Tracking Areas Planning with Cooperative Game in Heterogeneous and Small Cell Networks

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Abstract. Increasing demands of data transmissions are promoting the acceleration of peaking rate per terminal especially in hot-spots. Numerous irregular deployments of small cells require efficient TA planning method in heterogeneous cellular networks. Macrocells preferred access is not a fundamental solution for TA planning, result from reducing the offloading ability of small cells. In this paper, a novel TA planning algorithm based on cooperative games is proposed by detecting similar communities. Simulation results show that it can reduce the signalling overhead while maintaining the utilization proportion of femtocells.

Keywords: Heterogeneous and small cell networks · Location management · Tracking areas planning · Cooperative game

1 Introduction

In recent years, various mobile terminals with high performance have captured the market rapidly all over the world. This leads a new era that varieties of services such as cloud computing, multimedia broadcasting, social networks and online game inspire the ubiquitous demands [1,2]. According to the statistics, numerous data transmissions are proceeding in residents or hot-spot areas [3]. Consequently, the desired quality of service (QoS) is accelerating the progress of hyper dense networks (HDN) in beyond 4G and 5G [4–6]. Heterogeneous and small cell networks (HetSNets), as one of the options for HDN, can support higher system throughput by introducing small cells (such as femtocells and picocells) [7,8]. The HetSNets infrastructure has been illustrated in Fig. 1, and different small cells have corresponding backhaul ways and scope of services [9]. However, massive deployments of small cells increase the signaling overhead and complexity of mobility management in HetSNets [10], and tracking area (TA) planning is part of the issue in hybrid mobility managements [11].

The dense deployments of small cells have been found to cause the heavy signaling overhead for location tracking with conventional principles of TA planning [12,13]. Several novel algorithms are therefore proposed to replan TA efficiently. In [14], an automatic replanning of TA for long term evolution (LTE) networks

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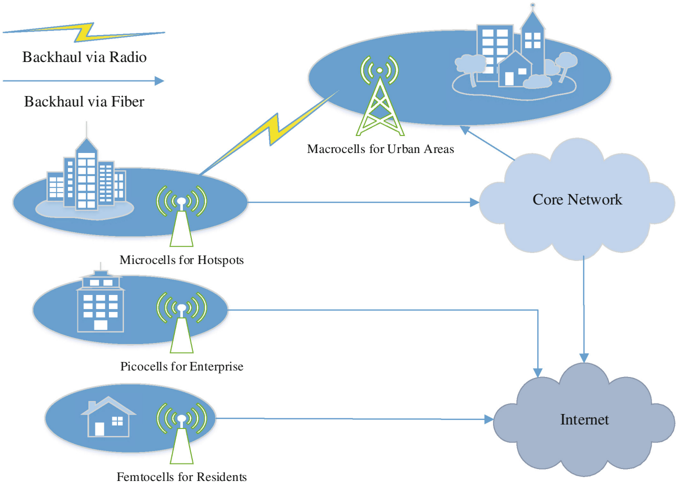

Fig. 1. Diagram of HetSNets infrastructure.

is presented via formulating the problem as a classical graph partitioning, which is solved by a multi-level graph partitioning algorithm. [15] presents an alternative method via modifying the handover decision and cell reselection, while considering the femtocells as groups for location tracking. Nevertheless, massive base stations consisting of the graph vertexes may bring the challenge of the algorithm proposed in [14], and forcing the users to stay in the macrocells as long as possible is not always efficient due to various user traffic and motion features [15].

Game theory has been widely used as a central tool for the design of future wireless and communication networks in recent years [16]. Game theory formulated interaction main incentive structures. It is a mathematical study of the theory and methods of the competitive nature of the phenomenon. Game theory considers the game to predict individual behavior and actual behavior, and to study their optimization strategy. Biologists use game theory to understand and predict the evolution of some of the results. Cooperative games encompass coalitional games that describe the formation of cooperating groups of players, referred to as coalitions. In [17], it utilizes coalitional games to detect communities in social networks. Inspired by [17], this paper considers TA planning as a detection of similar communities based on cooperative games.

2 System Model

Small cells are low-power access nodes, working on both the authorization and non-licensed spectrum. The coverage is from 10 m to 200 m, compared to the coverage of the macrocell, which can reach several kilometers. Mobile operators are worried about the growth of data traffic, and many operators believe that

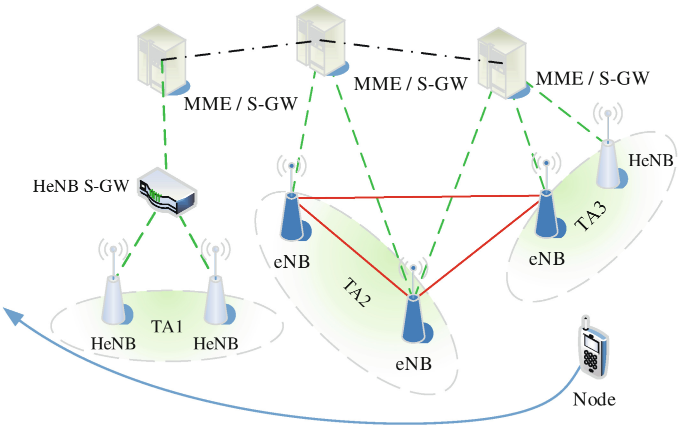

Fig. 2. Diagram of tracking area configuration.

mobile data is a good way to bypass the efficient use of radio spectrum resources. Data distribution is an important component that many operators take seriously. Small cells are an effective way to manage LTE -A spectrum instead of just using the macrocell. Small cells can be used both indoors and outdoors. Mobile operators is eager to extend the use of small cell cover range and improve the network capacity. In hot-spot areas, mobile operators can offload 80 % of the traffic. The report predicts that by 2015, 48% of mobile data traffic is streaming out from the macrocell. No single technology can rule the data distribution. It also believes that operators can discover new profit by small cell growth. When the registered user enters a femtocell zone, the network can learn the location information. With the obtaining permission, the location information can be updated immediately to social networks.

4G LTE networks defines the traditional method of location management as TA, which has its own identity called tracking area identity (TAI). One TA without overlapping is comprised of a group of continuous base stations. In each TA, the core network of LTE sends the paging request (PR) to idle users while the calling arrives, and the mobility management entity (MME) is responsible for location updating (LU) while the users move out of the TA. Consequently, the upper bound of TA is limited by the maximum paging load that the MME supports, and the lower bound is determined by signaling overheads that the users go across the TAs. The basic principles of TA planning are to balance PR load and LU signaling overhead, which are namely unique frequencies, MME, continuous areas, and topography oriented. The principle can avoid the channel congestion of PR, while reducing the LU signaling overhead. As shown in Fig. 2, the Femtocells in the same area may belong to different MME. If the Femtocell and eNB are considered as single TA, the backhaul bandwidth is a limitation of the fast transmission of paging signalling. Moreover, if the coexisted Femtocells are considered as single TA, the limited coverage of this TA may cause

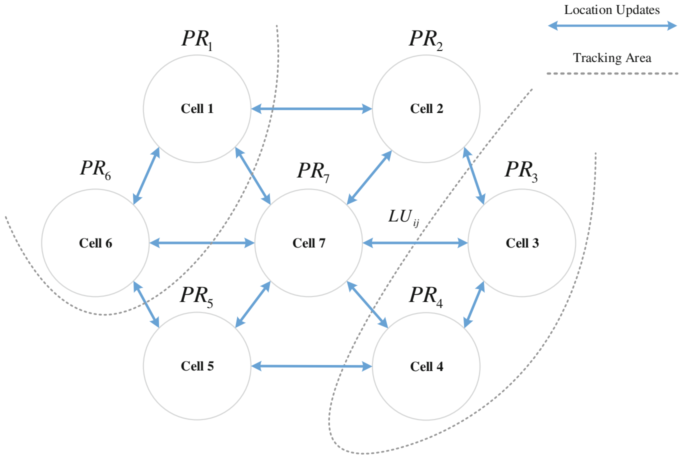

Fig. 3. TA planning as a graph modeling.

massive location updating signalling due to the frequent moving out of the TA. Therefore, the conventional TA replanning is not quite appropriate for HetSNets. The application of the corresponding location area concept, this area is called tracking area location. EPC for the UE is an idle state and connection status, and have their registered TA management, exchanging the registration information of the UE. EPC also deals with TA changed. Tracking area update (TAU) can tell EPC that UE is available, or handover between cellulars. Tracking area identity (TAI) is not in the list of UE. When TA is engaged in registration, it is necessary to perform TAU process.

Figure 3 shows a graph model $G(V, E)$ of TA planning, whose vertices V and edges E represent the base stations and adjacency of networks, respectively. The weight of vertex PR_i is the number of paging request in cell i, and the weight of edge LU_{ij} is the number of idle users, who move from cell i to cell j. We define n partitions of $G(V, E)$ as $G_1, G_2, \cdots G_n$, therefore, the optimal TA planning can be modeled as

$$\text{Min} \sum_{(i,j)\in(V_1,\cdots,V_n)} LU_{ij} \tag{1}$$

$$\text{s.t.} \sum_{i\in V_k} PR_i \le C_{\max} \quad \forall k = 1:n \tag{2}$$

where C_{max} is the capacity of the paging channel. In the following section, the solution of this problem is discussed.

3 Proposed TA Planning Algorithm Based on Cooperative Game

Before the cooperative game is introduced to solve the classical graph model presented in the previous section, we need to transform the expression of $G(V, E)$.

For all $LU_{ij} \geq 1$ and $LU_{ij} \in \mathbf{Z}$, expand $G(V,E)$ to $G'(V,E)$ via generating LU_{ij} vertices of v_i and v_j themselves, and making the new v'_i and v'_j connected. Namely, the original graph is extended by self-replicating based on value of LU_{ij}. Therefore, the new graph can be obtained by $G(V,E) = G'(V,E)$.

For the new $G(V,E)$, if v_i and v_j $(i,j \in N)$ have connections, we define $e_{ij} = 1$, or $e_{ij} = 0$. Therefore, the community detection model based on cooperative game can be expressed by $\mathrm{CG} = (N, \mathrm{Eigen})$, shown as

$$\mathrm{Eigen}\,(S) = \begin{cases} 0 & S \subseteq N, |S| = 1, or, S = \varPhi \\ \sum\limits_{i \in S} \sum\limits_{j \in S, j \neq 1} \frac{e_{ij}}{d(i)} & S \subseteq N, |S| \geq 2, d\,(i) \neq 0 \end{cases} \tag{3}$$

where $d\,(i) = \sum\limits_{j \in N} e_{ij}$ is the degree of v_i and $\mathrm{Eigen}(S)$ represents the benefit corresponding to the sum value of all edges [17]. So the Shapley value SH_{Eigen} can be calculated as

$$SH_{\mathrm{Eigen}}\,(S,i) = SH_{\mathrm{Eigen}}\,(S_1,i) + \frac{1}{2} \sum_{j \in S_2} \left(\frac{e_{ij}}{d\,(i)} + \frac{e_{ji}}{d\,(j)} \right), i \in S_1 \tag{4}$$

$$SH_{\mathrm{Eigen}}\,(S,j) = SH_{\mathrm{Eigen}}\,(S_2,j) + \frac{1}{2} \sum_{i \in S_1} \left(\frac{e_{ij}}{d\,(i)} + \frac{e_{ji}}{d\,(j)} \right), j \in S_2 \tag{5}$$

where $\forall S_1, S_2 \subseteq N$, $S = S_1 + S_2$. The detailed solution algorithm is shown as below:

Algorithm 1. CG procedure

```
get the network vertices $N = 1, 2, \cdots, n$
get the network edges $E = (e_{ij})_{n \times n}, i, j \in N$
suppose the level number $l = 1$
suppose the set of coalitions $S^l = \{\varPhi\}$
for $i = 1$ to $n$ do
    get the $i$th coalition from $S^l$ $S^l_i = \{i\}$, $S^l = S^l \cup \{S^l_i\}$
end for
while $|S^l| > 1$ do
    $l = l + 1$
    for all $x \in S^{l-1}_i$ such that $S^{l-1}_j, S^{l-1}_k \in S^{l-1}, j \neq k$, or $S^{l-1}_k = \varPhi$ do
        if $SH_e\left(S^{l-1}_i \cup S^{l-1}_j, x\right) \geq SH_e\left(S^{l-1}_i \cup S^{l-1}_k, x\right)$ then
            $S_r = S^{l-1}_i \cup S^{l-1}_j$
            $S^l = S^{l-1} - \{S^{l-1}_i\} - \{S^{l-1}_j\}$
            $S^l = S^l + \{S_r\}$
        end if
    end for
end while
get communities from $S^{l'}$
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4 Performance Evaluation

For definiteness and without loss of generality, this paper considers a two-tier HetSNet, which is comprised of macrocell and femtocell operated with open access [18]. Additionally, macrocell is modeled as a hexagonal with three sectors depending on the carrier's deployment. Femtocell is assumed for a random distribution that follows a Poisson Point Process (PPP) based on stochastic geometry theory [19]. The SINR layout in the integration of macro cells and small cells is shown in Fig. 4.

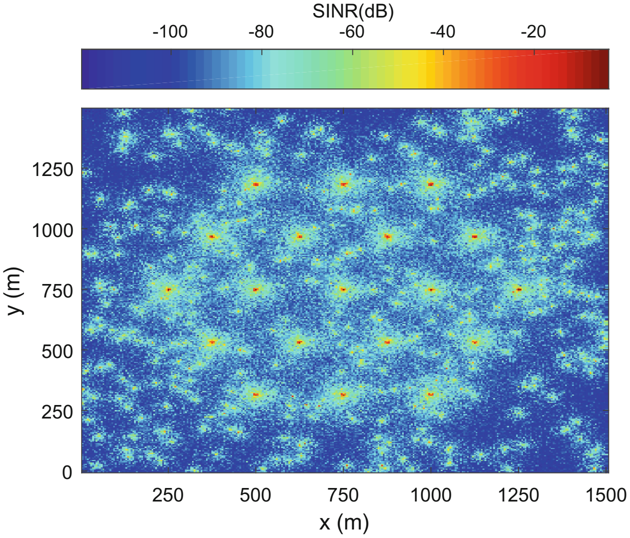

Fig. 4. SINR layout in the integration of macro cells and small cells.

According to 3GPP, the particular simulation parameters are summarised in Table 1. For the traffic type, the calling arrival rate λ is subject to a homogeneous Poisson process, and the mean holding time is 90 ms. For the mobility model, this paper introduces a opportunistic one that represents the human motion features in hot-spot area [20]. To illustrate the advantage of the proposed algorithm, two representative methods [14,15] are introduced as comparisons, which are short for TORIL 2013 and YU 2013 respectively.

The performance metric of TA planning is the total signalling overhead C_{total}, which is calculated by the sum of TA updating and PR, shown as

$$C_{\text{total}} = p\left\{\text{paging}\right\} \cdot \bar{N}_{\text{cells}} \cdot c_{\text{p}} + p\left\{\text{TAU}\right\} \cdot c_{\text{tau}} \tag{6}$$

where $p\left\{\text{paging}\right\}$ is the arriving rate of paging in one time slot, $\bar{N}_{\text{cells}}$ is the average number of cells in the TA list, c_p is the signalling overhead of every

Table 1. Simulation parameters

Parameter	Value
Carrier frequency/system bandwidth	2.0 (GHz)/10 (MHz)
UE distribution/speed	Uniform/30 (km/h)
Channel model	Typical urban (6 rays)
Transmit power of macro/femto	46 (dBm)/20 (dBm)
Path loss model (Macro)	128.1 + 37.6log10(R) (dB)
Path loss model (Femto)	127 + 30log10(R) (dB)
Shadowing standard deviation	Macro 8 (dB), Femto 4 (dB)
Macro/femto antenna gain	14 (dBi)/5 (dBi)
Macro/femto noise figure	5 (dB)/8 (dB)
A3 offset/TTT	3 (dB)/160 (ms)
Handover decision delay	50 (ms)
Handover execution time	40 (ms)

paging operation, and $p\{\text{TAU}\}$ is the probability of TA updating with the cost of c_{tau}. Generally, we make $\lambda = p\{\text{paging}\} = 0.05$, $c_{\text{tau}} = 10 \cdot c_p$.

Figure 5 shows the normalized signaling cost with various rate of femtocelll residence. Due to hyper dense deployments of femtocells in the given circumstance, the probability grows slowly as the increasing rate of femtocelll residence. It is clear that the method (YU 2013) via forcing the user to attach the macrocell as much as possible demonstrates the best signaling cost performance, and the proposed algorithm with cooperative game shows a better performance compared to TORIL 2013.

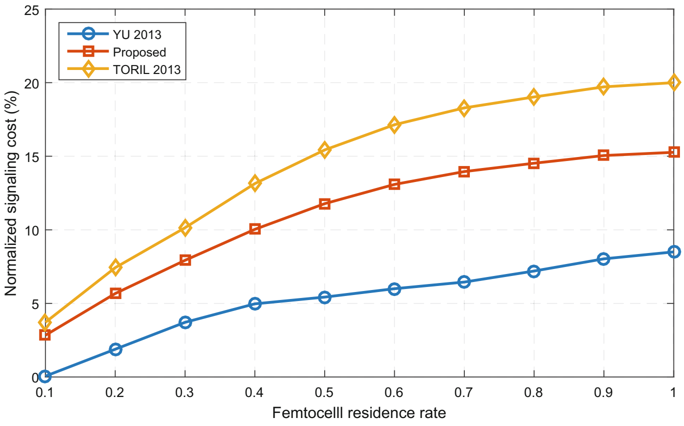

Fig. 5. The normalized signalling overhead with various rate of femtocelll residence.

The deployment of small cells is to improve the transmissions rate and offload the traffic from macrocells in hot-spots, so it is beneficial for users to attach small cells as much as possible. $p(k)$ is defined as the access probability to femtocells, where k is the sample time. The utilization of femtocells can be expressed as

$$U_{\text{small-cell}} = \sum_{k=1}^{n} P\left[k\right] \left(\sum_{j=1}^{k} p\left[j\right]/k \right) \tag{7}$$

where n is the sample time when the user is out of service by femtocells.

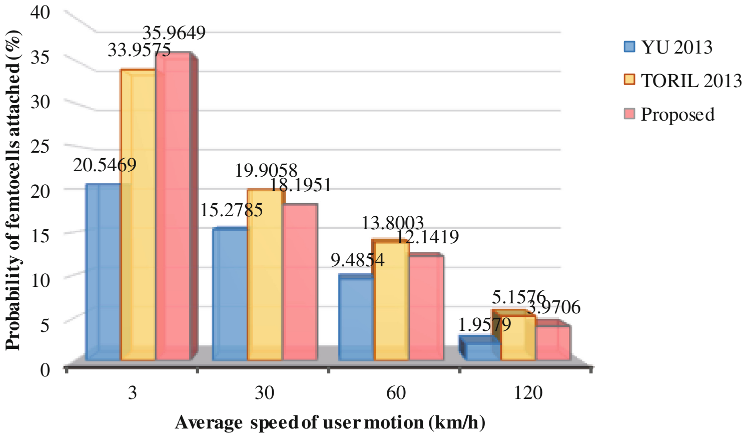

Fig. 6. Probability of femtocells attached with various speed of user motions.

Figure 6 describes probability of femtocells attached with various speed of user motions. Obviously, as the increasing of average speed, the utilization rate of femtocells is reducing, since the handover decision shall guarantee a specific successful access to networks for limited coverage of femtocells. Due to forcing the user to stay in macrocells as long as possible, YU 2013 has a lowest probability of femtocells attachment. In contrast to YU 2013, the proposed algorithm and TORIL 2013 have a better utilizing performance of femtocells. Meanwhile, the two methods perform quite close, which results from the optimal springboard of TA planning.

5 Conclusion

In this paper, a TA planning method based on cooperative game was proposed to reduce the signalling overhead of location management in HetSNets. After self replication of vertices and edges based on the paging requests and location updates, the modeled graph will be classified into new communities, which represent a planning of TA. Simulation results showed that the proposed algorithm reduces the signalling overhead while maintaining the utilization proportion of femtocells. In the future, the proposed method will be performed a detailed analysis on human mobility features that affect TA planning in various deployment scenarios.

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