation. Initially, the AHC method treats every user device as a single cluster. Then, it recursively merges two nearest clusters, until all user devices belong to the same cluster. Fig. 1 (a) and (b) give an example. We add u_2 and u_3 to cluster c_1 since $D(u_2, u_3)$ is the minimum. Similarly, both u_4 and u_5 are added to cluster c_2. Then, we merge u_6 with c_2 so a new cluster c_3 is found. Following the recursive manner, we can eventually compute five clusters. In fact, we can observe that the clustering result forms a binary tree, where each cluster has exact two children.

Based on the binary tree of clusters, we can estimate both K_{ma} and K_{mi}, which are initially set to zero. Then, starting

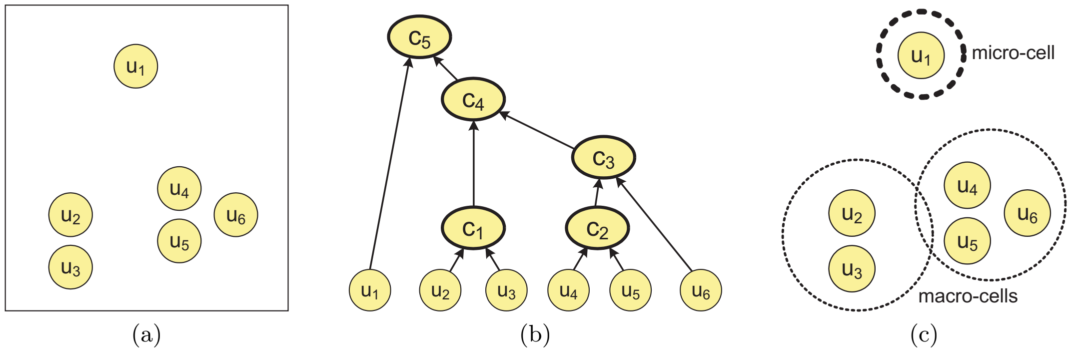


Figure 1: The AHC clustering scheme: (a) the positions of user devices, (b) the binary tree of clusters, and (c) estimating K_{ma} and K_{mi}.

from the root, we iteratively check whether a cell can cover all user devices in each cluster. Specifically, If a micro-cell can cover the cluster, we add K_{mi} by one. Otherwise, we check if a macro-cell can cover the cluster. If so, we add K_{ma} by one. Otherwise, we recursively check the two children of that cluster. Fig. 1 (b) and (c) give an example. Initially, we check cluster c_5 but find that no single cell can cover it. Thus, we check its two children, u_1 and c_4. For u_1, we can use a micro-cell to cover it. Because no single cell can cover cluster c_4, we then check its two children, c_1 and c_3. In this case, both two clusters each can be covered by a macro-cell. Therefore, we have $K_{ma} = 2$ and $K_{mi} = 1$.

4.2 The Adjusting Phase

The aforementioned covering phase places BSs from a geometric perspective, but it does not consider the practical situation where there could be too many user devices in a cell so that the BS cannot afford to provide service to them. Therefore, the adjusting phase takes each BS's power and bandwidth limitations into consideration by removing some user devices if necessary. In particular, we adopt the Shannon theorem [20] to check whether the overall demand from the user devices in a cell exceeds the maximum power and bandwidth supported by the BS. Supposing that the bandwidth of a BS is B and the current *signal-to-noise ratio (SNR)* is δ, then the Shannon theorem calculates the maximum data rate C supported by the BS as

$$C = B \cdot \log_2(1 + \delta).$$

Let us denote by b_j and p_j the bandwidth and transmission power that a BS needs to give a user device u_j so as to satisfy its demand. Then, based on the Shannon theorem, we can calculate the achievable data rate of BS_i to u_j:

$$\begin{aligned} r_j &= b_j \cdot \log_2(1 + \delta) \\ &= b_j \cdot \log_2\left(1 + \frac{p_j \cdot \Psi_j}{b_j}\right), \end{aligned}$$

and

$$\Psi_j = \frac{g_j^2}{\Theta \cdot N_a},$$

where g_j is the BS's channel gain to u_j, Θ is the SNR gap (a constant), and N_a is the AWGN power spectral density. Therefore, we can compute the necessary power of the BS to satisfy u_j's demand as follows:

$$\begin{aligned} p_j &= \frac{b_j}{\Psi_j}(2^{r_j/b_j} - 1) \\ &= \frac{b_j \cdot \Theta \cdot N_a}{g_j^2}(2^{r_j/b_j} - 1). \end{aligned}$$

By using the above equation, we can determine whether the sum of the necessary power for each user device exceeds the overall transmission power of the BS. If so, the BS iteratively removes the farthest user device in its cell, until it has sufficient power (and bandwidth) resource to serve all residual user devices.

The remaining issue is how to provide service to the above uncovered user devices. To address this issue, we suggest adding pico-cell BSs to serve these user devices. Here, we employ the *modified geometric disk cover approach* in [21] to find the sites to place pico-cells. It involves the following three rules:

1. Suppose that two user devices u_i and u_j have a distance $D(u_i, u_j) < 2R_{pi}$, where R_{pi} is the radius of a pico-cell. Then, we place two pico-cells such that their peripheries intersect at u_i and u_j.

2. Suppose that two user devices u_i and u_j have a distance $D(u_i, u_j) = 2R_{pi}$. Then, we place a pico-cell such that both u_i and u_j locate on its periphery.

3. Suppose that a user device u_k is *isolated*, which means that its distance to the nearest user device exceeds $2R_{pi}$. Then, we place a pico-cell such that u_k locates at its center.

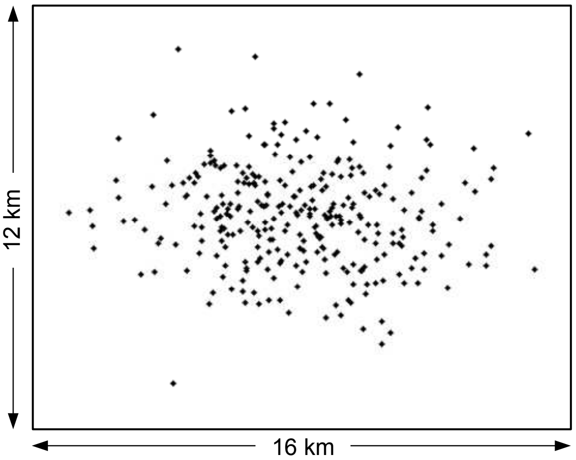
Then, among all found pico-cells, we iteratively pick the pico-cell such that it can cover the most number of user devices, until all user devices are served. Finally, the residual pico-cells are discarded as they do not serve any user device.

5. SIMULATION STUDIES

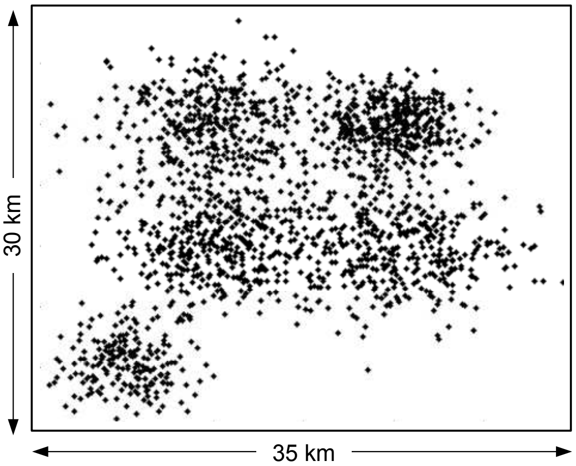
We evaluate the performance of our two-phase heuristic by MATLAB, where Table 1 gives the simulation parameters. Two distributions of user devices, namely *random* and *multi-group*, are considered in the simulation, as shown in Fig. 2. In the random distribution, totally 300 user devices are scattered over a 16 km × 12 km service area. On the other hand, in the multi-group distribution, totally 1800 user devices are scattered over a 35 km × 30 km service area.

Table 1: **Simulation parameters.**

parameter	setting
AGWN power spectral density (N_a)	-174 dBm/Hz
SNR gap (Θ)	7.62 (so the bit error rate is around 10^{-6})
Radii of a macro/micro/pico-cell	3 km/1 km/0.1 km
Power of a macro/micro/pico-cell BS	40 W/2 W/0.25 W
Bandwidth of macro/micro/pico-cell BS	100 MHz/100 MHz/30 MHz
Cost to set up a macro/micro/pico-cell BS [22]	397.8 k€/42.2 k€/12.4 k€



(a) random distribution



(b) multi-group distribution

Figure 2: Two distributions of user devices.

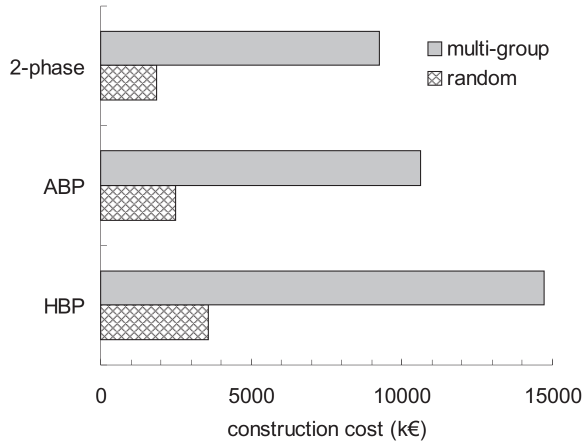


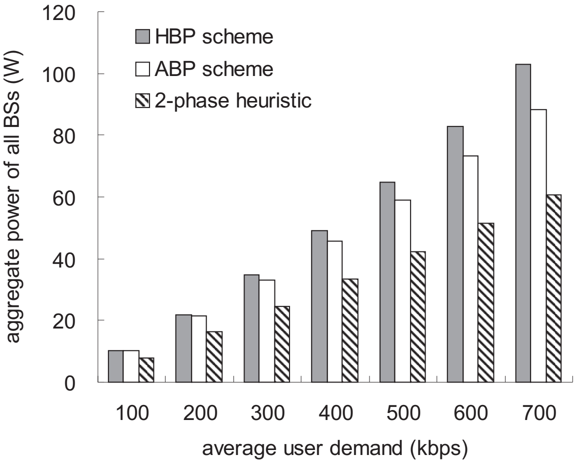
Figure 3: Comparison on the construction cost.

For comparison, we consider two BS placement schemes. The *homogeneous BS placement (HBP)* scheme works similarly to traditional 2G and 3G BS placement approaches, where only macro-cells are considered. On the other hand, in the *AHC-grouping BS placement (ABP)* scheme, we directly place macro-cells and micro-cells based on the AHC clustering result (in other words, we do not execute the modified K-means approach) and then use the rules in the adjusting phase to shrink the cell coverage if necessary.

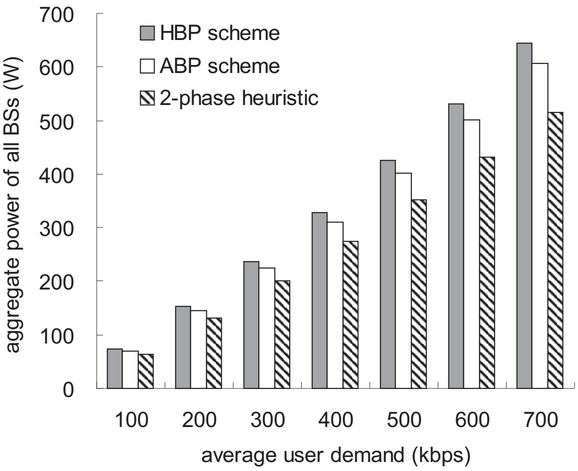
Fig. 3 presents the construction cost required by the three BS placement schemes. Apparently, the HBP scheme always results in the highest construction cost because it only uses macro-cells to serve user devices. When few user devices are sparsely distributed or they are far away from others, the HBP scheme still has to place some macro-cell BSs to serve these user devices, causing unnecessary waste. On the contrary, both the ABP scheme and our two-phase heuristic take advantage of LTE cell heterogeneity to provide flexible BS placement and thus save the overall construction cost. Comparing with the ABP scheme, our two-phase heuristic can find where most user devices congregate (by the proposed modified K-means approach) and place BSs accordingly. In this way, our two-phase heuristic can further save the total construction cost.

Fig. 4 shows the aggregate power consumption of all BSs in the HBP, ABP, and two-phase schemes, where we range the average user demand from 100 kbps to 700 kbps. As can be seen easily, when the average user demand increases, BSs have to emit higher transmission power in order to satisfy the growing demands of user devices. The HBP scheme employs only large-power macro-cell BSs, so it will suffer from significantly higher power consumption compared with other schemes that use low-power BSs. Our two-phase heuristic can have less power consumption compared with the ABP scheme due to two reasons. First, it requires fewer BSs than the ABP scheme, especially the large-power macro-cells. Second, our two-phase heuristic will place macro-cell BSs on those sites where most user devices congregate. However, the ABP scheme may sometimes place macro-cells to cover those sparsely-distributed user devices. Therefore, macro-cell BSs will have better power utilization in our two-phase heuristic.

6. CONCLUSION AND FUTURE WORK



(a) random distribution



(b) multi-group distribution

Figure 4: Comparison on the aggregate power consumption of all BSs.

Unlike traditional 2G and 3G networks, LTE introduces the concept of cell heterogeneity by employing various types of base stations to cooperatively provide service to user devices. This paper aims at exploiting such cell heterogeneity to provide flexible and minimum-cost network construction. An efficient BS placement heuristic containing both covering and adjusting phases is proposed. The covering phase places large cells to cover user devices in a geometric manner. On the other hand, the adjusting phase considers the practical situation by taking the power and bandwidth limitations of BSs into account. By comparing with both the HBP and ABP schemes, we show the effectiveness of our two-phase heuristic in terms of reducing the construction cost and BSs' power consumption.

For future work, both WiMAX and LTE introduce *relay stations* in order to help balance the loads of BSs, enhance signal quality, and extend the service coverage [23, 24]. Therefore, it deserves further investigation to take relay station into consideration in the BS placement heuristic so as to improve the system performance while reducing the construction cost.

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