Small-cell Planning in LTE HetNet to Improve Energy Efficiency

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Abstract—Cell planning is one essential operation in wireless networks, and it significantly affects system performance and cost. Many research efforts consider the cell planning problem with identical *base stations (BSs)* or to construct a new network on the region without any infrastructure. However, *long term evolution (LTE)* adopts *heterogeneous network (HetNet)*, which allows operators to tactically deploy small cells to enhance signal coverage and improve performance. It thus motivates us to propose a *small-cell planning problem* by adaptively adding low-powered BSs with the limitation of budget to an existing network in order to increase its energy efficiency, which is defined by the ratio of network throughput to the amount of energy consumption of BSs. We consider two types of LTE small cells, namely *microcells* and *picocells*, and develop different clustering strategies to deploy these cells. Based on the available resource and traffic demand in each cell, we then adjust the transmitted power of the deployed BS with energy concern. Experimental results demonstrate that our small-cell planning solution can achieve high energy efficiency of LTE networks, which means that BSs can better utilize their transmitted energy to satisfy the traffic demands of user devices. This paper contributes in proposing a practical problem for cell planning with HetNet consideration and developing an efficient solution to provide green communications.

Index Terms—cell planning, energy efficiency, heterogeneous network (HetNet), long term evolution (LTE), small cell.

1 Introduction

In wireless networks, cell planning is a critical problem which determines how to deploy *base stations (BSs)* in a given area to improve the service coverage and save the system cost. In past generations of wireless networks, operators usually adopt homogeneous BSs with similar features such as cell range and antenna parameters for system deployment. They calculate the locations of BSs to cover user devices and reduce signal interference. Specifically, in 2G networks [1]–[3], operators select some candidate locations to deploy BSs in order to satisfy the given demand of capacity and then allocate different channels for these BSs to avoid interference between each other. On the other hand, cell planning in 3G networks [4]–[6] aims at determining both locations and transmitted power of BSs, so as to reduce cell interference. The above solutions are feasible when users request light-load traffics, for example, voice communications or webpage browsing.

With the coming of 4G epoch, users are thirsty for broadband wireless communications and operators have to make sure that their deployed networks can support various services with high traffic demands such as mobile television, online gaming, and teleconferences [7]. In fact, Cisco points out in its report [8] that multimedia streaming and video downloads have occupied a large portion of the global network bandwidth today, and will keep growing to over 80% of all consumer Internet traffics in 2020. Inevitably, the cell planning solutions in 2G/3G networks according to homogeneous BSs will become inefficient, especially when many users congregate in small hotspots (for example, markets or airports) and ask for large-demand data transmissions [9].

Consequently, *long term evolution (LTE)* employs the concept of *heterogeneous network (HetNet)* to allow diverse BSs to cooperate in the same network. In particular, LTE defines four types of BSs [10], called *macrocell*, *micorcell*, *picocell*, and *femtocell* BSs, whose comparison is given in Table 1. Generally speaking, operators adopt macrocell BSs to be the network's backbone to provide a wide range of service coverage and also support those user devices with high mobility by reducing their frequencies of handoff. In addition, microcell and picocell BSs are adaptively added to enhance signal strength in small hotspots or cover some holes left by macrocells. Therefore, both microcells and picocells are usually referred to *small cells* from the operator's perspective. On the other hand, users can install their own femtocell BSs for private usage or to enhance channel quality. Recently, it has bee pointed out that HetNet can efficiently reduce energy consumption of BSs and thus provide green communications [11].

TABLE 1: Comparison on the four types of BSs defined by LTE, where 'dBm' is decibel based on one milliwatt and 'm' denotes meter.

BS	power (dBm)	cell radius (m)	installation
macrocell	43–52 (usually 46)	at least 1,000	operator-installed
microcell	33–43	250–1,000	operator-installed
picocell	24–33	100–300	operator-installed
femtocell	less than 23	less than 50	user-installed

The cell planning problem for LTE HetNets is also discussed in the literature, which is shown to be NP-hard [12]. Given a 'blank' service area, most solutions construct a completely new network with both macrocell and small-cell BSs. However, in practical applications, there usually exists a network in the area which is composed of solely macrocell BSs to provide underlying service. The operator wants to mitigate power consumption of these BSs and increase network throughput by deploying small cells to the network. In essence, the problem of constructing a new HetNet and the problem of deploying only small cells are different. In the former, the operator is able to *freely* deploy different BSs in the service area (once the operator acquires rights to install sites), and coordinate these BSs to maximize system performance. On the contrary, in the latter, the operator has to consider the

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existence of macrocells and carefully add small cells to *improve* the original network. Interestingly, the problem of deploying small cells is somewhat like the selection problem of *remote radio heads (RRHs)* in a *cloud radio network (C-RAN)*. Specifically, a C-RAN is composed of RRHs and baseband units, where RRHs is responsible for radio communications while baseband units provide a set of common computing resource for signal processing. The selection of RRH has to consider the locations of baseband units [13]. Similarly, the deployment of small cells needs to take care of the positions and statuses of existing macrocells.

Based on the above motivation, this paper investigates the *small-cell planning problem*, which determines how to efficiently add microcell and picocell BSs to an existing macrocell network in order to improve its energy efficiency, under a given deployment budget. In particular, the energy efficiency is defined by the ratio of the HetNet's throughput to the amount of energy consumed by the whole BSs (including the newly deployed ones) [14], [15]. To solve the problem, our idea is to first identify those user devices whose traffic demands cannot be satisfied by the original (macrocell) BSs. Afterwards, we develop different clustering strategies to find out the suitable locations to place microcell and picocell BSs, and check whether they have sufficient resource to serve their user devices. Finally, we adjust the transmitted power of BSs (including macrocell ones) in order to save their energy and support green communications accordingly. Our proposed small-cell planning solution allows the operator to flexibly add low-powered, cheap BSs to the operating network, so as to improve network throughput while alleviating the traffic loads and also energy consumption of existing macrocell BSs.

In our previous work [16], we propose an *eNB deployment with the minimum cost (EDMC)* problem which asks how to construct a new LTE HetNet with macrocells, microcells, and picocells. A four-stage solution is developed: Stage 1 estimates the number of required macrocells and microcells, while stage 2 gives preliminary deployment of these cells. Then, stage 3 checks if each BS has enough resource to serve user devices and adjusts its cell range accordingly. Afterwards, stage 4 places picocells to cover unserved user devices. At first glance, this paper seems to be an extension of EDMC. Nevertheless, there are four major differences between them. First of all, the EDMC problem focuses on deploying BSs in a blank service area with the objective of minimizing the total cost. On the other hand, our small-cell planning problem aims at improving an existing macrocell network by adding microcells and picocells under a limited amount of budget. More specifically, we seek to improve the energy efficiency of the original network, and this issue is not addressed in EDMC. Second, the EDMC solution jointly deploys macrocells and microcells in its stage 2. This method is efficient when the service area is blank but may not work well when there already exist macrocells in the area. To deal with this case, our small-cell planning solution will find out the 'weak points' in the original network (that is, the macrocells which cannot meet the traffic demands of their user devices), and add small cells to improve them. Third, when estimating the amount of resource supported by each BS, the EDMC solution only computes the (maximum) theoretical capacity of each cell according to its bandwidth. In contrast to EDMC, our small-cell planning solution practically calculates the available number of *physical resource blocks (PRBs)* provided by each BS, which takes the LTE specification into consideration and thus helps us acquire more accurate estimation of a cell's resource. Fourth, the EDMC solution and our small-cell planning solution have different design philosophies in deploying picocells. In particular, the EDMC solution uses picocells to cover those *isolated* user devices which cannot be served by macrocells and microcells. On the contrary, our small-cell planning solution considers the hotspot scenario and develops a novel clustering strategy to group the user devices that congregate in some small regions. The aforementioned four issues obviously distinguish the proposed small-cell planning solution from our previous EDMC work in [16], and also emphasize the contributions of this paper. Through simulations, we show that our proposed solution can significantly outperform other schemes (including the EDMC solution) in terms of the satisfaction ratio of user devices and the amount of energy consumption by BSs, thereby achieving high energy efficiency of the LTE HetNet.

We organize the rest of this paper as follows: Section 2 presents both channel model and problem definition. Section 3 gives a survey of related work. Afterwards, we propose our solution to the small-cell planning problem and evaluate its performance in Section 4 and Section 5, respectively. Section 6 finally concludes this paper and gives some future work.

2 Preliminary

2.1 Channel Model

We follow the LTE specification in both [17] and [18] to estimate the transmission behavior of a signal through a wireless channel. Specifically, the *additive white Gaussian noise (AWGN)* is used to describe the environmental noise caused by the thermal agitation (that is, thermal noise), where its power spectral density is set to -174 dBm/Hz (decibel-milliwatt per hertz). The free-space path loss results in attenuation of a wireless signal at the receiver side, which depends on the Euclidean distance d_i between a user device and its associated BS. In particular, LTE employs a log-distance model to measure its effect, which is formally expressed by:

- Macrocell: $\zeta = 128.1 + 37.6 \log d_i$, where d_i is measured in kilometers.
- Microcell[1]: $\zeta = 34.53 + 38 \log d_i$, where d_i is measured in meters.
- Picocell: $\zeta = 38 + 30 \log d_i$, where d_i is measured in meters.

A wireless signal will be also influenced by the shadowing fading. It occurs when large objects (for example, buildings) block the transmission path, which causes impediment to the signal. Such fading will add random variation to the signal's amplitude. To evaluate the effect of shadowing fading, LTE adopts a log-normal distribution as follows:

$$p(\mathcal{X}) = \frac{\exp[-(\mathcal{X} - \varepsilon)^2 / 2\sigma^2]}{\sqrt{2\pi}\sigma}, \tag{1}$$

where $\mathcal{X}$ is a random variable used to describe the ratio of the received power to the transmitted power in the unit of decibel, $p(\mathcal{X})$ is the probability distribution function of $\mathcal{X}$, $\exp[\cdot]$ denotes the exponential function, and ε and σ represent the mean and standard deviation of $\mathcal{X}$, respectively. The mean ε is usually set to zero. For a picocell, the standard deviation σ is set to 6 dB; otherwise, it is set to 10 dB.

1. For microcells, we consider the non-line-of-sight case.

Broadly speaking, both path loss and shadowing fading significantly affect the power strength of a wireless signal at the receiver side. Consequently, they are useful to evaluate the channel quality of user devices and determine their data rates for cell planning.

2.2 Problem Definition

Suppose that there exists an LTE network consisting of a set $\mathcal{B}_o$ of macrocell BSs. We are given a set $\mathcal{U}$ of user devices, where the position (x_i, y_i) and traffic demand r_i of each user device $u_i \in \mathcal{U}$ is known beforehand. In general, since the network has been operated for a period of time, the operator can refer to the historical statistics to derive the positions where most user devices appear and their average amount of traffic demands [19]. The operator has a total budget of Γ to deploy a set $\mathcal{B}_s$ of small-cell BSs (including microcell and picocell BSs) in the network, where each BS $b_j \in \mathcal{B}_s$ has the cost of ϱ_j (for example, installation and hardware costs).

Then, the small-cell planning problem asks how to find the set $\mathcal{B}_s$, determine the locations of BSs in $\mathcal{B}_s$, and compute the transmitted power of each BS in $\mathcal{B} = \mathcal{B}_o \cup \mathcal{B}_s$ (that is, the set of all BSs in the LTE HetNet), with the objective of

$$\max \frac{\sum_{u_i \in \mathcal{U}, b_j \in \mathcal{B}} r_{i,j}}{\sum_{b_j \in \mathcal{B}} p_j}, \tag{2}$$

subject to

[Budget constraint]

$$\sum_{b_j \in \mathcal{B}_s} \varrho_j \leq \Gamma, \tag{3}$$

[Capacity constraint]

$$\sum \{r_{i,j} \mid u_i \text{ links to } b_j\} \leq c_j,\ 0 \leq r_{i,j} \leq r_i,\ \forall b_j \in \mathcal{B}, \tag{4}$$

[Power constraint]

$$\sum \{p_{i,j} \mid u_i \text{ links to } b_j\} \leq p_j,\ \ p_{i,j} \geq 0,\ \ \forall b_j \in \mathcal{B}, \tag{5}$$

where $r_{i,j}$ is the data rate of a user device u_i supported by its associated BS b_j, $p_{i,j}$ is the amount of power that b_j allocates to u_i for data transmission, c_j is the available capacity of b_j, and p_j is the maximum transmitted power of b_j. Here, the objective function in Eq. (2) seeks to maximize the overall energy efficiency of the LTE HetNet, which is calculated by the ratio of network throughput to the energy consumption of BSs in $\mathcal{B}$. Eq. (3) indicates that the sum of the cost of each BS in $\mathcal{B}_s$ cannot exceed the operator's budget Γ. Moreover, for each BS, we have to make sure that the amount of data rate and power allocated to all user devices in the corresponding cell should be restricted by its capacity and maximum transmitted power, as expressed by Eqs. (4) and (5), respectively.

3 Related Work

In the literature, there have been various approaches developed to solve the cell planning problem with solely macrocells, for instance, simulated annealing [20], genetic algorithm [21], tabu search [22], and geo-clustering [23]. They target at finding the feasible locations to place macrocell BSs in order to cover user devices while alleviating signal interference between cells. Nevertheless, these approaches do not exploit the feature of HetNet and thus lack flexibility in network deployment.

A number of studies address different issues occurred in a HetNet where macrocells and femtocells coexist. In particular, the work of [24] deals with the co-channel interference problem when a macrocell has coverage overlap with multiple femtocells. It allows the macrocell BS to make usage of the spectrum configuration information from femtocell BSs to reduce signal interference. In [25], three business models for femtocell deployment are proposed, namely *joint deployment*, *wireless service provider deployment*, and *user deployment*, which depends on who (in particular, the user or the operator) should pay the cost to install and maintain femtocells. It then develops the channel allocation and pricing methods to satisfy the user's requirement and improve the operator's revenue, respectively. Given the budget's limitation, the study of [26] adds femtocell BSs in a macrocell to increase not only the number of user devices served but also the amount of profit received by the operator. Yunas et al. [27] discuss different femtocell deployment strategies in suburban regions by considering the effect of penetration loss caused by buildings, and analyze interference, spectral efficiency, and energy efficiency of these strategies. However, according to Table 1, femtocells have very short cell radiuses and thus can support just few user devices.

How to combine macrocells with either microcells or picocells is also discussed. In particular, Kaneko et al. [28] iteratively add picocells within the communication range of each macrocell BS, and pick muted subframes during which a macrocell BS will stop data transmissions (to avoid signal interference to picocells), until the traffic demands of user devices become satisfied. The work of [29] proposes two approximation algorithms to deploy both macrocell BSs and relay stations (which can be viewed as a kind of microcells but they have to share spectral resource with macrocell BSs). One is to minimize the deployment cost while the other is to deploy BSs with the consideration of budget. Shih and Zain [30] apply a geo-clustering scheme to deploy macrocells and picocells according to the terrain in the service area rather than the distribution of user devices. Thus, the traffic demands of some user devices may not be met. Li et al. [31] employ a genetic algorithm to iteratively add microcells, so as to improve the energy utilization of macrocell BSs. However, it requires to repeat the algorithm many times (in particular, more than 600 times) to get a stable result. Zhao et al. [32] first propose an algorithm to deploy only macrocells with an approximation ratio of $O(\log R_m)$, where R_m is the maximum achievable capacity of a macrocell. Based on the result, another $O(\log R_p)$-approximation algorithm for the picocell scenario is also developed, where R_p is the maximum achievable capacity of a macrocell whose range contains picocells. It can be observed that the above studies address only one combination of HetNets (that is, macrocells with microcells, or macrocells with picocells).

Few research efforts consider deploying multiple types of small cells. The work of [33] formulates an APX[2]-hard problem to deploy macrocell BSs, picocell BSs, and relay stations in a service region. An approximation algorithm is then proposed to allow user devices to be served by multiple BSs. In [12], a divide-and-rule strategy is developed to deploy macrocells and small cells under a given budget. This work translates the deployment problem to a convex optimization problem and solves it by the Karush-Kuhn-Tucker condition [34]. As discussed earlier in Section 1, our previous work in [16] allows an operator to deploy macrocells, microcells, and picocells in

2. Based on the complexity theory, the class of approximable (APX) problems is the set of NP optimization problems which allow polynomial-time approximation algorithms to have the approximation ratio bounded by a constant.

a service area to reduce the deployment cost. However, these research efforts consider deploying a completely new network on the blank area without any infrastructure. It thereby motivates us to propose the small-cell planning problem in this paper to allow operators to dynamically deploy small cells in an existing network to improve its performance and save energy consumption of BSs.

4 The Proposed Small-Cell Planning Solution

Given the set $\mathcal{B}_o$ of existing macrocell BSs and the set $\mathcal{U}$ of user devices, our proposed small-cell planning solution involves the four phases to deploy a set $\mathcal{B}_s$ of small-cell BSs to improve the energy efficiency of the original network under the constraint of budget Γ as follows:

1) *Identify user devices:* In the beginning, we find out those user devices that require the service of small cells. Such user devices include 1) the user devices which are not covered by any BS yet and 2) the user devices whose traffic demands cannot be satisfied by its macrocell BS. We denote by $\mathcal{U}_L$ the set of these user devices.
2) *Deploy microcells:* Since a microcell provides much larger coverage than a picocell (referring to Table 1), we thus prefer deploying microcells to serve the user devices in $\mathcal{U}_L$, subject to the budget Γ. We then adjust the communication range of each microcell according to its BS's capacity and the traffic demands of user devices.
3) *Deploy picocells:* In case that $\mathcal{U}_L$ is not empty and there still exists a budget surplus, we then add picocells to the network to serve the remaining user devices in $\mathcal{U}_L$. To consider cost-effectiveness, we will deploy picocells to cover the user devices in hotspot regions first. Afterwards, we also check whether each picocell BS possesses sufficient capacity to serve user devices and adjust its cell range accordingly.
4) *Adjust macrocells:* Since some user devices of a macrocell may be reassigned to other small cells, we are able to shrink the communication range of that macrocell and reduce the energy consumption of its BS accordingly.

Below, we detail the design of each phase, followed by the discussion of our rationale. Then, we address the issue of inter-cell interference.

4.1 Phase 1: Identify User Devices

As mentioned earlier, $\mathcal{U}_L$ is composed of two non-overlapped subsets. One subset (denoted by $\mathcal{U}_c$) contains the user devices that are not covered by any macrocell BS in $\mathcal{B}_o$ due to the original network deployment. The other subset (denoted by $\mathcal{U}_d$) consists of the user devices whose traffic demands cannot be satisfied by their macrocell BSs because of insufficient resource. It is relatively easy to calculate $\mathcal{U}_c$ by checking whether a user device is located inside the communication range of any macrocell. If not, we will add the user device to $\mathcal{U}_c$. The above check is repeated until all user devices are examined.

To calculate $\mathcal{U}_d$, we adopt the Shannon's equation [35] to estimate the maximum capacity of each macrocell and check whether the BS possesses enough bandwidth and transmitted power to support its user devices in the cell. Specifically, let $p_{i,j}$ and $\lambda_{i,j}$ be the amount of transmitted power and bandwidth that a macrocell BS b_j allocates to a user device u_i. Given the *signal to interference plus noise ratio (SINR)* γ, the achievable data rate of u_i provided by BS b_j is measured as follows:

$$r_{i,j} = \lambda_{i,j} \times \log_2(1+\gamma). \tag{6}$$

In particular, SINR γ primarily depends on both transmitted power $p_{i,j}$ and bandwidth $\lambda_{i,j}$, and its value can be calculated by

$$\gamma = \tau_{i,j} \times \frac{p_{i,j}}{\lambda_{i,j}} = \frac{|g_{i,j}|^2}{\epsilon N_0} \times \frac{p_{i,j}}{\lambda_{i,j}}, \tag{7}$$

where $g_{i,j}$ denotes the channel gain, ϵ represents the SINR gap, and N_0 is the power spectral density of AWGN. Specifically, the gap ϵ is a constant which depends on both the symbol error rate and the *modulation and coding scheme (MCS)*, where the work of [36] presents some suggested values for ϵ. On the other hand, N_0 is set to -174 dBm/Hz according to the LTE specification, as discussed in Section 2.1.

Through both Eqs. (6) and (7), we can evaluate the necessary amount of BS b_j's transmitted power to allow a user device u_i to have data rate of $r_{i,j}$ and bandwidth of $\lambda_{i,j}$ as follows:

$$p_{i,j} = \frac{\lambda_{i,j}}{\tau_{i,j}} \times \left(2^{r_{i,j}/\lambda_{i,j}} - 1\right). \tag{8}$$

By setting $r_{i,j} = r_i$ (in other words, the traffic demand of user device u_i is satisfied by BS b_j), we can reexpress Eq. (8) to

$$p_{i,j} = \frac{\epsilon N_0 \lambda_{i,j}}{|g_{i,j}|^2} \times \left(2^{r_j/\lambda_{i,j}} - 1\right). \tag{9}$$

Let $\mathcal{U}_j$ be the set of user devices which associate with a BS b_j. By checking both conditions:

$$\sum_{u_i \in \mathcal{U}_j} p_{i,j} \leq p_j, \tag{10}$$

$$\sum_{u_i \in \mathcal{U}_j} \lambda_{i,j} \leq \lambda_j, \tag{11}$$

where p_j and λ_j denote the total transmitted power and bandwidth of b_j, we can determine whether this BS has sufficient resource to satisfy the traffic demands of all it user devices. If any of Eqs. (10) and (11) does not hold, BS b_j should remove some user devices from its cell in order to satisfy both equations. In particular, we let BS b_j iteratively mark the *farthest* user device in its cell as 'uncovered' and add the user device to the set $\mathcal{U}_d$, until b_j has enough transmitted power and bandwidth to serve the remaining user devices. Remark 1 discusses the reasons why BS b_j should select (and remove) such user devices.

Remark 1. Our method to find the set $\mathcal{U}_d$ has two benefits. First, according to the discussion in Section 2.1, the strength of the received power by a user device significantly degrades when it has a longer distance to the BS because of the path-loss effect. In other words, there is a high possibility that the user device will encounter worse channel quality, thereby consuming more resource of its BS. Thus, removing such user devices can help alleviate the BS's load. Second, it is not a good idea to deploy a small cell close to the central part of a macrocell, otherwise the macrocell BS will exert stronger noises to the user devices in the small cell. Therefore, by iteratively adding the farthest user device in a macrocell to the set $\mathcal{U}_d$, we can alleviate inter-cell interference when deploying small cells to cover the user devices in $\mathcal{U}_d$.

By calculating $\mathcal{U}_L = \mathcal{U}_c \cup \mathcal{U}_d$, we can deploy small cells by the following phases to serve the user devices in $\mathcal{U}_L$, so as to improve the original network. Notice that $\mathcal{U}_L = \emptyset$ implies that the current BSs have sufficient capacity to serve all user devices, so there is no need to add small cells (and thus the algorithm terminates).

4.2 Phase 2: Deploy Microcells

This phase is further composed of four steps to deploy microcells to cover the user devices in $\mathcal{U}_L$.

- **Step 1:** We first cluster the user devices of the set $\mathcal{U}_L$ according to their positions in the service area. In particular, we adopt the popular K-means clustering scheme, which can put the user devices whose positions are close to each other in the same cluster. Specifically, we set $K = \lfloor \Gamma/\varrho_{\text{micro}} \rfloor$, where ϱ_{micro} denotes the cost of a microcell BS. We also update the residual budget by

$$\Gamma = \Gamma - K \times \varrho_{\text{micro}}. \tag{12}$$

  Then, the K-means scheme works as follows: In the beginning, $\mathcal{U}_L$ is arbitrarily divided into K nonempty clusters. Afterwards, an iterative process is conducted. In every iteration, the *centroid* of each cluster is computed. In particular, given a cluster of user devices whose positions are $\{(x_1, y_1), (x_2, y_2), \cdots, (x_k, y_k)\}$, its centroid is computed by $(\sum_{i=1}^{k} x_i/k, \sum_{i=1}^{k} y_i/k)$. Then, we redivide $\mathcal{U}_L$ into clusters such that the user devices closest to the same centroid are assigned to the same cluster. The above process is repeated until no cluster can be further changed. After getting the K-means result, we place a microcell BS on the centroid of each cluster to cover its user devices, and set $\mathcal{U}_L = \emptyset$.
- **Step 2:** Afterwards, we eliminate those user devices from microcells due to very weak received signals. In particular, suppose that $\gamma_{\min}$ is the minimum value of SINR that a user device can employ the simplest MCS[3] to receive and decode data sent from its BS. For each user device u_i, we check its SINR value by

$$\gamma_{i,j} = \frac{p_j - \zeta_i - p(\mathcal{X}_i)}{\eta\lambda_j + \sum_{b_v \in \mathbf{B}, b_v \neq b_j} \mathcal{I}_{i,v}} \geq \gamma_{\min}, \tag{13}$$

  where p_j is the transmitted power of the microcell BS b_j that u_i expects to link, ζ_i is the effect of path loss on u_i, and $p(\mathcal{X}_i)$ is the effect of shadowing effect on u_i (which we have discussed in Section 2.1), η is the effect of noise, which can be calculated by the product of noise figure and noise spectral density, and $\mathcal{I}_{i,v}$ represents the power of signal interference from another BS b_v (for example, the BS of the umbrella macrocell). In Eq. (13), the numerator is the received signal strength by u_i (which considers both path-loss and shadowing effects), and the denominator addresses inter-cell interference by taking the term of $\mathcal{I}_{i,v}$ into account. In case that Eq. (13) is violated, it means that u_i may not be able to correctly receive data from BS b_j. Consequently, we eliminate u_i from the microcell and add it to the set $\mathcal{U}_L$ again.
- **Step 3:** With the knowledge of $\gamma_{i,j}$ from Eq. (13), we can estimate the *channel quality indicator (CQI)* of each user device in a microcell. In particular, it can be done by consulting Table 2 [37] to find the corresponding CQI value. Then, the LTE standard [38] provides three tables to calculate the amount of data that each user device is able to receive according to its CQI value. Specifically, the first table maps between the MCS index and the CQI index for the user device. Afterwards, the second table maps between the *transport block size (TBS)* index and the MCS index. Finally, given the TBS index and the number of PRBs of that user device, we can calculate the amount of data carried by these PRBs by referring to the third table. Through these tables, we are able to measure whether a macrocell BS b_j has enough PRBs to serve all user devices in the cell. In particular, suppose that b_j has n_j^{PRB} PRBs. We then check

$$\sum \{\lceil r_i/t_{i,j} \rceil \mid u_i \text{ links to } b_j\} \leq n_j^{\text{PRB}}, \tag{14}$$

  where r_i is the (minimum) traffic demand of u_i and $t_{i,j}$ represents u_i's TBS supported by b_j. When Eq. (14) does not hold, it implies that b_j does not have sufficient resource to satisfy the traffic demands of all its user devices. In this case, we have to remove some user devices from the microcell. With the consideration of Remark 1, we iteratively remove the user device farthest from the BS and add the user device to the set $\mathcal{U}_L$, until Eq. (14) becomes satisfied.
- **Step 4:** For each microcell BS that satisfies the traffic demands of its user devices, we gradually test whether it is possible to decrease the transmitted power and still make both Eqs. (13) and (14) hold (for example, by decreasing 5% amount of the power). In this way, we can save the energy consumption of microcell BSs. When the transmitted power of a microcell BS b_j is decreased to less than or equal to p_{pico} and the number of user devices served in the microcell is no larger than m_{pico}, where p_{pico} is the maximum transmitted power of a picocell BS and m_{pico} denotes the maximum number of user devices allowed in a picocell, we can

TABLE 2: The modulation and minimum required SINR value for each CQI index, where QAM is the acronym of 'quadrature amplitude modulation'.

CQI	modulation	SINR (in dB)
1	QPSK	-6.936
2	QPSK	-5.147
3	QPSK	-3.180
4	QPSK	-1.253
5	QPSK	0.761
6	QPSK	2.699
7	16QAM	4.694
8	16QAM	6.525
9	16QAM	8.573
10	64QAM	10.366
11	64QAM	12.289
12	64QAM	14.173
13	64QAM	15.888
14	64QAM	17.814
15	64QAM	19.829

3. Quadrature phase-shift keying (QPSK) with code rate 78 is the simplest MCS defined in LTE.

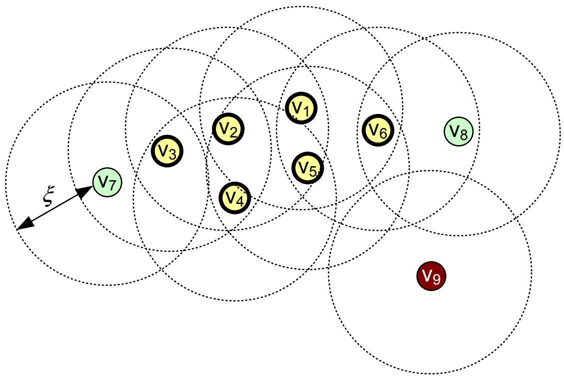


Fig. 1: An example of the DBSCAN algorithm.

replace b_j by a picocell BS to further save the budget. In this case, we can update the residual budget by

$$\Gamma = \Gamma + (\varrho_{\text{micro}} - \varrho_{\text{pico}}) \times \alpha, \tag{15}$$

where ϱ_{pico} denotes the cost of a picocell BS and α is the number of replaced (microcell) BSs.

4.3 Phase 3: Deploy Picocells

This phase is conducted only when $\mathcal{U}_L \neq \emptyset$ (that is, there still exist user devices needed to be served) and $\Gamma \geq \varrho_{\text{pico}}$ (that is, we can afford picocell BSs based on the residual budget). In order to serve more user devices in $\mathcal{U}_L$ with a limited number of picocell BSs, we prefer deploying picocells to cover those regions where user devices congregate (in other words, the hotspot regions). To do so, we employ the concept of *density-based spatial clustering of applications with noise (DBSCAN)* [39] to cluster user devices. In particular, given a set of points, DBSCAN can cluster the points which are closely packed together (in other words, these points have more neighbors in their surroundings). Besides, it also identifies the points which lie alone in low-density regions (in other words, the nearest neighbors of such points are far away from them). Specifically, given a density threshold φ and the maximum radius ξ of the neighborhood from a point, DBSCAN classifies all points into three categories:

- *Core points:* A point v_i is said to be a core point if at least φ points (including v_i itself) locate within the circle centered at v_i whose radius is ξ. In this case, we call these points *directly reachable* from v_i.
- *Density-reachable points:* A point v_j is density-reachable from another point v_i if we can find a path $\{v_i, v_1, v_2, \cdots, v_k, v_j\}$ such that each point v_{l+1} on the path is directly reachable from v_l, where $l = 1, \cdots, k-1$.
- *Outlier points:* If a point cannot be density-reachable from other points, it is viewed as an outlier point (also called *noise point*).

In DBSCAN, a core point together with all of its density-reachable neighbors will be put into the same cluster. Fig. 1 illustrates an example, where we set $\varphi = 4$. Points $v_1 \sim v_6$ are core points (and they are also density-reachable with each other). Both v_7 and v_8 are not core points but they can be density-reachable from some core points. Therefore, we group $v_1 \sim v_8$ into the same cluster. In this example, v_9 will be a noise point. Algorithm 1 presents the pseudocode of DBSCAN.

Algorithm 1: DBSCAN

Input: a set of points $\mathcal{V}$, density threshold φ, and radius ξ
Output: Clusters of $\mathcal{V}$

Mark all points in $\mathcal{V}$ as unvisited;
foreach *unvisited point* $v_i \in \mathcal{V}$ **do**
  Mark v_i as visited;
  Let $\mathcal{V}_i$ be the set of points in the circle centered at v_i with radius ξ;
  if $|\mathcal{V}_i| \geq \varphi$ **then**
    Create a new cluster $\mathcal{C}_i = \{v_i\}$;
    foreach *point* $v_j \in \mathcal{V}_i$ **do**
      if v_j *is not visited* **then**
        Mark v_j as visited;
        Find the set of points $\mathcal{V}_j$ (based on v_j);
        if $|\mathcal{V}_j| \geq \varphi$ **then**
          $\mathcal{V}_i = \mathcal{V}_i \cup \mathcal{V}_j$;
        end
      end
      if v_j *is not a member of any cluster* **then**
        add v_j to $\mathcal{C}_i$;
      end
    end
  else
    Mark v_i as a noise point;
  end
end

However, the original DBSCAN algorithm cannot be directly used in our picocell deployment due to three reasons. First, DBSCAN requires the parameter of density threshold φ, which is not applicable to the picocell deployment scheme. Second, DBSCAN does not consider the size of each cluster, but we have to limit the cluster's size to the communication range of a picocell. Third, DBSCAN removes noise points from its clustering result. In practice, even though some user devices are isolated (that is, they are noise points), we should place picocell BSs to serve them when the budget is sufficient.

To solve the above three problems, we tailor DBSCAN in Algorithm 1 to the needs of picocell deployment, called *number-based spatial clustering (NBSC)*, whose pseudocode is presented in Algorithm 2. In particular, there are three differences between DBSCAN and NBSC. First of all, the clustering criterion in NBSC is based on the number of user devices, instead of the density threshold. Second, the range of each cluster will be bound to the communication range of a picocell. Finally, when a user device is a noise point, it is still added to a cluster containing only itself.

Then, phase 3 is composed of the following steps:

- **Step 1:** Given the transmitted power of a picocell BS, we can refer to Eq. (13) to estimate R_{pico}. Then, we adopt NBSC in Algorithm 2 to cluster the user devices in the set $\mathcal{U}_L$, and sort these clusters according to their sizes (in particular, the number of user devices in the cluster).
- **Step 2:** We then calculate the number of affordable picocell BSs by $\lfloor \Gamma / \varrho_{\text{pico}} \rfloor$, and iteratively place one picocell to cover the cluster with the maximum number of user devices.
- **Step 3:** For each picocell, we then check whether 1) the number of user devices exceeds m_{pico} (that is, the

Algorithm 2: NBSC

Input: a set of user devices $\mathcal{U}_L$ and picocell radius R_{pico}
Output: Clusters of $\mathcal{U}_L$

Mark all user devices in $\mathcal{U}_L$ as unvisited;
foreach *unvisited user device* $u_i \in \mathcal{U}_L$ **do**
    Mark u_i as visited;
    Let $\mathcal{U}_i$ be the set of user devices in the circle centered at u_i with radius R_{pico};
    Create a new cluster $\mathcal{C}_i = \mathcal{U}_i$;
    foreach *user device* $u_j \in \mathcal{U}_i$ **do**
        if u_j *is not visited* **then**
            Mark u_j as visited;
            Find the set of user devices $\mathcal{U}_j$ (based on u_j);
            if $|\mathcal{U}_j| > |\mathcal{C}_i|$ **then**
                Replace $\mathcal{C}_i$ by $\mathcal{U}_j$;
            end
        end
    end
end

maximum number of user devices allowed in a picocell) and 2) its BS does not have sufficient resource to satisfy the traffic demands of all user devices according to Eq. (14). If so, we iteratively remove the farthest user device from the picocell, until it can pass the above two checks.

4.4 Phase 4: Adjust Macrocells

With the help of small cells, macrocell BSs are able to reduce their traffic loads by reassigning some user devices to nearby small-cell BSs. In this case, we can also lower down their transmitted power to save the system maintenance cost and also provide green communications. Specifically, let $\widetilde{\mathcal{U}}_j$ denote the set of user devices originally served by a macrocell BS b_j but reassigned to other small cells (by phases 2 or 3). For each user device u_i in $\widetilde{\mathcal{U}}_j$, we can employ Eq. (8) to calculate the amount of transmitted power $p_{i,j}$ that b_j allocates to it for communication. Then, the transmitted power of b_j can be decreased to

$$p_j = p_j - \sum_{u_i \in \widetilde{\mathcal{U}}_j} p_{i,j}, \tag{16}$$

to save its energy.

4.5 Design Rationale

We then discuss the rationale of our small-cell planning solution. It first finds out the set of user devices which are not covered by any macrocell or whose traffic demands cannot be satisfied by their associated BSs. Then, our solution adopts two different clustering strategies to determine the locations to place microcell and picocell BSs in order to serve these user devices. Specifically, in phase 2, we choose the K-means clustering algorithm due to two reasons. First, it requires the knowledge of the number of groups, which we can easily derive according to the deployment budget Γ. Second, the objective of K-means is to minimize

$$\sum_{j=1}^{K} \sum_{u_i \in \mathcal{C}_j} D(u_i, \beta_j)^2, \tag{17}$$

where β_j is the centroid of each cluster $\mathcal{C}_j$, and $D(u_i, \beta_j)$ denotes the distance between a user device u_i and the centroid. Eq. (17) implicitly implies that β_j must be the closest centroid for any user device in cluster $\mathcal{C}_j$. In other words, β_j is the 'best' location to deploy a microcell BS b_j to cover $\mathcal{C}_j$ from the geometric perspective, because the user devices in $\mathcal{C}_j$ cannot find another microcell BS which is closer than b_j. On the other hand, since we could afford only few picocell BSs from the remaining budget, it would be better to deploy these BSs to cover those regions where most user devices congregate (that is, hotspot regions). Therefore, we develop a new NBSC algorithm modified from the DBSCAN algorithm to organize clusters which can consist of more user devices. Both phases 2 and 3 consider the number of PRBs supported by each small-cell BS and adjust the range of its cell accordingly. Finally, the last phase also shrinks the communication range of macrocells to further save the energy consumption of their BSs.

We remark that our small-cell planning solution can efficiently deal with the situation where the density of user devices in the service area fluctuates over different times. For instance, there usually exist numerous user devices in a downtown office area on daytime of workdays, but the same area may contain much fewer user devices on weekends or nighttime. Consequently, the operator can use macrocells along with dense small cells to provide service so as to handle the former case, while turn off small cells (or even some macrocells) to save the energy consumption of the operating network in the latter case. Moreover, the service area may be crowed with many user devices in a short time because of big events such as a singing concert. In this case, the operator can adaptively deploy small-cell BSs in the service area according to the expected distribution of user devices by our small-cell planning solution, and withdraw these BSs after the event for the economic consideration.

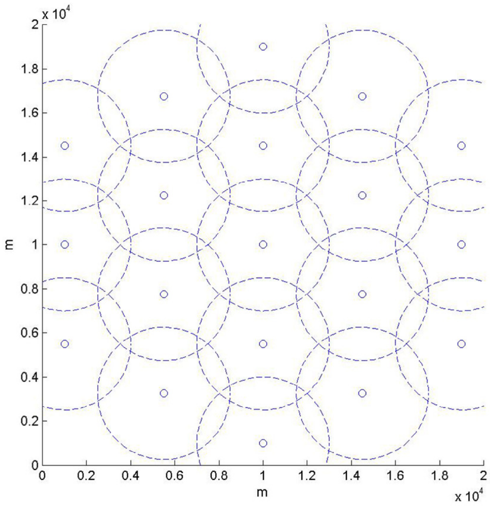
4.6 Discussion on Inter-cell Interference

In our small-cell planning solution, there are two special designs which address the issue of inter-cell interference. First of all, when constructing the set $\mathcal{U}_d$ in phase 1, we consider iteratively moving the user device that has the longest distance from a macrocell BS to $\mathcal{U}_d$. As discussed in Remark 1, it prevents from deploying small cells to cover the user devices in $\mathcal{U}_d$ which are very close to macrocell BSs, thereby alleviating signal interference from these high-powered BSs. Second, when deploying microcell and picocell BSs (in both phases 2 and 3), we refer to Eq. (13) to calculate the SINR value of each user device in these small cells. The calculation of SINR in Eq. (13) considers the effect of signal interference from nearby BSs and thus provides more accurate estimation of spectral resource in each small cell.

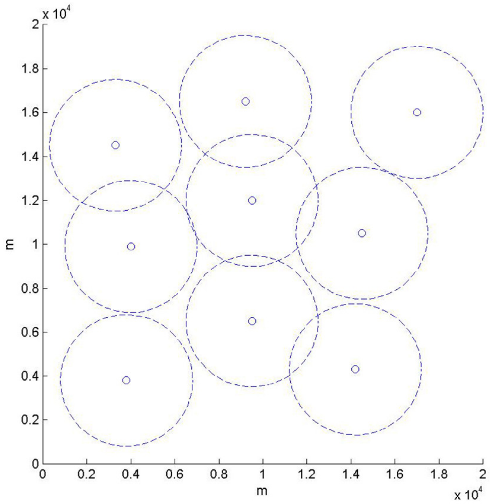
On the other hand, LTE develops the technique of *enhanced inter-cell interference coordination (eICIC)* to deal with the inter-cell interference problem in a HetNet, which proposes both frequency-domain and time-domain mechanisms. The frequency-domain eICIC mechanism assigns different frequency bands for macrocell and small-cell BSs to separately transmit their data, so as to avoid signal interference with each other. The time-domain eICIC mechanism aims at mitigating the interference problem in small cells. More specifically, the macrocell BS selects a number of subframes as *almost blank subframes (ABSs)* in each period, during which it sends nothing but only control signals with very low power. In this way,

TABLE 3: Simulation parameters of BSs.

BS	macrocell	microcell	picocell
cell radius	3,000 m	1,000 m	300 m
maximum power	46 dBm	38 dBm	30 dBm
bandwidth	50 MHz	30 MHz	20 MHz
cost [42]	\$397,800	\$42,200	\$12,400
channel model	referring to Section 2.1		



(a) Scenario 1: regular deployment



(b) Scenario 2: arbitrary deployment

Fig. 2: Two scenarios used to model the deployment of macrocells.

the user devices in small cells are capable of receiving data from their BSs without signal interference from the macrocell BS. Generally speaking, the time-domain eICIC mechanism is more flexible than the frequency-domain one, since it can better utilize the spectral resource by allowing different cells to share the same frequency band. Both studies [40], [41] survey some approaches for frequency-domain and time-domain eICIC mechanisms, respectively.

5 Performance Evaluation

We adopt MATLAB to evaluate the performance of our proposed small-cell planning solution, where Table 3 presents the simulation parameters of BSs and the deployment budget Γ is set to \$1,000,000. The service area is a $20{,}000 \times 20{,}000\,\mathrm{m}^2$ square, on which there have been some macrocells deployed.

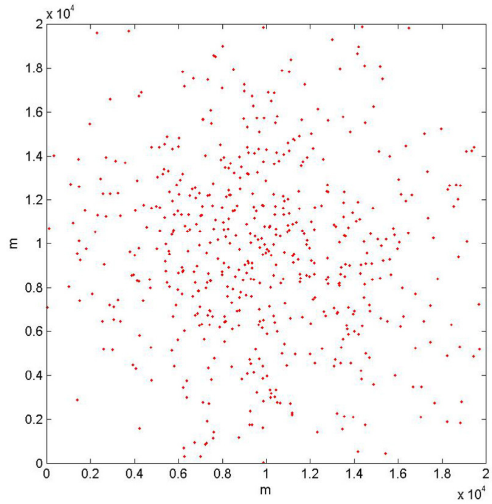


Fig. 3: Scenario A (sparse distribution) to model the distribution of user devices.

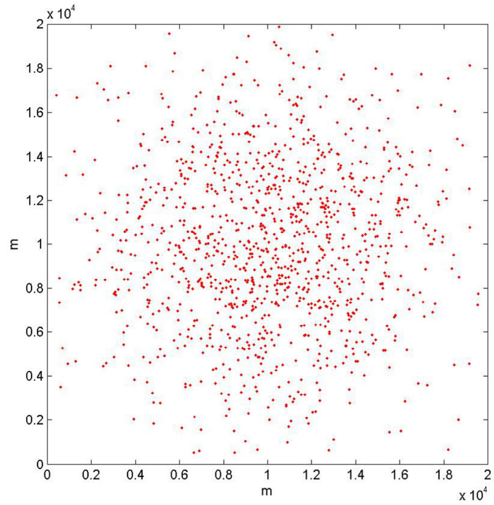


Fig. 4: Scenario B (dense distribution) to model the distribution of user devices.

In particular, we consider two scenarios to model the deployment of macrocells, as illustrated in Fig. 2:

- *Scenario 1–regular deployment:* There are 19 macrocells deployed according to the popular hexagon-like manner [43], where the distance between any two adjacent macrocell BSs will be the same (around 5,100 m). We adopt this scenario to simulate an ideal situation where the service area can be almost covered by macrocells.
- *Scenario 2–arbitrary deployment:* There are 9 macrocells randomly placed, where the signal coverage of two adjacent macrocells may not necessary overlap with each other. We employ this scenario to imitate a practical situation where the macrocell BSs can be deployed only on certain locations in the service area (where the operator has acquired the right to purchase and install these sites).

Moreover, four scenarios are used to model the distribution of user devices in the service area.

- *Scenario A–sparse distribution:* There are 600 user devices placed in the service area by employing the normal distribution, where more user devices locate in the central part of the service area, as shown in Fig. 3.

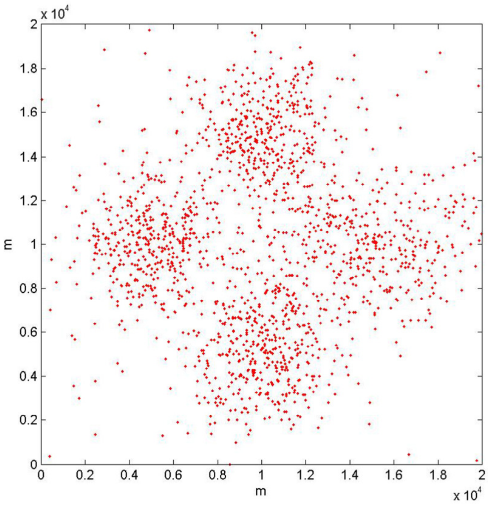


Fig. 5: Scenario C (multiple groups) to model the distribution of user devices.

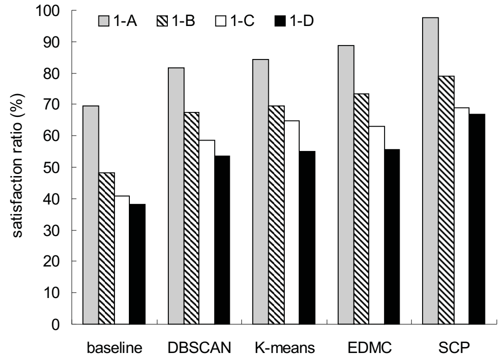
Fig. 6: Scenario D (streets in Kaohsiung City) to model the distribution of user devices.

- *Scenario B–dense distribution:* This scenario is similar to scenario A but has twice of the density of user devices (that is, 1,200 user devices). Fig. 4 illustrates the dense distribution.
- *Scenario C–multiple groups:* The service area contains totally 1,800 user devices. Observing from Fig. 5, there are four conspicuous groups of user devices where they are closely packed together.
- *Scenario D–streets:* We refer to the street map of the downtown region in Kaohsiung City to construct the service area (as presented in Fig. 6), where 2,600 user devices are placed along streets.

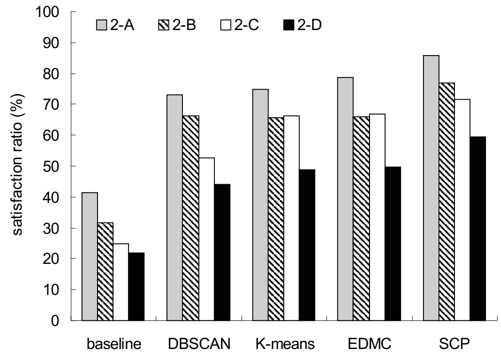
We combine the two scenarios for the deployment of macrocells with the four scenarios for the distribution of user devices, so there are totally eight scenarios adopted in our simulations, which is summarized in Table 4. The average traffic demand of user devices is set to 1Mbps (with the standard deviation of 0.1Mbps).

We compare our small-cell planning solution (abbreviated to 'SCP' in simulation figures) with four schemes:

- *Baseline:* In this scheme, we do not deploy any small cell in the service area. The baseline scheme is merely used as a reference to demonstrate the system performance of the original (macrocell) network.
- *DBSCAN:* We adopt the DBSCAN clustering method to group user devices, where the density threshold φ is set to 4 and the radius ξ is set to 1,000 m. Then, we iteratively place one microcell to cover the cluster which contains the most number of user devices, until the budget is used up.
- *K-means:* We employ the K-means clustering method to group user devices and place microcells accordingly, where K is the number of affordable microcell BSs based on the budget. If there is a budget surplus, we use the K-means clustering method again to group the unserved user devices and deploy picocells to cover them.
- *EDMC [16]:* As discussed earlier in Section 1, the EDMC scheme is composed of four stages. In stage 2, it uses a weighted K-means clustering method to determine the locations to place microcell BSs. On the other hand, the EDMC scheme adopts the *modified geometric disk cover method* [44] in its stage 4 to compute the locations to place picocell BSs. In the EDMC scheme, around 2/3 of the budget is spent on microcell BSs and the residual budget is used to install picocell BSs.



(a) Scenario 1



(b) Scenario 2

Fig. 7: Comparison on the satisfaction ratio of user devices.

Except for the baseline scheme, all other schemes adopt phase 1 of our small-cell planning solution to find the set $\mathcal{U}_L$ of user devices to be served by small cells. For each experiment, we repeat 100 times of simulations and take their average value.

5.1 Satisfaction Ratio of User Devices

We first measure the satisfaction ratio of user devices, which is defined by the ratio of the number of user devices whose traffic demands are satisfied to the number of total user devices in the

TABLE 4: The eight scenarios used in the simulations.

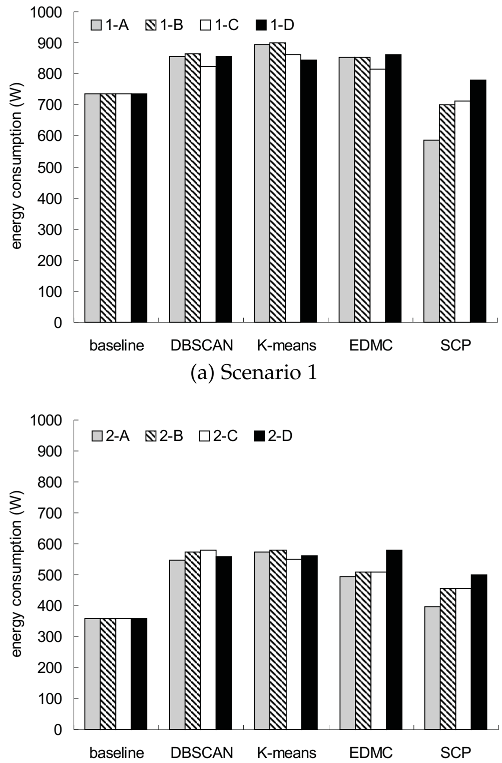
scenario	deployment of macrocells	number of macrocell BSs	distribution of user devices	number of user devices
1-A	Fig. 2(a)	19	Fig. 3	600
1-B	Fig. 2(a)	19	Fig. 4	1,200
1-C	Fig. 2(a)	19	Fig. 5	1,800
1-D	Fig. 2(a)	19	Fig. 6	2,600
2-A	Fig. 2(b)	9	Fig. 3	600
2-B	Fig. 2(b)	9	Fig. 4	1,200
2-C	Fig. 2(b)	9	Fig. 5	1,800
2-D	Fig. 2(b)	9	Fig. 6	2,600

service area. Obviously, a higher satisfaction ratio implies that the network throughput also becomes higher. Fig. 7 illustrates the experiment result. Generally speaking, each scheme is able to achieve a higher satisfaction ratio in scenario 1, because there have existed more macrocells to provide service and they cover the most part of the service area. When we take a deep look at the effect of different distributions of user devices, we can find that the following relationship holds:

$$\text{scenario A} > \text{scenario B} > \text{scenario C} > \text{scenario D}.$$

The major reason is that the number of user devices grows and their distribution becomes more complex (from scenario A to scenario D).

From Fig. 7, by adding small cells to the network, all other schemes can substantially increase the satisfaction ratio comparing with the baseline scheme, especially in scenario 2 (where macrocells only provide partial coverage in the service area). This phenomenon exhibits the superiority of the HetNet over the traditional network consisting of only homogeneous macrocells. Both the K-means and EDMC schemes outperform the DBSCAN scheme, because these two schemes are allowed to deploy (cheap) picocells to serve more user devices, under the constraint of limited budget. Our small-cell planning solution can further increase the satisfaction ratio than K-means and EDMC, because it not only checks whether each microcell BS possesses enough PRBs to serve user devices but also employs the NBSC clustering algorithm to greedily deploy picocells to cover those hotspot regions where user devices congregate. This experiment demonstrates that the proposed small-cell planning solution can make good use of the budget to adaptively add small cells to a network to significantly improve its throughput.



(a) Scenario 1

(b) Scenario 2

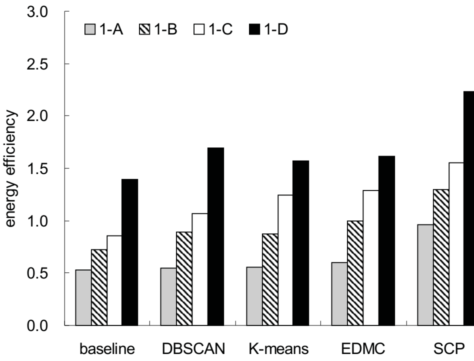
Fig. 8: Comparison on the amount of energy consumption of BSs.

5.2 Energy Consumption of BSs

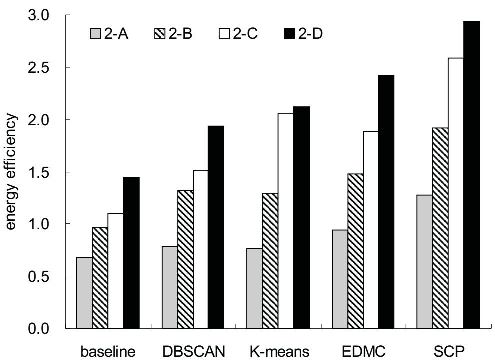
Afterwards, we evaluate the amount of energy consumption of BSs, which is estimated by the aggregate amount of transmitted power of each BS (including the original macrocell BSs). Fig. 8 presents the experimental result. As mentioned earlier in Section 1, a macrocell BS possesses much larger transmitted power than a small-cell BS. Consequently, all schemes result in much higher energy consumption in scenario 1 (with 19 macrocell BSs) than scenario 2 (with only 9 macrocell BSs). Obviously, the amount of energy consumption in the baseline scheme does not change with different distributions of user devices, because it does not add extra small cells and each macrocell BS uses the same transmitted power to serve user devices. Broadly speaking, the distribution of user devices has less effect on the DBSCAN, K-means, EDMC, and our small-cell planning schemes. The reason is that these schemes deploy additional microcell and picocell BSs for service, whose transmitted power is much smaller than the original macrocell BSs (referring to Table 3). However, our small-cell planning solution will seek to further reduce the transmitted power of macrocell BSs by its phase 4, when some user devices originally served by these macrocell BSs can be reassigned to nearby small cells. In this way, it is possible to decrease the overall energy consumption in the network. Such a phenomenon is more conspicuous in scenario 1-A, where the service area is almost covered by macrocells and there are only 600 user devices needed to be served. In this case, adding microcells and picocells can not only balance the traffic loads of macrocells but also substantially reduce the amount of energy consumed by macrocell BSs. From Fig. 8, our small-cell planning solution always has a smaller amount of energy consumption than the DBSCAN, K-means, and EDMC schemes in each scenario, which verifies its effectiveness in energy usage.

5.3 Energy Efficiency of Network

Finally, we investigate the energy efficiency of the overall network, which is defined by the ratio of the amount of network throughput to the amount of energy consumed by BSs. Fig. 9 gives the experimental result. Generally speaking, when there are more user devices in the service area (for example, scenarios C and D) or fewer macrocells are deployed for



(a) Scenario 1



(b) Scenario 2

Fig. 9: Comparison on the energy efficiency of network.

service (in particular, scenario 2), the value of energy efficiency will significantly increase. Although the DBSCAN, K-means, and EDMC schemes can deploy small cells to increase the network throughput (referring to Fig. 7) but they also make BSs spend more energy on communications (referring to Fig. 8). Consequently, these schemes result in slightly higher energy efficiency than the baseline scheme, especially in scenario 1. By adaptively adding small cells to meet the traffic demands of user devices and also reduce energy consumption of macrocell BSs, our small-cell planning solution can have much larger energy efficiency than all other schemes, especially in scenarios 1-D, 2-C, and 2-D, where there are more user devices in the service area. This experimental result demonstrates that our proposed small-cell planning solution can better support green communications than the DBSCAN, K-means, and EDMC schemes.

6 Conclusion and Future Work

LTE HetNet allows operators to flexibly and tactically add small-cell BSs to improve performance of an existing network. This paper thus proposes the small-cell planning problem with the objective to increase the energy efficiency of an LTE HetNet subject to the deployment budget. An efficient solution is developed by deploying both microcell and picocell BSs to satisfy the traffic demands of user devices while reducing energy consumption and traffic loads of original macrocell BSs. We propose the K-means and NBSC clustering strategies to determine the locations to place microcells and picocells, respectively. For each cell, we further check whether the BS has enough resource to serve its user devices and adjust the cell range accordingly by calculating a suitable value of transmitted power. Simulation results by MATLAB demonstrate that our proposed small-cell planning solution satisfies the traffic demands of more user devices and also reduces energy consumption of BSs, under the eight scenarios with different macrocell deployment and distributions of user devices. Consequently, it can significantly improve the HetNet's energy efficiency and supports green communications.

We finally give some future work. First, our clustering strategies take into consideration the geographical locations of user devices. In [45], a clustering approach to improve spectrum utilization for a cognitive radio network is proposed. It is interesting to apply such an idea to the small-cell planning solution by addressing the issue of spectrum sharing. Second, as discussed in Section 4.6, we can adopt the eICIC technique to deal with the inter-cell interference problem. How to efficiently integrate the small-cell planning solution with the interference management mechanism by eICIC (for example, jointly determining the ABS ratio [46], [47] and cell deployment) deserves further investigation.

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