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User Association and Base Station Sleep Management in Dense Heterogeneous Cellular Networks

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Abstract

Dense Heterogeneous Cellular Networks(HCNs) offer a promising approach to meet the target of 1000x increase in aggregate data rates in 5G wireless communication systems. However how to best utilize the available radio resources at densely deployed small cells remains an open problem as those small cells are typically unplanned. In this paper we focus on balancing loads across macro cells and small cells by offloading users to small cells, as well as dynamically switching off underutilized small cells. We propose a joint user association and base station(BS) sleep mangement(UA-BSM) scheme that proactively offloads users to a fraction of the densely deployed small cells. We propose a heuristic algorithm that iteratively solves the user association problem and puts BSs with low loads into sleep. An interference relation matrix(IRM) is constructed to help us identify the candidate BSs that can be put into sleep. User associations are then aggregated to selected small cells that remain active. Simulation results show that our proposed approach achieves load balancing across macro and small cells and reduces the number of active BSs. Numerical results show user signal to interference ratio(SINR) can be improved by small cell sleep control.

Keywords: heterogeneous networks, load balancing, user association, BS sleep operation

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1. Introduction

Heterogeneous cellular networks(HCNs) have been prosposed as a promising solution to cope with the explosive growth of mobile devices and data traffic. In HCNs, low power low cost small cell base stations(SCBSs),e.g. picocells, femtocells, are introduced into the coverage area of macro cells. HCNs can significantly boost network capacity by providing more radio resourses and allowing more aggressive frequency reuse[1]. HCNs with densely deployed small cells are envisioned as key technologies to achieve the 1000x increase in network capacity for future 5G wireless communication systems[2]. This continuing cellular paradigm shift towards heterogeneity, along with the coexistence of other radio acess technologies such as Wi-Fi, zigbee, device-to-device communications, etc., call for a converging solution for heterogeneous mobile networks in order to offer seamless connectivities and reliable quality of experiences(QoE) for mobile users[3]. The heterogeneous wireless architecture also brings benefits to cloud radio access networks(C-RAN), where computational loads can be shifted to mobile computing clouds so that the overall network capacity can be further increased[4].

Contrary to macro cells, small cells are not operated by network operators and their deployments are typically unplanned[5]. Their locations might be random and they can operate at the same frequency band with macro cells, resulting in uncoordinated interference with macro cells and between neighbouring small cells. Indeed, self-organizing mechanisms must be developed to fulfill the potential performance gains. In a dense HCN, how to best utilize the available resources at a large number of small cells becomes a key problem. Clearly we should offload more users to small cells in order to utilize these resources. The traditional user assocation scheme that assign users to a serving BS with highest received power does not work well under such scenarios due to the massive difference in transmission power between small cells and macro cells. Thus a user association policy that can proactively offload users to small cell must be developed. However,even with proactive offloading most of these densely deployed small cells only serve a few users due to their relatively small coverage area,while the aggregate interference from these small cells can not be overlooked. As traffic fluctuate over time, it is desirable that we can put some small cells into sleep mode which reduce energy consumptions and interference to nearby users associated with other cells as well. Hence users should be offloaded to a selected subset of deployed small cells and the remaining idle BSs should be put into sleep mode. We note that user offloading and BS sleep management are highly coupled with each other : user association policies determine which BSs can be put into sleep mode, while BS sleep management determines the available active BSs that users can be offloaded to.

There have been a number of research on the user association problem in the context of HCN. A comprehensive overview of popular approaches is presented in [6]. Of interest in this paper are user association problem formulations that maximize system utilities. Corroy *et al.* [7] propose a user association scheme that maximize network sum rates. Sun *et al.* [8] propose a user association rule that promote max min fairness among users. Ye *et al.* [9] propose a proportional fairness utility maximization framework that is shown to achieve load balancing among different tiers of BSs. The formulated combinatorial optimization problem is relaxed into a convex one. The user association scheme is obtained by rounding the solution. Furthermore, a primal-dual approach is proposed in [9, 10] to solve the utility maximization problem in a distributed manner. Wildman *et al.*[11] propose a utility maximization problem formulation that minimize nework sum delay. However none of these works considers BS sleep management. On the other hand, Many of the research work on BS sleep operations and on-off control focus on optimizing energy efficiencies. The authors in [12,13] discuss the BS operation and user association in single tier cellular nework. Their appoach are designed for macro cells and are not directly appilicable to HCNs. Kim *et al.* [14] study the BS on/off operation and user association in heterogeneous networks composed of cellular networks and wireless local area networks(WLAN). BSs are opportunistically switched off and users are offloaded to WLAN access points. Cao *et al.*[15]analyze the optimal small cell density that optimizes system energy efficiencies in two tier HCNs. However such method does not specify the sleep operation for each SCBS in a given HCN configuration. Cho *et al.*[16] propose a repulsive cell activation mechasim which set a minimum seperation distance between BSs. However it is difficult to determine the minimum seperation distance for a given HCN configuration. Peng *et al.* [17] propose joint optimizing BS density and transmission power to minimize network energy consumption under coverage constraint. Vereecken *et al.*[18] propose a heuristic algorithm to turn off a fraction of small cells with the priori knowledge on the locations of BSs and users. Although these works show that dynamic BS sleeping schemes can improve network energy efficiencies, they do not consider proactive user association approaches. A recent work [19] studies the joint decision of BS operation and user association with the intention of enchancing energy efficiency and load balancing is not a primary concern.

In this paper we propose a joint user association and BS sleep management(UA-BSM) scheme that maximize the network wide proportional fairness utilities. Through the utility maximization framework, we intend to offload users to small cells and achieve load balancing across macro and small cell. Meanwhile, we intend to associate offloaded users with a fraction of the densely deployed small cells and put those BSs with empty or low loads into sleep mode to reduce intercell interference and energy consumptions. Due to the combinatorial nature of the formulated problem, we decompose the optimization problem into a user association(UA) subproblem and a BS sleep control subproblem. Then we develop a heuristic algorithm to shut down BSs with low loads individually and solve the UA subproblem iteratively. Simulation results validate the effectiveness of our scheme.

The rest of this paper is organized as follows. In Section 2, we present our system model. The joint optimization problem is formulated and the UA-BSM scheme is proposed in Section 3. Numerial results are presented in Section 4 and Section 5 concludes the paper..

2. System Model

We consider a two tier downlink HCN in which a number of small cells are overlaid with a macro cell within a finite Euclidean plane,as illstrated in **Fig. 1**. There are N users and $M-1$ small cells. Each user and each BS is equipped with a single antenna. Let $U=\{1,2,...,N\}$ denote the index set of users and $B=\{2,3,...,M\}$ denote the index set of SCBSs. Let $B_M=\{1\}$ denote the index of the macro cell BS. Both users and SCBSs are randomly and independently distributed across the macro cell coverage area.

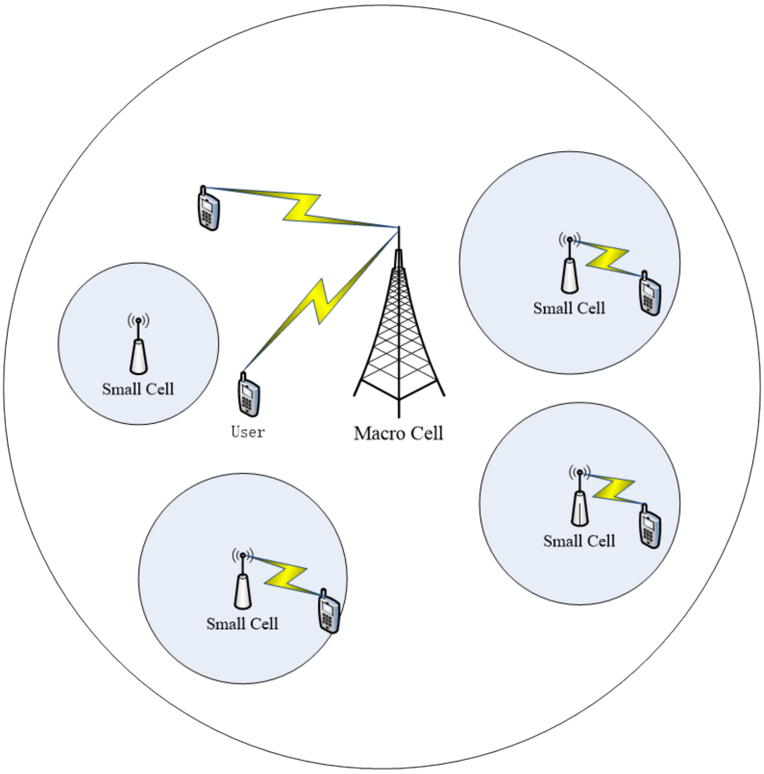


Fig. 1. A two tier Heterogeneous Cellular Network(HCN)

We assume there are two kinds of operational modes for every SCBS . In the active mode, a BS $j \in B$ keeps its transmission power at a maximum and constant value, $P_j^{\max}$. In the sleep mode, a BS $j \in B$ keeps its transmission power at zero in order to reduce interference to neighbouring BSs. We further assume that the macro BS(MBS) is always in the active mode to provide coverage for users not associated with SCBSs. We use a binary vector $z = \{z_1, z_2, ..., z_M\}$ to denote the active-sleep status of all BSs. $z_j = 1, j \in B$ indicates BS j is active, otherwise $z_j = 0$. For a user $i \in U$, the received signal power from BS j is expressed as $z_j P_j^{\max} h_{ij} d_{ij}^{-\alpha}$, where d_{ij} is the distance between user i and BS j, $\alpha > 2$ is the path loss factor and $h_{ij} \sim \exp(1)$ denotes the random channel gains. System bandwidth is W Hz and universal frequency reuse is assumed. Hence the signal to noise plus interference ratio(SINR) for user i served by BS j is given by

$$SINR_{ij}(z) = \frac{z_j P_j^{\max} h_{ij} d_{ij}^{-\alpha}}{\sum_{k \in B \cup B_M \setminus \{j\}} z_k P_k^{\max} h_{ik} d_{ik}^{-\alpha} + \sigma^2} \tag{1}$$

where σ^2 is the thermal noise power. Accordingly, the expected spectral efficiency for user i served by BS j is written as

$$S_{ij}(z) = \log_2(1 + SINR_{ij}(z)) \tag{2}$$

We define a binary matix X whose element $x_{ij}, i \in U, j \in B$ denotes the user-BS association. If user i is associated with BS j then $x_{ij} = 1$. Otherwise $x_{ij} = 0$. We assume that each BS equally allocates radio resourses to its users. Hence the data rate of user i at cell j is given by

$$R_{ij}(x,z) = \frac{W}{\sum_{i \in U} x_{ij}} \log_2(1 + SINR_{ij}(z)) \tag{3}$$

Each user must be associated with exactly one serving BS. Hence $\sum_{j \in B} x_{ij} = 1, \forall i \in U$. Furthermore, if a BS is in sleep mode, it will not serve any user. The coupling relation between user association and BS sleep operation indicates that $z_j = 1\left\{\sum_{i \in U} x_{ij} > 0\right\}, \forall j \in B$.

3. Problem Formulation

In order to proactively offload users to small cells, we adopt the proportional fairness utility maximization framework in [9,10], which maximizes the sum log utilities of user rates. With BS sleep control, the utility maximization problem is formulated as

$$\max_{x,z} \sum_{i \in U} \sum_{j \in B \cup B_M} x_{ij} \log\left(\frac{W}{\sum_{i \in U} x_{ij}} \log_2(1 + SINR_{ij}(z))\right) \tag{4}$$

$$\text{s.t.} \quad \sum_{j \in B \cup B_M} x_{ij} = 1 \tag{5}$$

$$x_{ij} \in \{0,1\} \tag{6}$$

$$z_j = 1\left\{\sum_{i \in U} x_{ij} > 0\right\} \tag{7}$$

The utility maximization problem (4-7) is a joint UA-BSM optimization problem. Unfortunately, it is hard to solve as both the sets of $\{x_{ij}\}$ and $\{z_j\}$ are discrete variables and the coupling constraints (7) is not convex. To solve the joint UA-BSM optimization problem, we decompose it into a UA subproblem and a BSM subproblem. We define $B^{sleep} = \{j \mid z_j = 0, j \in B\}$ as the set of SCBSs in sleep mode. Accordingly we define $B^{active} = B \setminus B^{sleep}$ as the set of active SCBSs. We propose a heuristic algorithm that iteratively solves the UA subproblem and updates B^{sleep}. At each iteration, given B^{active} we solve the UA subproblem first. Then we update B^{sleep} based on the solution of the UA subproblem. We devise several criteria for updating B^{sleep}.

3.1 The UA subproblem

When B^{active} is given, the UA subproblem can be formulated as

$$\max_{x} \sum_{i\in U} \sum_{j\in B^{active}\cup B_M} x_{ij} \log\left(\frac{W}{\sum_{i\in U} x_{ij}} \log_2(1+SINR_{ij})\right) \quad \text{s.t. } (5)\text{-}(6) \tag{8}$$

The optimization problem (8) is a combinatorial optimization problem over user association and its objective function is a proportional fairness utility with respect to user rates[9]. The optimal solution to (8) promotes fairness in terms of user rates among HCN users. Such a problem formulation then encourages users with low rates (e.g. cell edge users with low SINRs) to seek more resources from BSs, thus encourages these users to associate themselves with small cells which are less congested than the macro cells and offers more radio resources. Hence more users are offloaded to small cells compared with the max SINR scheme.

Ref.[9] proposes a fraction-rouding approach to solve the combinatorial optimization problem (8). The UA subproblem (8) can be converted into a convex optimization problem by relaxing x_{ij} to a continuous variable that satisfies $0 \le x_{ij} \le 1$. The resulting convex optimization problem can be readily solved by standard optimization tools. To get a feasible solution to the UA subproblem (8), the solution obtained from solving the convex optimization problem can be rounded

$$x_{ij} = \begin{cases} 1, \; j = \arg\max_j x_{ij} \\ 0, \; j \ne \arg\max_j x_{ij} \end{cases} \tag{9}$$

We note that the relaxed convex optimization problem can be solved in a centralized manner using a centralized controller(e.g.at the macro cell), however this central entity needs to collect information such as per link channel quality from users. In large sized HCNs this approach may require excessively amount of signaling. However, the relaxed convex optimization problem can be solved in the dual domain via Lagrangian dual decomposition and gradient descend method and Ref. [9] proposes a distributed algorithm that solves the decomposed subproblems at user side and BS side separately. The amount of information exchanged between users and BSs is significantly reduced compared with the centralized approach and the distributed algorithm can be applied to large sized HCN scenarios.

The UA solutions to (8) promote load balancing between macro cells and small cells because log utilities offer diminishing returns and users are encouraged to choose SCBSs as their serving BSs [9, 10].

In **Fig. 2**, we illustrate the user associations in a dense HCN with 100 users and 50 small cells. The solution is obtained by assuming $B^{active} = B$ and solving (8). SCBSs are randomly placed across the HCN area. Each small cell is characterized as a voronoi cell by constructing a voronoi tessellation [20]. It can be seen from **Fig. 2** that as more users are offloaded to small cells, it is highly likely that some SCBSs serve only a few users, even one user. There are also some SCBSs with empty association set. Therefore it is desirable that we aggregate user associations to a fraction of the deployed small cells and put more SCBSs into sleep so as to reduce the energy consumption.

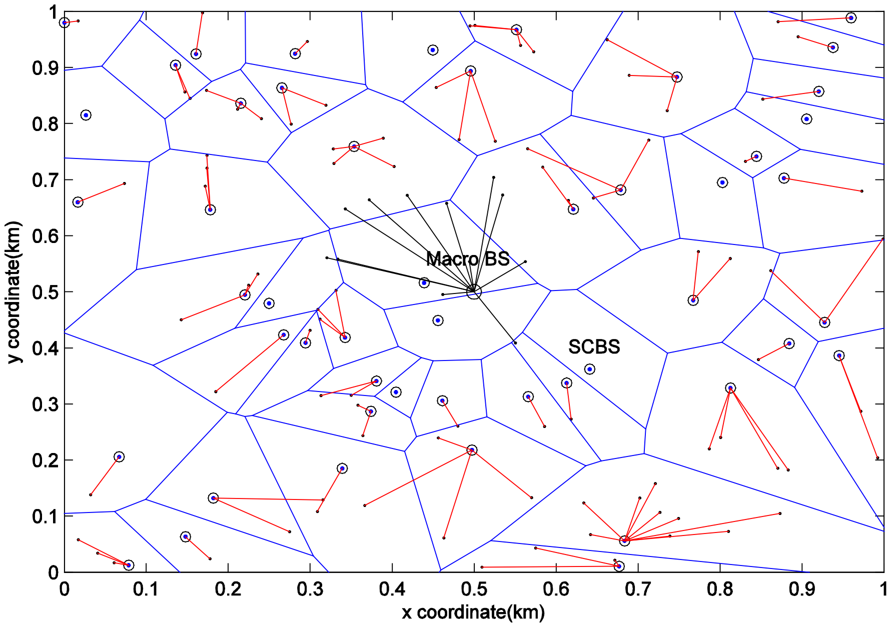


Fig. 2. User associations in log utility maximization scheme in a HCN consisting of 100 users, 50 SCBSs and one MBS. Black lines represent user associations with the macro BS. Red lines represent user associations with the SCBSs. Blue lines represent the Voronoi tessellation boundaries of the active small cells.

3.2 The BSM Subproblem

In this section we focus on selecting appropriate SCBSs to put into sleep mode and updating B^{active}. Intuitively, for any subset $B^{active} \subseteq B$ we can solve (8) separately and we can adopt a brutal force search method to find the best B^{active} that maximizes the utility function. However such method requires us to repeatedly solve the UA subproblem for $O(2^{M-1})$ times, hence it is intractable for a dense HCN with a large number of small cells. Instead we suggest a heuristic approach to determine B^{active} and B^{sleep}. Initially we set $B^{active} = B$ and solve the corresponding UA problem (8). From the user associations we obtain the information on loads of each BS, $\sum_{i \in U} x_{ij}$.

Next we set our criteria to put candidate SCBSs into sleep. Our establishment is that fully utilized SCBSs with multiple associated users should remain active. It means that we prefer putting SCBSs with low loads into sleep mode. It can be seen form **Fig. 2** that there are many SCBSs which serve only one user, even no users at all. Therefore our objective is to put those SCBSs with low loads into sleep mode, whose loads satisfy $\sum_{i \in U} x_{ij} \le 1$. To this end, a list of candidate SCBSs is constructed

$$\overline{B} = \{ j \mid \sum_{i \in U} x_{ij} \le 1, j \in B \} \tag{10}$$

which is then sorted in an ascending order based on BS loads.

Note that if we put any SCBS into sleep mode, the received SINRs at its nearby users are altered. Hence we propose a heuristic algorithm. At each iteration, with the current set of active SCBSs the algorithm calculates SINRs for all users and solve the UA subproblem. Then the algorithm constructs the list of candidate SCBSs according to (10) and chooses one SCBS from the top of the list $\overline{B}$ and put this SCBS into sleep.When all SCBS with empty loads are put into sleep, it proceeds to choose SCBSs which serve one user. However, when a SCBS is put into sleep, its associated user will be handed over to another BS. When there is no nearby SCBS for this user, it will be handed over to a SCBS far away and suffer from a degradation in SINR, or it will be handed over back to the MBS. In both cases, this SCBS should remain active to avoid sacrificing the QoS performance of its associated user or affecting the load balance between small cells and the macro cell.

Hence we summarize our criteria for candidate SCBSs that are considered eligible for sleep operation :

(1) Each candidate SCBS is associated with empty user sets or serves only one user in current iteration.
(2) For candidate SCBSs with one associated user, they are prioritized in terms of intercell interference with users of other small cells. We prefer shutting down the SCBS that causes the highest intercell interference to users of other small cells.
(3) The candidate SCBS with one associated user is put to sleep only if its served user can find a nearby SCBS as a replacement as its serving BS.

To this end, we construct a $N \times M$ matrix I whose element is written as

$$I_{ij} = \begin{cases} 1, \text{ if } P_j^{\max} h_{ij} d_{ij}^{-\alpha} \geq \varepsilon P_k^{\max} h_{ik} d_{ik}^{-\alpha}, j \neq k, k = \{k \mid x_{ik} = 1\}, j, k \in B \\ \qquad 0, \qquad \text{otherwise} \end{cases} \tag{11}$$

where $0 < \varepsilon \leq 1$ is a constant.

We refer to matrix I as the Interference Relation Matrix (IRM). It can be seen from (11) that for a user $i \in U$, I_{ij} determines whether a SCBS j is a potential interferer from which the received signal power is at least a fraction of the received signal power from the serving BS. Moreover, it also determines the candidate SCBSs that user i can be handed over if its serving BS is put to sleep. The sum over each column of matrix I, denoted as $\sum_{i \in U} I_{ij}$, determines the number of users for which SCBS j is acting as an apparent interferer when serving its lone user. The sum over each row of matrix I, denoted as $\sum_{j \in B} I_{ij}$, determines the number of BSs to which user i can be handed over from its currently serving SCBS without greatly sacrificing its SINR. We can further infer that if $\sum_{i \in U} I_{ij}$ is large for SCBS j then this SCBS is interfering with many users associated with other SCBSs and it is also highly likely that there are some nearby SCBSs. Then shutting down this BS can reduce interferences for multiple users and it is also possible to hand over its served user to nearby SCBSs. If $\sum_{j \in B} I_{ij} = 0$ then it is highly likely that there are no nearby SCBSs for user i and the serving SCBS for user i should remain active.

We now present our UA-BSM algorithm. At the initial stage, we set $B^{active} = B$. At each iteration, we first solve the UA subproblem (8). Then a set of candidate SCBSs $\overline{B}$ is constructed according to (10). The IRM matrix is constructed according to (11). Then the algorithm sort the SCBSs in an ascending order based on their respective loads. Those SCBSs with one associated user are sorted in a descending order based on their respective $\sum_{i\in U} I_{ij}$. The algorithm chooses a BS from the top of the list. If the load of this BS is empty then this BS is put into sleep. If this BS serves only one user then the algorithm checks whether $\sum_{j\in B} I_{ij} > 0$ is satisfied for its served user. If this condition is satisfied then this BS is put to sleep. The iterations end when no BSs from $\overline{B}$ can be put to sleep. The UA-BSM algorithm is described in **Table 1**.

Table 1. The UA-BSM algorithm

```
1: Initialize: $B^{active} \leftarrow B$
2: Do
3:     Computer SINRs for all users. Solve the UA subproblem(8) and obtain the user association solutions $\{x_{ij}\}$.
4:     Construct $\overline{B}$ according to (10) and $I$ according to (11). Set $B^{sleep} = \varnothing$.
5:     Sort $\overline{B}$ in an ascending order based on BS loads and sort those BSs with one served user in a descending order according to $\sum_{i\in U} I_{ij}$.
6:     for each BS $j \in \overline{B}$ do
7:         if $\sum_{i} x_{ij} = 0$
8:             $B^{active} \leftarrow B^{active} \setminus \{j\}$, $B^{sleep} \leftarrow B^{sleep} \bigcup \{j\}$ ,go to step 2
9:         end if
10:        if $\sum_{i} x_{ij} = 1$
11:            if $\sum_{j\in B} I_{ij} > 0$
12:                $B^{active} \leftarrow B^{active} \setminus \{j\}$, $B^{sleep} \leftarrow B^{sleep} \bigcup \{j\}$,go to step 2
13:            end if
14:        end if
15:    end for
16: while $B^{sleep} \neq \varnothing$
17: Output the user association $\{x_{ij}\}$ and the set of active BSs $B^{active}$.
```

3.3 Discussion

The idea presented in this paper is an attempt to jointly consider traffic offloading and BS sleep control in a dense heterogeneous cellular network scenario. Most of the existing research either focus on user association problem that can proactively offload users to small cells, or focus on BS on/off control mechanism that reduces the number of active BS and energy consumption, but few research addresses the joint decision of user association and BS sleep control. We believe that in dense HCN scenarios both problems must be considered in that (1) proactive user association is essential for utilizing the potential performance gains of dense small cells deployment and (2) BS sleep control is also important because it reduces intra-tier intercell interference which constitutes a large part of the overall intercell interference. In dense HCN scenarios, as small cells are densely overlaid with macro cells and users are proactively offloaded to small cells, many SCBSs remains empty or lightly loaded. By adopting the proportional fairness optimization framework, the proposed UA-BSM algorithm aims at offloading more users to small cells. At the same time, the algorithm tries to aggregate user associations to a fraction of the deployed small cells and reduce the numbers of BSs with empty or few associated user sets. In worse cases the algorithm will terminate after $M-1$ iterations since the SCBSs are put to sleep one by one. However the convergence rate in practice is much faster since a SCBS has to meet the proposed requirement to be considered as eligible for sleep operations. The proposed requirement is a mixture of BS loads and interference relations between users and SCBSs. The IRM matrix can be obtained through user feedback. The IRM matrix also brings additional information that help us decide whether a SCBS is suitable for sleep operations. Our approach can work in any given HCN configuration.

4. Numerical Results

In this section, we evaluate the performance of our proposed UA-BSM scheme by carrying out simulations in MATLAB. The simulation parameters are summarized in **Table 2**. Note that we neglect thermal noises since interference dominates noise in a dense HCN.

Table 2. Simulation Parameters

Coverage area	1km^2
Number of small cells	50
Number of users	100
Number of macro cells	1
Macro cell transmission power	46 dBm
Small cell transmission power	20 dBm
Path loss factor	4
Interference threshold ε	0.2

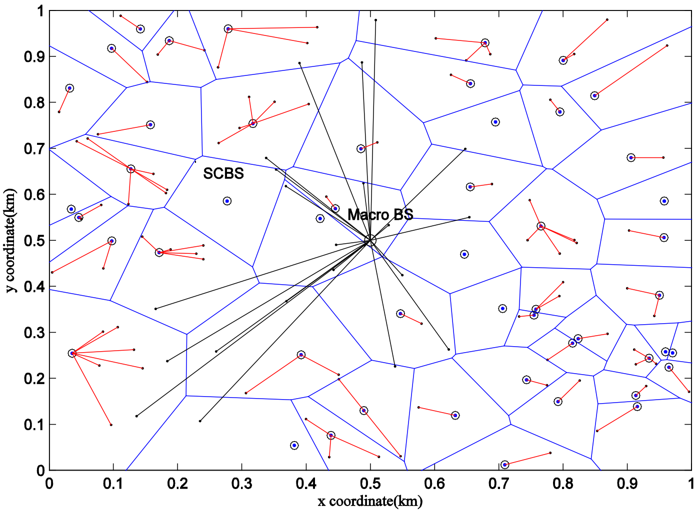
In order to evaluate the performance of the UA-BSM scheme, we consider three user association and BS sleep management strategies as benchmarks:

(1) the baseline max SINR association scheme without BS sleep control, which associates each user with the strongest BS in terms of received signal power;

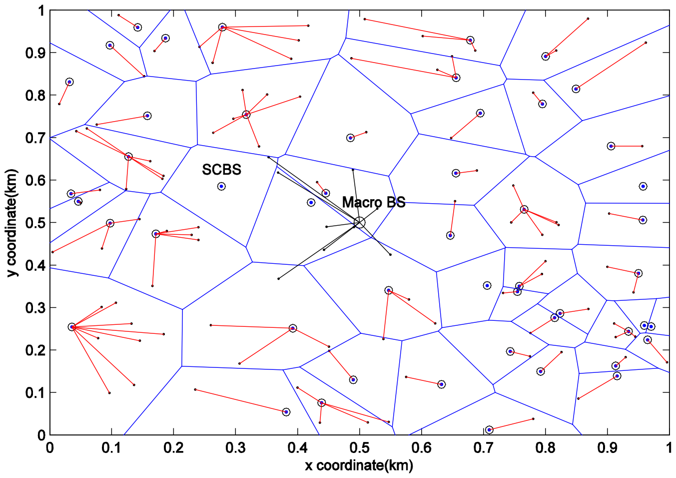
(2) log utility maximization framework without BS sleep control[9], where user associations are derived from the optimal solution to sum log utility maximization problem(8)

(3) heuritic small cells sleep control with the primary goal of reducing the number of active BSs[18], where use association is carried out on a max SINR association basis and each small cell BS is switched on sequentially according to the number of users it can potentially serves and its proximity to those users.

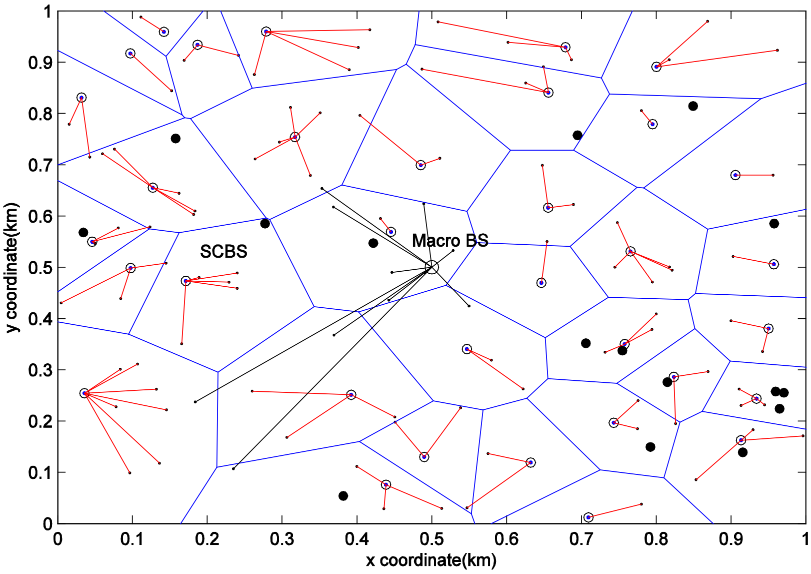
Fig. 3 illustrate user associations in a HCN configuration. **Fig. 3 (a)** depicts the user associations obtained in a max SINR scheme where each user is associated with the strongest BS in terms of received signal power. All BSs remain in active mode. Without proactive user offloading, many users stay connected to the macro cell BS and many SCBSs are underutilized. In **Fig. 3 (b)**, under the log utility maximization framework, more users are offloaded to the SCBSs. However, some of the SCBSs serve only one user and there are still some SCBSs with empty user sets. Due to the geographical randomness, the distances between active SCBSs can be very small. User associations are largely dispersed among SCBSs. In **Fig. 3 (c)**, user associations are more aggregated to a fraction of the SCBSs. Compared with **Fig. 3 (b)**, the UA-BSM scheme puts the SCBSs with empty user sets in the utility maximization scheme into sleep and it puts some of the SCBSs with one served user into sleep as well. The fraction of active SCBSs is significantly reduced. Moreover, the distances between active SCBSs are also enlarged. Note that as the number of active SCBSs is reduced, some of the users previously associated with SCBSs in the utility maximization scheme are now handed over to the macro BS. This phenomenon shows the inherent tradeoff: while adding more active SCBSs increases the chance that a user can find a nearby SCBS as a good replacement for the MBS, switching off SCBSs reduces this possibility. Fig. 3 (d) depicts user associations and BS sleep operation in the heuristic small cells sleep control scheme. Since the intention of the heuristic BS sleep control is to reduce the number of active small cells while providing coverage for users and a max SINR association approach is employed, most of the users stay connected with the macro cell and the load balancing performance of this scheme is even worse than the max SINR scheme with all BS active. This shows that if we only consider BS sleep control and do not proactively offload users to small cells, the benefits of dense small cell deployment cannot be fully utilized.



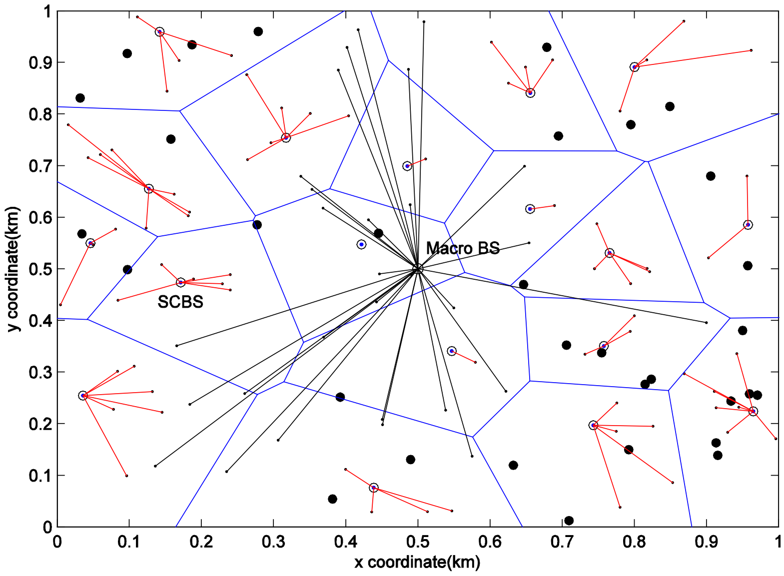
(a) Max SINR association with all SCBSs active



(b) log utility maximization with all SCBSs active



(c) the UA-BSM scheme



(d)heuristic small cell sleep control with max SINR association

Fig. 3. User associations in a HCN configuration. Black lines represent user associations with the macro BS. Red lines represent user associations with the SCBSs. Blue lines represent the Voronoi tessellation boundaries of the active small cells. Dark filled circles represent BSs in sleep mode.

We compare the load balancing performance of different user association and BS sleep control schemes in **Fig. 4**. The number of deployed SCBSs varies from 5 to 50 in a two tier HCN with 100 users. It is clear that both the log utility maximization scheme and the UA-BSM scheme offer more balanced loads between macro tier and small cell tier BSs. In the UA-BSM scheme the portion of macro cell users is slightly higher than the log utility maximization scheme. This result confirms that the UA- BSM scheme achieves a good performance in load balancing. On the other hand, when BS sleep control is carried out without proactive traffic offloading, as the density of small cell increases and more small cells are put into sleep, the percentage of user population associated with the macro cell is significantly higher than the other three scheme and the macro cell is much more congested. In a dense HCN scenario this approach without jointly considering traffic offloading and BS sleep control is suboptimal since it will partly negate the performance gains of dense small cells deployment.

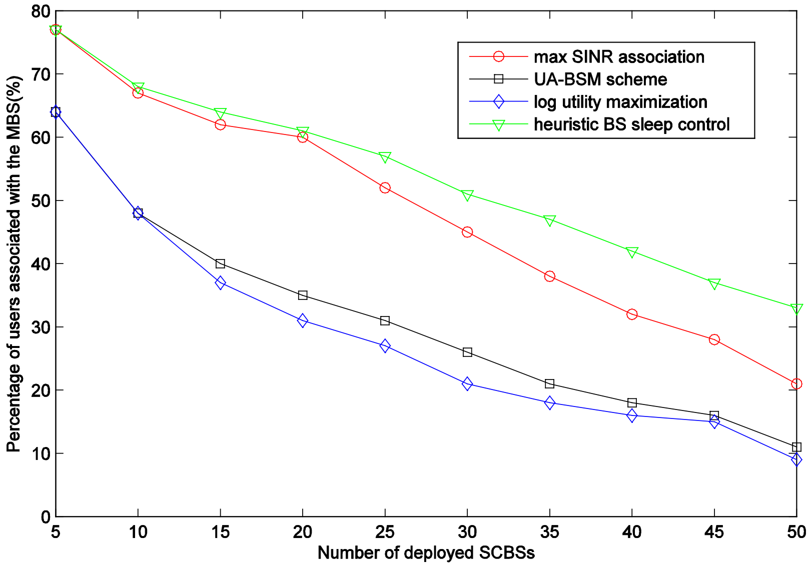


Fig. 4. Percentage of macro cell users versus number of deployed SCBSs

Fig. 5 shows the number of active SCBS versus the number of deployed SCBSs in a two tier HCN with 100 users. When the density of SCBSs is low, the possibility of closing idle SCBS is low because these SCBSs serve quite a few users. However, as the density of SCBSs grows, the number of users served by each SCBS decreases and it is more likely to have some SCBSs whose loads are very low or even empty. Thus those SCBSs can be put to sleep in our UA-BSM scheme. When the number of deployed SCBSs is increased to 50, we can approximately put 40% of the deployed SCBSs into sleep.

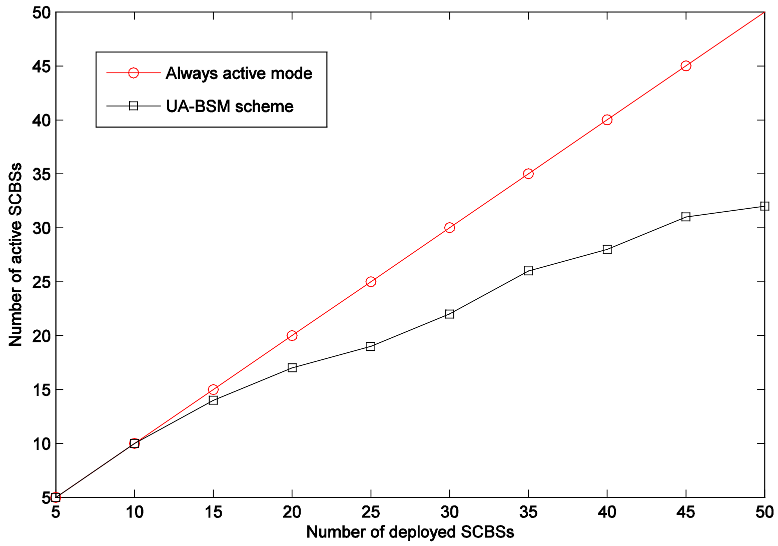


Fig. 5. Number of active SCBSs versus number of deployed SCBSs

Next we show the difference in the number of active SCBSs with nonempty loads for various association schemes in **Fig. 6**. The number of deployed SCBSs is fixed at 50.The number of users varies from 10 to 100. As the number of HCN users increases, the number of active SCBSs with nonempty associated user sets grows rapidly in the log utility maximization scheme. User associations are dispersed among active SCBSs. However, in the UA-BSM scheme it is clear that the number of active SCBSs is much lower because user associations are now aggregated and SCBSs with low loads are put into sleep. This result show that aggregating user association can effectively reduce the number of active SCBSs.

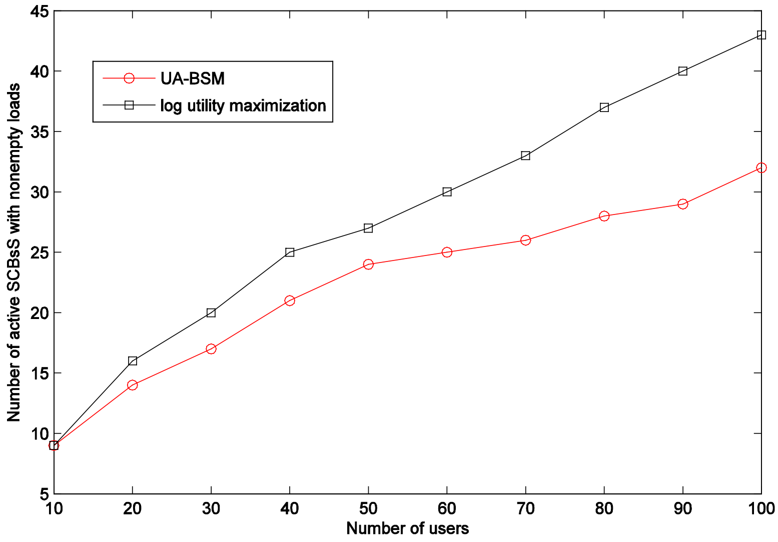


Fig. 6. The number of active SCBSs with nonempty user sets versus the number of HCN users

Fig. 7 shows the cumulative distribution function (CDF) of average received SINRs for HCN users. Compared with the max SINR association, user SINRs deteriorate in the utility maximization scheme. The rationale is that as some macro cell users in the max SINR scheme are now offloaded to small cells, they suffer from strong interference from the MBS. With BS sleep control, there is a remarkable improvement in almost every SINR region and the median of user SINRs is improved at a magnitude close to 3dB. It shows that in dense HCNs the aggregate intercell interference from small cells constitutes a significant portion of the overall interference and BS sleep management can reduce the intercell interference by shutting down nearby SCBSs.

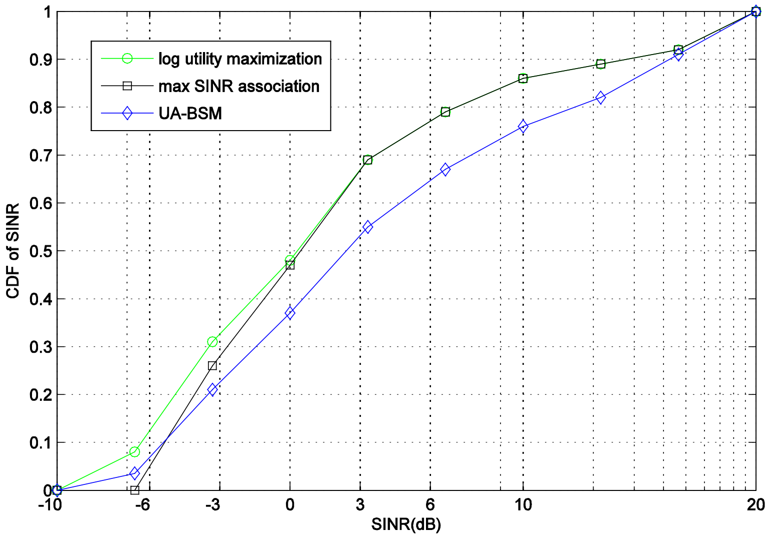


Fig. 7. CDFs of average user SINR

5. Conclusion

In this paper, we investigate the joint decisions of user association and BS sleep operation in a two tier HCN. We propose a UA-BSM scheme that aims at achieving load balancing across different tiers of BSs and switching off the underutilized small cells. A combinatorial joint optimization problem over user association and BS sleep control is formulated. Then we propose a heuristic algorithm that jointly determines the BS sleep operation and user association by exploiting the interference relations between users and adjacent small cells and aggregating user associations to a selected subset of deployed SCBSs. Simulation results confirm the effectiveness of our proposed scheme. Numerical results also show that dynamically switching off small cells improves user SINR.

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