Mobile Small Cell Deployment for Next Generation Cellular Networks

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***Abstract*—With the rapid growth of mobile broadband traffic, adopting small cell is a promising trend for operators to improve network capacity with low cost. However, static small cells cannot be flexibly placed to fulfill time/space-varying traffic. The static small cells might stay in idle or under-utilized mode during some time periods, which wastes resources. Therefore, this paper utilizes the mobile small cell concept and studies the deployment problem for mobile small cells. The objective is to maximize the service time provided by mobile small cells for all users. If a finite number of mobile small cells can serve more users for more time, the mobile small cell deployment will have more gains. Specifically, we show an interesting trade-off in the service time maximization. Then, we prove our target problem is $\mathcal{NP}$-hard and propose an efficient mobile small cell deployment algorithm to deal with the trade-off to maximize the total service time. We construct a series of simulations with realistic parameter settings to evaluate the performance of our proposed algorithm. Compared with a static small cell deployment algorithm and a random mobile small cell deployment algorithm, the simulation results show that our proposed scheme can significantly increase the total service time provided for all users.**

***Index Terms*—cellular network, mobile small cell, small cell deployment**

I. Introduction

With the tremendous increase of mobile subscribers and connected devices, mobile data traffic grows explosively. It is predicted that wireless communication systems will have to support more than 1000 times today's traffic volume beyond 2020 [1]. As expected, current cellular networks cannot afford to meet such huge traffic demand with the provisioning of good user experience. The possible solutions include the dense deployment and short-range coverage of small base stations. In 2013, operators already paid more than 22 billion US dollars for purchasing, setting up and maintaining these extra base stations [2], [3]. Even with the existing solutions, the hotzones with heavy traffic load cannot be easily located, which highly depends on the properties of user mobility and time-varying traffic demand [4]. Furthermore, considering the energy consumption and cost issues for operating a considerable number of base stations, another energy-efficient and cost-effective solution should be identified. Fortunately, the mobile/portable base station concept [5] has emerged and has been under development in recent years. With this new technology, mobile small cells can be seen as one of the promising solutions for handling massive data traffic in next-generation cellular networks.

Mobile small cells are provided by low-power and low-cost radio access nodes with mobility capability. They provide the following benefits. Firstly, unlike traditional static cell deployment, mobile small cells can be deployed in an efficient and economic way, according to dynamic traffic load, to complement the macrocell coverage holes and enhance its service coverage. Secondly, mobile small cells can potentially move to the locations closer to users so that they can receive stronger signal and obtain higher data rate. Finally, adopting mobile small cells, more data traffic can be truly released from the macrocell to improve the system performance of the whole system. Although mobile small cells can provide many advantages, the mobile small cell deployment problem still faces some challenges: (1) Each mobile small cell consumes time for moving to a location. During the moving period, mobile small cells cannot provide service due to serious channel fading and thus sacrifice service time. (2) Inter-cell interference (among small cells) and cross-cell interference (between the macrocell and small cells) would make the deployment problem more complicated.

In the literature, static small cell deployment has been widely studied, especially for the urban or hotzone environment [6]. Several researches devote to find the optimal small cell deployment with the consideration of different performance metrics. Guo *et al.* [7] proposed a theoretical framework to maximize spectral efficiency of the network and to avoid interference posed by small cell placement. Cheng *et al*. [8] and Shimodaira *et al*. [9] adopted system throughput as the performance metric to find optimal locations for placing static small cells. Chen *et al*. [10] further considered the impact of different deployment topologies, e.g., random and grid topologies, on throughput and spatial outage performance. Coletti *et al*. [11], [12] and Hu *et al*. [13] devised outage-minimum deployment mechanisms under realistic metropolitan scenarios. Most of the researches only considered the static small cell deployment and assumed that the user or traffic distribution is invariant. However, the user and traffic distribution, in fact, vary over time. The above solutions cannot adapt to those dynamic changes, and cannot address the new challenges arising from the mobile small cell deployment problem.

In this paper, we study the mobile small cell deployment problem for next generation cellular networks. The objective is to maximize the service time provided by mobile small cells for all users with the consideration of a finite number of mobile small cells and inter-cell/cross-cell interference. The contributions of this paper are summarized as follows. Firstly, this is one of the pioneering works to study the deployment problem of small cells with mobility property. A trade-off between the movement of small cells and user density, in maximization of the total in-service time, is observed. Secondly, the mobile small cell deployment is formulated as an optimization problem. We prove that the problem is $\mathcal{NP}$-hard and propose an efficient heuristic algorithm to tackle the problem. Finally, we conduct a series of simulations with realistic parameter settings to evaluate the performance of the proposed algorithm and to provide some useful insights to the mobile small cell deployment.

The rest of the paper is organized as follows. The system model and problem formulation are described in Section II. Section III presents the dynamic mobile small cell deployment algorithm. Simulation results and analyses are presented in Section IV. Section V concludes the paper.

II. System Model and Problem Formulation

In next-generation cellular systems, operators are required to provide better service quality for users, especially for cell-edge users. Among the latest technologies to tackle the problem, deploying small cells is considered as an efficient and promising way. Instead of deploying small cells in some fixed locations, "mobile" small cells can be flexibly placed to fulfill time/space-varying traffic demands so that users will enjoy their cellular services better and the system throughput/capacity will be more increased [14]. Note that the backhaul connection for mobile small cells could be accomplished through the wireless technologies such as microwave/millimeter wave radio [15].

Future cellular systems are anticipated to adopt the two-tier structure where one macrocell covers the whole service area and several mobile small cells freely move to dynamically provide services for the users residing in the densely populated areas or in the areas with high traffic loads [16]. With a finite number of mobile small cells, it is critical to fully utilize their resources and effectively offload traffic from the macrocell to optimize the overall system performance. Users are supposed to receive better service quality through mobile small cells than the macrocell. If the limited number of mobile small cells can serve more users for more time, we will have more gains with the mobile small cell deployment, which is the core concept of this study. Here we define *in-service time*, i.e., the time that a mobile small cell can serve for a user. In this paper, we are interested in maximizing total *in-service time* of all users. In fact, when a mobile small cell is moving, its service will temporarily suspend due to serious channel fading until the mobile small cell arrives at its target location. If the target location is far from the original location, the *in-service time* of the mobile small cell is then reduced. It is not a trivial issue to determine which mobile small cell should move to which location such that the total in-service time of all users is maximized. Specifically, a mobile small cell might move to a far location with densely distributed users, but consume a lot of time moving to the target location. Conversely, the mobile small cell can choose to move to a non-distant location with few users and save time for moving. There exists a trade-off on the total in-service time between the moving time of a mobile small cell and the user density. When a mobile small cell is moving, the users originally served by the mobile small cell might switch its service to the macrocell to maintain their network connectivity.

In this paper, a two-tier cellular network is considered, which consists of a macrocell and several operator-deployed mobile small cells. Under the network structure and scenario, we study the dynamic deployment problem for a finite number of mobile small cells for next-generation cellular systems, with the objective of maximizing the total in-service time of all users. The system model under consideration can be formulated as follows. In a single cell, a set of users $\mathcal{U}$ should be served. Each user u with the location $l_u = (x_u, y_u)$ has an estimated sojourn time t_u^s based on the moving speed [17]. Let $\mathcal{C}$ denote a set of mobile small cells. For each mobile small cell c, it can serve the number of users N under the limited capacity [18]. Moreover, the mobile small cell c at location $l_c = (x_c, y_c)$ requires the time of $t_c(l_c, l'_c)$ to move from the location l_c to a particular location l'_c, and a set of users $\mathcal{U}_c(l_c, l'_c)$ can be served by the small cell c. If the user $u \in \mathcal{U}_c(l_c, l'_c)$ is covered by the mobile small cell c, the in-service time of the user u is $t_u = t_u^s - t_c(l_c, l'_c)$. To avoid the unnecessary overheads caused by the frequent movements of mobile small cells, the decision for our dynamic mobile small cell deployment is made every T time period (called "deployment interval"). To alleviate the co-tier interference, a minimum Inter-Site Distance (ISD) D between a pair of small cells is required, based on the transmit power and cell size [19]. Also, a minimum ISD $\bar{D}$ is used to reduce the cross-tier interference between the macrocell and any small cell. It is assumed that the dynamic deployment is performed at the beginning of each deployment interval, and is feasible if the following constraints are met:

1) Maximum User Service Time: Equation (1) ensures that each user's statistical sojourn time does not exceed the deployment interval T.

$$t_u^s \leq T, \forall u \in \mathcal{U} \tag{1}$$

2) Minimum ISD Requirement: For the purpose of alleviating the cross-tier and co-tier interference, the deployment of mobile small cells should satisfy the minimum ISD requirement. Equation (2) represents the minimum ISD between the macrocell and mobile small cells, where $l_0 = (x_0, y_0)$ is the location of the macro base station. The minimum ISD constraint among small cells is shown in Equation (3).

$$\sqrt{(x_c - x_0)^2 + (y_c - y_0)^2} \geq \bar{D}, \forall c \in \mathcal{C} \tag{2}$$

$$\sqrt{(x_c - x_{c'})^2 + (y_c - y_{c'})^2} \geq D, \forall c, c' \in \mathcal{C}, c \neq c' \tag{3}$$

3) Small Cell Capacity: Each mobile small cell c cannot serve the number of users more than N under the limited resources [18].

$$|\mathcal{U}_c(l_c, l'_c)| \leq N, \forall c \in \mathcal{C}, l'_c \tag{4}$$

4) User Connectivity: This constraint states that each user can be served by at most one mobile small cell.

$$\mathcal{U}_c(l_c, l'_c) \cap \mathcal{U}_{c'}(l_{c'}, l'_{c'}) = \phi, \forall c, c' \in \mathcal{C}, l'_c, l'_{c'}, c \neq c' \tag{5}$$

The Dynamic Mobile Small Cell Deployment Problem

Input instance: Consider a set of users $\mathcal{U}$. Each user u has

TABLE I
SUMMARY OF NOTATIONS

Symbol	Description
$\mathcal{C}$	Set of mobile small cells
$\mathcal{U}$	Set of users
$\mathcal{U}_c(l_c, l'_c)$	Set of the served users for mobile small cell c after the mobile small cell arrives at the target location l'_c from the original location l_c
$l_u = (x_u, y_u)$	Location for user u
$l_c = (x_c, y_c)$	Location for mobile small cell c
t_u^s	Sojourn time for user u
$t_c(l_c, l'_c)$	Moving time for mobile small cell c from original location l_c to target location l'_c
t_u	In-service time for user u
N	Capacity for a mobile small cell
T	Deployment interval
D	Minimum ISD among small cells
$\bar{D}$	Minimum ISD between the macrocell and small cells

a sojourn time t_u^s and a location $l_u = (x_u, y_u)$. There is a set of mobile small cells $\mathcal{C}$. Each mobile small cell c has a location $l_c = (x_c, y_c)$ and can serve at most N users. The mobile small cell c requires a moving time $t_c(l_c, l'_c)$ from the location l_c to the location l'_c, and the user set $\mathcal{U}_c(l_c, l'_c)$ can be served in a deployment interval T. D and $\bar{D}$ are the minimum ISDs among small cells and between the macrocell and small cells, respectively.

Objective: Our objective is to find a target location l'_c for each mobile small cell c such that total in-service time of all users is maximized. The objective function is formalized as follows.

$$\max \sum_{\forall c \in \mathcal{C}} \sum_{\forall u \in \mathcal{U}_c(l_c, l'_c)} t_u \tag{6}$$

subject to the constraints (1) to (5). The variables mentioned above is summarized in Table I.

III. MOBILE SMALL CELL DEPLOYMENT

In this section, we prove the $\mathcal{NP}$-hardness of the problem by a reduction from the *facility location problem*, which is known to be $\mathcal{NP}$-complete [20], and propose a heuristic algorithm, named *Mobile Small Cell Deployment (MSCD)* algorithm, to tackle the problem. Then, we analyze the time complexity of the proposed algorithm and show that it is a polynomial-time algorithm.

A. NP Hardness

Theorem 1. *The mobile small cell deployment problem is $\mathcal{NP}$-hard.*

Proof: This problem obviously is $\mathcal{NP}$-hard and can be proved by a reduction from the *facility location problem*. The proof is omitted due to lack of space. ■

B. Mobile Small Cell Deployment Algorithm

The in-service time is decided jointly by the number of served users and the length of moving time to each target location. The out-of-service time needed by a mobile small cell moving to a particular target location depends on the distance between the original and target locations. Once a mobile small cell arrives at its target location, more users covered by the cell lead to a larger total in-service time. Consequently, in order to maximize the total in-service time of all users, each mobile small cell should consider both the user density and the length of moving time when deciding its target location. The basic concept of our proposed MSCD algorithm is described as follows. In the beginning, for each mobile small cell, MSCD tries to move the cell to the location of each user and selects a suitable location such that the total in-service time is maximized. Next, to prevent the co-tier and cross-tier interference problems, the *Minimum_ISD_Check*(.) function is executed. Finally, MSCD will output those target locations and complete the mobile small cell deployment procedure.

Algorithm 1 Mobile Small Cell Deployment

Input: $\mathcal{U}, l_u, t_u^s, \mathcal{C}, t_c(l_c, l'_c), \mathcal{U}_c(l_c, l'_c), N, D, \bar{D}, T$
Output: $l'_c, \forall c \in \mathcal{C}$
1: **for all** $c \in \mathcal{C}$ **do**
2:   **for all** $u \in \mathcal{U}$ **do**
3:     Sort user set $\mathcal{U}_c(l_c, l_u)$ by sojourn time $t_{u'}^s, \forall u' \in \mathcal{U}_c(l_c, l_u)$, in descending order
4:     $s_u \leftarrow 0$
5:     **for** $j = 1 \to N$ **do**
6:       $s_u \leftarrow s_u + \max\{0, t_j^s - t_c(l_c, l_u)\}$
7:   Sort user set $\mathcal{U}$ by s_u in descending order
8:   **for** $j = 1 \to |\mathcal{U}|$ **do**
9:     Flag = Minimum_ISD_Check(l_j)
10:     **if** Flag = TRUE **then**
11:       $l'_c \leftarrow l_j$
12:       Break the **for** loop
13: **return** $l'_c, \forall c \in \mathcal{C}$

Procedure : Minimum_ISD_Check (l_j)
Flag $\leftarrow$ TRUE
if DISTANCE $(l_j, l_0) < \bar{D}$ **then**
  Flag $\leftarrow$ FALSE
else
  for all $c' \neq j \in \mathcal{C}$ **do**
    if DISTANCE $(l_j, l_{c'}) < D$ **then**
      Flag $\leftarrow$ FALSE
      Break the **for** loop
return Flag

The pseudo code of the proposed MSCD scheme is shown in Algorithm 1. Each mobile small cell c attempts to move to each location l_u of user u and to find a location to provide the maximum total in-service time (Lines 1-12). If the mobile small cell c moves to the location l_u of user u from the location l_c, a set of users $\mathcal{U}_c(l_c, l_u)$ can be served by the mobile small cell c. Then, we sort the users in the user set $\mathcal{U}_c(l_c, l_u)$ in descending order based on each user's sojourn time $t_{u'}^s$, such that $t_1^s \geq t_2^s \geq \cdots \geq t_{|\mathcal{U}_c(l_c, l_u)|}^s, \forall u' \in \mathcal{U}_c(l_c, l_u)$. The users are ordered to select the first N users with higher sojourn times and thus higher total in-service time can be obtained (Line 3). A variable s_u, initialized as 0, is used to record the total in-service time if the mobile small cell c moves to the location l_u (Line 4). Since the number of users that a mobile small cell can serve is limited, the variable s_u accumulates the in-service time of the first N users (Lines 5-6).

After the mobile small cell c tries to move to each location l_u and obtains s_u, we sort the user set $\mathcal{U}$ by s_u in descending order, such that $s_1 \geq s_2 \geq \cdots \geq s_{|\mathcal{U}|}$. It is used to deal with the trade-off on the total in-service time between the moving time of the mobile small cell and user density (Line 7). For avoiding cross-tier/co-tier interference, before the mobile small cell c moves to the target location l_j, we have to check whether the minimum ISD requirement is satisfied (Lines 8-12). If yes (i.e., "Flag=TRUE"), the mobile small cell c can move to the location l_j and l'_c is set as l_j. Then, we break the **for** loop. Otherwise, the mobile small cell c will try to move to the next location. Finally, MSCD returns the target location l'_c of each mobile small cell $c, \forall c \in \mathcal{C}$ (Line 13).

Procedure Minimum_ISD_Check(l_j) is executed to check whether a mobile small cell moving to the location l_j interferes with the macrocell or the other mobile small cells. That is, the minimum ISD constraint can be satisfied or not (Lines 1-9). Let "Flag" be the indicator, which is TRUE if the constraint is satisfied and FALSE otherwise. Initially, the value of "Flag" is set as TRUE, which means that the mobile small cell does not interfere with the macrocell and other mobile small cells (Line 1). Then, we use the function DISTANCE(l_j, l_0) to calculate the distance between the location l_j and the location l_0, where l_0 is the location of the macrocell (Line 2). If the distance is less than $\bar{D}$, the cross-tier interference will occur and then "Flag" is set as FALSE (Line 3). On the other hand, if the location l_j passes the cross-tier minimum ISD check, we proceed to examine the co-tier minimum ISD requirement. Once the distance between the location l_j and the location $l_{c'}$ of any other mobile small cell c' is less than D, "Flag" is set as FALSE and the **for** loop exits (Lines 5-8). If the location l_j satisfies the minimum ISD constraint against all of the other mobile small cells, a TRUE value is returned (Line 9). That is, the mobile small cell decides its target location as l_j.

Theorem 2. *The time complexity of Algorithm 1 is* $O(|\mathcal{C}||\mathcal{U}|(|\mathcal{U}|\log|\mathcal{U}| + |\mathcal{C}|))$.

Proof: For the first inner **for** loop (Lines 2-6), each mobile small cell has to try $|\mathcal{U}|$ locations. For each location, we have to sort the user set $\mathcal{U}_c(l_c, l_u)$ and take $O(|\mathcal{U}|\log|\mathcal{U}|)$ time for the adopted sorting algorithm. Hence, the time complexity of the first inner **for** loop is $O(|\mathcal{U}|^2\log|\mathcal{U}|)$. For the second inner **for** loop (Lines 8-12), Minimum_ISD_Check(.) function is executed at most $|\mathcal{U}|$ times. In Minimum_ISD_Check(.) function, a mobile small cell checks whether it interferes with the macrocell and the other $|\mathcal{C}| - 1$ mobile small cells (Line 9). This process takes $O(|\mathcal{C}|)$ time. Thus, the time complexity of the second inner **for** loop is $O(|\mathcal{U}||\mathcal{C}|)$. Since each mobile small cell has to execute the two **for** loops and there are at most $|\mathcal{C}|$ mobile small cells, the time complexity of Algorithm 1 is $O(|\mathcal{C}||\mathcal{U}|(|\mathcal{U}|\log|\mathcal{U}| + |\mathcal{C}|))$. ■

IV. Performance Evaluation

A. Simulation Setups

In this section, we develop a simulation model based on a two-tier network topology to evaluate the performance of our proposed scheme, *Mobile Small Cell Deployment (MSCD)*, in comparison with two algorithms. The first algorithm, denoted as *static*, is designed for conventional cell planning [7], [8] in which small cells are deployed in some fixed locations. The *static* algorithm can achieve pretty good performance with a given user or traffic distribution. However, the *static* algorithm could not adapt to capture the traffic variation in time, especially when users have mobility. The second algorithm, expressed as *dynamic*, is an extension of *static* algorithm. It is a two-stage algorithm with the consideration of mobile small cell deployment. The operation of the first stage in *dynamic* is similar to that of *static*. That is, *dynamic* will select the target locations based on user density. Then, the second stage deals with the placement problem of mobile small cells, where each mobile small cell is randomly assigned to one of the suggested locations given by the first stage. The performance metric is the total in-service time of all users.

TABLE II
PARAMETER SETTINGS

Parameter	Value
Macrocell radius	500 meters
Small cell radius	50 $\sim$ 150 meters
Number of mobile small cells	1 $\sim$ 15
Number of users in the system	25 $\sim$ 1000
Number of users served by a small cell	16 $\sim$ 46
Minimum ISD $\bar{D}$	75 meters
Minimum ISD D	40 meters
Moving distance for users	10 $\sim$ 500 meters
Deployment Interval T	500 seconds

The simulation settings are as follows. In the two-tier network topology, there are a marcocell and several mobile small cells. The number of mobile small cells varies from 1 to 15. The radius of the macrocell is 500 meters and the radius of a mobile small cell can be set from 50 to 150 meters [21]. Initially, mobile small cells are randomly deployed within the coverage of the macrocell. The cellular system accommodates at most 1000 users [22], and a mobile small cell can serve 16 to 46 users. For the user distribution, we refer to the clustered UE (user equipment) placement model for hotzone areas specified in 3GPP [19], and it is shown as follows.

$$N_h = \left\lfloor p \cdot \frac{|\mathcal{U}|}{|\mathcal{C}|} \right\rfloor \tag{7}$$

where N_h is the number of the users distributed in a hotzone area. p is the fraction of all hotzone users over the total number of users in the network. $|\mathcal{U}|$ and $|\mathcal{C}|$ are the total number of users and small cells, respectively. After considering the placement of the hotzone users, we randomly distribute the remaining users, $|\mathcal{U}| - N_h \times |\mathcal{C}|$, to the whole macrocell.

The random waypoint mobility model is adopted to demonstrate the movement pattern of users. The moving distance of a user can be up to 500 meters, and is determined by randomly assigning the movement speed and time. In addition, according to the 3GPP's heterogeneous system setting [19], the minimum ISDs $\bar{D}$ and D are set to 75 meters and 40 meters, respectively. The deployment interval T is 500 seconds. Parameter settings are listed in Table II. The simulation results are the average of 1000 consecutive runs.

B. Simulation Results

Fig. 1 shows the impacts of the number of users on the total in-service time. As the number of users increases, the

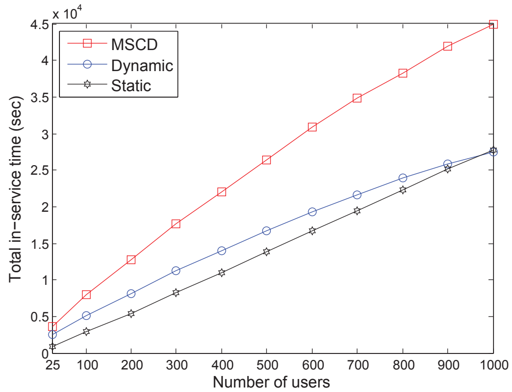

Fig. 1. Impacts of the number of users on the total in-service time (under each user with the average moving distance of 150 meters and 10 mobile small cells with a radius of 50 meters)

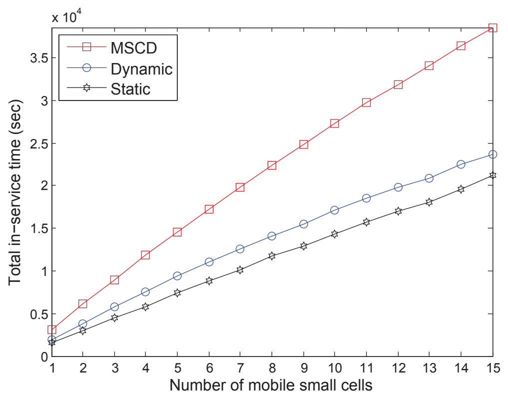

Fig. 2. Impacts of number of mobile small cells on the total in-service time (under 500 users with the average moving distance of 150 meters and the small-cell radius of 50 meters)

total in-service time increases. This is because a mobile small cell has a higher chance to serve more users when there are more users in the system. Compared with *static* and *dynamic*, our proposed *MSCD* scheme can significantly increase the total in-service time. The performance improvement is more evident when the number of users is larger. The reason is that, under our proposed scheme, the selection of the target location jointly considers the factors of the moving (out-of-service) time to the target location and the number of users around the target location. On the other hand, for the *dynamic* scheme, although the areas with densely distributed users are located as the target-location candidates in the first stage, the random selection from the candidate pool in the second stage would cause mobile small cells to move to a very far site and thus the traveling time (i.e., out-of-service time) is long. The negative impact becomes more significant as the number of users increases. It can be observed that the performance of *dynamic* is very close to that of *static* when the system has 1000 users. Since the deployment of small cells is fixed, static small cells can avoid the movement time and have a higher chance to serve more users, compared with the *dynamic* scheme, when there are abundant users in the cell. In summary, the simulation results show that *MSCD* outperforms *static* and *dynaimc* by up to 77%.

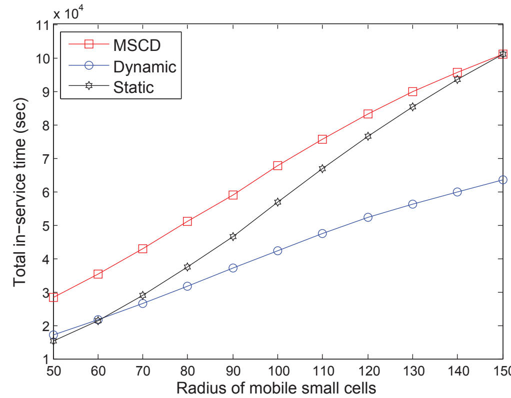

Fig. 3. Impacts of radius of mobile small cells on the total in-service time (under 500 users with the average moving distance of 150 meters and 10 mobile small cells)

Fig. 2 shows the impacts of the number of mobile small cells on the total in-service time. As the number of mobile small cells increases, the total in-service time increases for the three algorithms. This result can be expected because more users can be served by placing more small cells in the network. By jointly considering both the temporal and spatial factors, *MSCD* can obviously outperform the *static* and *dynamic* schemes. The *dynamic* scheme can obtain better performance than *static* through flexibly placing those small cells, according to the user distribution. However, when the number of mobile small cells increases, the performance gap between *dynamic* and *MSCD* becomes more significant. This is because for the *dynamic* scheme, mobile small cells might not be able to arrive at the proper target location in time due to the long distance. The situation will get worse when the number of mobile small cells is large because there would be more mobile small cells compete for the same location and some of the mobile small cells need to compromise with the competitors on the best choice. On the other hand, the *static* scheme lacks of dealing with the mobility of users. Hence, the room for improving the total in-service time is marginal even when the number of small cells increases.

In Fig. 3, we analyze the influence of the mobile small cell radius on the total in-service time. It is intuitive that a mobile small cell with a larger radius can cover more users and have more gains on the total in-service time. From the simulation result, we observe an interesting phenomenon. That is, when the radius of a small cell becomes larger, the *static* scheme outperforms the *dynamic* scheme, and gradually achieves the similar performance to the *MSCD* scheme. The reason is that the coverage area of the static small cells completely overlays the whole macrocell (i.e., full coverage). No matter how far a user moves, the user can be covered by at least one static small cell. For the *dynamic* scheme, however, mobile small cells waste a lot of time to find and move to proper locations at the expense of sacrificing the total in-service time of all users. The simulation result demonstrates that the *dynamic* scheme has poor performance when the radius of mobile small cells is large. On the other hand, although our proposed *MSCD* faces the same problem, the result is still satisfactory due to the fact that *MSCD* considers both the time and space dimensions at the same time.

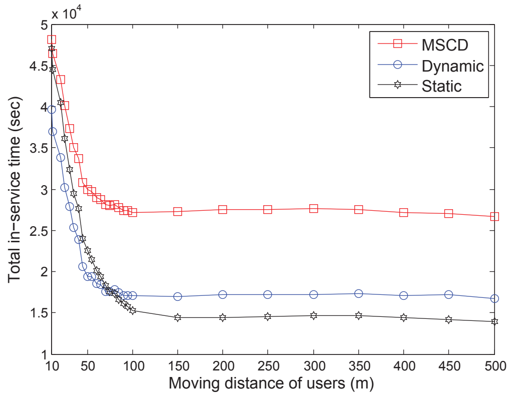

Fig. 4. Impacts of moving distance of users on the total in-service time (under 500 users and 10 mobile small cells with a radius of 50 meters)

Fig. 4 depicts the total in-service time of the three algorithms upon various settings on the moving distance. The moving distance of users in the x-axis represents the input that summarizes the moving speed and the moving time in random waypoint mobility model. As shown in the figure, our proposed *MSCD* scheme outperforms *static* and *dynamic* schemes no matter how the user mobility changes. This is because our proposed scheme can efficiently select a location for each mobile small cell to increase the in-service time as much as possible according to different user distributions. From the simulation results, when the moving distance is below 100 meters, the total in-service time degrades rapidly as the moving distance increases. It means that when user mobility is low, its negative impact on the total in-service time is significant for the three algorithms. On the other hand, when the moving distance is above 100 meters, the total in-service time seems to become stable as the moving distance of users increases. Due to the fact that high mobility results in more random and dynamic user topology, it is very difficult for mobile small cells to maintain long-term connections with users. Actually, based on [14], the cellular users with frequent movement and high movement speed should be served by the macrocell, instead of small cells.

V. Conclusion

In this paper, we have studied the mobile small cell deployment problem for next-generation cellular networks. The objective is to maximize the total in-service time of all users by deploying a finite number of mobile small cells. We formulate the mobile small cell deployment as an optimization problem and prove that this problem is $\mathcal{NP}$-hard. We then propose an efficient heuristic algorithm to tackle the problem. The simulations are conducted to show that our proposed scheme can significantly increase the total in-service time of all users, compared with the conventional static deployment scheme and the random mobile small cell deployment scheme. The performance improvement of the proposed algorithm is more evident in large scale networks when there are more number of mobile small cells and users.

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