Dynamic Sector Sleeping Schemes for Small Cell Networks

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Abstract—Small cell networks (SCNs) with a dense infrastructure of base stations (BSs) can offer tremendous potentials for high data rate traffic requirements. However, the serious issue of energy consumption is mainly due to base stations while not mobile terminals. In this paper, we focus on reducing the energy consumption of the SCN by adjusting BS sectors' working mode, i.e. active mode or sleep mode. Specifically, we propose two centralized schemes which can dynamically switch off the unnecessary sectors for energy saving and also track traffic variations for real-time adjustment. The schemes consist of two stages, including the switching-off stage and the readjusting stage. They differ in the first-stage switching-off scheme, i.e., a heuristic scheme and a progressive scheme, while have the same second-stage readjusting scheme. Both of the two first-stage schemes rely on a utility function to switch off redundant sectors. Results of simulation analysis demonstrate that the execution time of the progressive switching-off scheme is about one third of that of the heuristic one, which reduces the system overhead significantly. Besides, the progressive scheme can achieve a similar energy saving target while slightly affect the blocking probability.

Index Terms—Small cell network, dynamic sleeping scheme, energy saving, blocking probability.

1 INTRODUCTION

NOWADAYS, people's demand for wireless data service is increasing dramatically and the current mobile communication systems can hardly meet this huge expanding demand. A promising solution to this problem is the concept of small cell network (SCN) with a very dense infrastructure of self-organizing, low-cost and low-power base stations (BSs). On the other hand, the information and communication technology industry is one of the leading sources of worldwide energy consumption and is expected to grow dramatically in the future [1]. This makes energy efficiency a key design target for the current and future cellular networks. Hence it is worthwhile to explore energy saving methods for SCNs [2].

Recent surveys showed that BSs contribute a major portion of the energy consumption of cellular networks. When a BS is in its active mode, the energy consumption of processing circuits and air conditioner takes about 60 percent of the total consumption [3], which means that even there is no user being served, BSs still consume a lot of energy. Therefore, turning BSs into sleep mode whenever possible is considered as a promising technique to reduce energy consumption effectively. In fact, due to traffic variations in the time domain and dynamic distribution among cells [4], it is possible to switch BSs into sleep mode when traffic load in their coverage is low enough.

BS sleeping has been drawing more and more attention in recent years [5], [6], [7], [8], [9]. Ref. [5] suggested to switch off a half of cells at night while guaranteeing a tolerable blocking probability. Ref. [6] proposed a dynamic BS sleeping scheme which was dependent on the distance between the user and the BS. In [7], a switching off planning method was presented to save energy of cellular systems. This method allows the acquisition for the ratio of the deactivated BSs to the remaining active BSs, as well as the switching-off period during which the traffic is low enough without violating a blocking probability limit. Ref. [8] investigated a centralized and a decentralized scheme which dynamically minimized the number of active BSs to track the random traffic variations in both space and time domain. Ref. [9] proposed an algorithm of traffic-aware cell management, where an evolved base station observes and updates its memory, based on which actions are taken from the action set consisting of cell division, cell migration and cell death. However, most of the previous works did not consider the interference among cells or just simplified the interference as a constant value. Due to the dense deployment of BSs, SCN is an interference-limited network. Therefore, more work is expected to explore appropriate BS sleeping schemes for such SCNs.

In this paper, we suppose that each cell is divided into three sectors and each sector can go to sleep independently for energy saving. By taking algorithm complexity and user behavior into consideration, we propose two dynamic schemes to determine the sleeping sectors every a fixed time interval, aiming at tracking the random traffic variations in both space and time domain. The two schemes both consist of two stages, i.e. the switching-off first-stage and the readjusting second-stage. There are two different schemes in the first-stage, i.e. a heuristic way and a progressive way, both of which are carried out in a centralized way to make as many sectors as possible to go to sleep, while the second-stage is mainly designed to re-adjust sectors' working mode in order to reduce the blocking probability. The proposed schemes aim to turn as many sectors as possible into sleep mode for energy saving under a certain blocking probability constraint.

The remaining of the paper is organized as follows. In Section II, we present the system model of the SCN. The proposed dynamic sector sleeping schemes will be given in Section III, followed by a detailed simulation analysis on performance evaluation in Section IV. Finally, we conclude the paper in Section V.

2 SYSTEM MODEL

Suppose that a theoretical homogeneous topology of base stations be in use. A two-dimensional cell arrangement over a rectangular region is shown in Fig. 1, where 10 hexagonal cells exist along each dimension with BSs at the center as in [10]. Consider that there are three 120 degree directional antennas at the center of each cell, and each cell with a side length of $R_b = 200$m is divided into three sectors. To avoid interference caused by neighboring cells, cells are arranged to tile a torus. It is also supposed that each sector can decide its working mode independently.

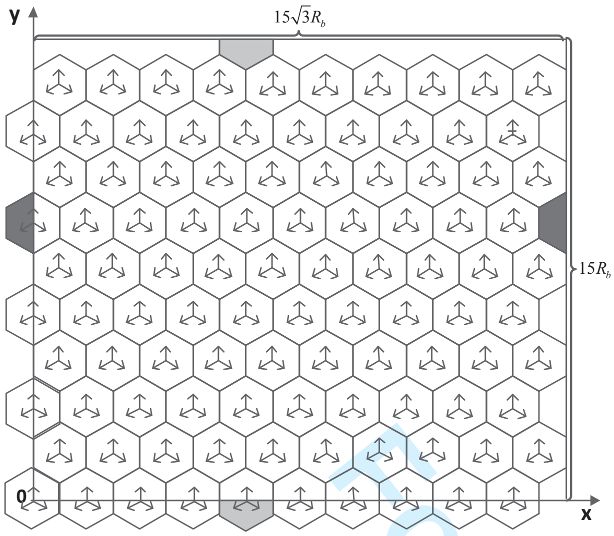

Fig. 1. System layout, where shadowed areas are out of the rectangle but reappear on the other side.

The traffic arrives in the area as a Poisson process with intensity $\lambda(t)$. We assume that the system has statistic traffic information as shown in Fig. 2. The traffic intensity $\lambda(t)$ has a simple sinusoidal shape with period $\mathrm{T} = 24\mathrm{h}$ and remains unchanged in one hour. Assuming that once traffic arrives, a user with a minimum rate requirement is sited uniformly in the rectangular region and remains stationary until the transmission is finished. Note that the designt of SCN aims to meet the potential increasing demand of user rate. Therefore, we define a relatively high minimum user rate demand $r_{min} = 1$ Mbps. The transmission duration of each user follows exponential distribution with mean $1/\mu = 180s$. However, if there is not enough resource to serve a user, the user will be blocked.

In this paper, we assume downlink access scheme is orthogonal frequency division multiple access (OFDMA) which is used for the downlink of LTE systems. Since the available spectrum is divided into resource blocks (RBs) consisting of 12 adjacent subcarriers, in the downlink a LTE terminal can be allocated at least one RB during 1 subframe. Only large-scale fading channel model is considered while small-scale fading is omitted. The subcarriers constituting a single RB are subjected to the same fading and hence channel gain on the subcarriers of a single RB is assumed the same. Additionally, the fading is assumed to be independent and identically distributed across RBs. Let $\mathcal{I}_{RB,k_l}$ be the set of RBs allocated to user k_l in sector l and r_{k_l} be the achievable rate of user k_l. Then the throughput of user k_l is given by

$$r_{k_l} = \sum_{i \in \mathcal{I}_{RB,k_l}} B_{RB} \cdot \log_2(1 + \gamma_{k_l,i,l}) \tag{1}$$

where $B_{RB} = 180\mathrm{KHz}$ is the bandwidth of a RB, $\gamma_{k_l,i,l}$ is the signal to interference plus noise ratio (SINR) of user k_l over RB i in sector l, and can be calculated as follows

$$\gamma_{k_l,i,l} = \frac{P_{i,l} H_{k_l,i,l}}{I_{i,k_l} + \sigma_i^2} \tag{2}$$

where $P_{i,l}$ represents the transmission power on RB i of sector l

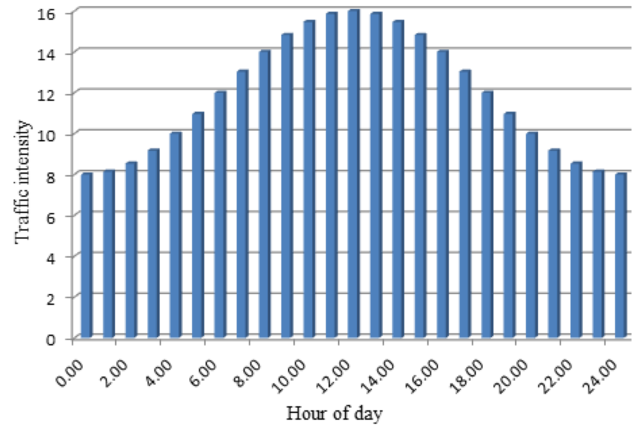

Fig. 2. Average traffic intensity versus time

[1], $H_{k_l,i,l}$ is the useful channel gain, σ_i^2 is the noise power over RB i in the receiver of user k_l, and I_{i,k_l} is the interference on RB i in the receiver of user k_l, which can be given by

$$I_{i,k_l} = \sum_{j=1, j \neq l}^{M} \Big(\sum_{k_j \in \mathcal{U}_j} \alpha_{k_j,i,j} \Big) \cdot P_{i,j} H_{k_l,i,j} \tag{3}$$

where M is the number of sectors with $M = 300$, $\mathcal{U}_j$ is the set of users associated with BS j, and $\alpha_{k_j,i,j} = 1$ if RB i is allocated to user k_j in sector j, i.e. $i \in \mathcal{I}_{RB,k_j}$, otherwise, $\alpha_{k_j,i,j} = 0$. In each cell, a RB can be allocated to a single user at a given time interval. Hence, in arbitrary sector j, we have $\sum_{k_j \in \mathcal{U}_j} \alpha_{k_j,i,j} \leq 1$. In summary, if a sector allocate RB i to a user, then the sector will interfere with the user associated with RB i in sector l. Otherwise, there is no interference between the sector and the user associated with RB i in sector l.

3 The Proposed Dynamic Sector Sleeping Scheme

In this section, a model of system operation is firstly introduced. Then two specific dynamic sector sleep schemes are given, which consist of two stages, i.e. switching off stage and readjusting stage. The first stage of the two schemes differs from each other, while the second stage keeps the same. A dense BS infrastructure indicates that the number of covered users per sector is small, which leads to more random traffic variations among sectors. On the other hand, the traffic of SCNs varies over time. Therefore, it is needed to investigate dynamic sector sleeping schemes for energy saving which make use of the spatial and temporal traffic load fluctuations in SCNs. As the traffic load fluctuates over time, the number of sleeping sectors should track this fluctuation to satisfy users' requirement. Based on this consideration, the traffic period T is divided into N equal time interval τ with N+1 time spot (each with index i) as shown in Fig. 3. At each time spot $t^{(i)}, i = 0, ..., N$, the proposed sector sleeping scheme is carried out to determine all sectors' working mode based on the current system information. Here the scheme execution time is ignored. The proposed scheme takes into consideration the requirements from both current users and new arrivals at the current time spot and guarantee a tolerable blocking probability.

1. In this paper, we consider equal power transmission over RBs.

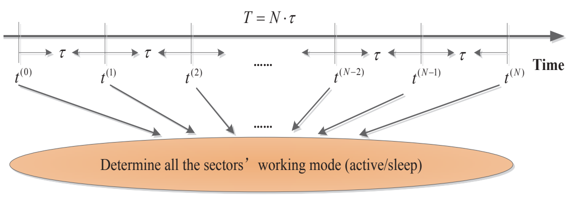

Fig. 3. System operation. Applying two-stage scheme at time spot $t^{(i)}$, and the network keeps a constant stage in each time interval τ.

As some sectors will go into sleeping mode after a set of sleeping sectors is determined, it may lead to coverage holes in the network area and the blocking probability will be out of tolerance. In order to guarantee a tolerable blocking probability, two specific two-stage sector sleeping schemes are designed. The first stage is called switch-off stage, which sets as many sectors as possible to sleep mode for energy saving while guaranteeing users' requirement at the time spot. The second stage is called readjusting stage, which is designed to reduce the blocking probability.

3.1 The First-stage Sector Sleeping Scheme

At each time spot $t(i), i = 0, ..., N$, the first-stage sector sleeping scheme is executed to get a preliminary set of sleeping sectors. The basic idea of this scheme is that sectors with low traffic load and low average associated user rate are likely to go to sleep. In other words, it is desired to turn off sectors which seldom make full use of its resource should go to sleep. A utility function is defined as

$$U_l = \alpha \cdot \frac{L_l}{L_{\max}} + \beta \cdot \frac{\overline{r}_l}{\overline{r}_{\max}} \tag{4}$$

where α and β are weighting factors satisfying $\alpha + \beta = 1$, L_l and $L_{\max}$ are the traffic load of sector l and the largest traffic load among all sectors, respectively, and $\overline{r}_l$ and $\overline{r}_{max}$ are the average transmission rate of users accessing to sector l and the largest average user transmission rate among all sectors, respectively [2]. Specially, $\overline{r}_l$ can be expressed as

$$\overline{r}_l = \frac{\sum\limits_{k_l \in \mathcal{U}_l} r_{k_l}}{|\mathcal{U}_l|} \tag{5}$$

where $|\mathcal{U}_l|$ represents the number of users associated to sector l . From the definition of utility function, it can be seen that the traffic load and the transmission rate are taken into consideration for the sleep-off setting, which seeks a balance between energy saving and network capacity. Particularly, a heuristic sector switch-off scheme and a progressive sector switch-off scheme are proposed in this work. The heuristic sector switch-off scheme based on the above defined utility function is summarized in Algorithm 1. When the algorithm terminates, the preliminary set of sleep sectors, i.e., $\mathcal{B}_{off}$ is derived. The remaining sectors in SCN denoted as $\mathcal{B}_{on}$ is the preliminary set of active sectors.

The above heuristic scheme greedily tests all sectors to be switched off, and thus commendably achieves the energy saving target. In addition, such a greedy approach is straightforward and easy to be implemented. However, the heuristic algorithm needs to traverse all sectors and all users in the network at any traffic condition, and obviously is inefficient. Note that some users can be handed over several times like playing a football till they finally settle. Besides, the complexity of the algorithm is proportional to the number of sectors and users, which will result in considerable network signaling overhead. When the traffic intensity is relatively high, it is almost impossible to switch off some sectors, hence part of the traversal is unnecessary. Based on the utility given in Eq.(4), the probability that a sector with relatively large utility is switched off is smaller than that of a sector with relatively small utility, which is intuitive and can be easily testified through simulation.

2. We define the traffic load as RBs allocated to the associated users normalized by the total RBs.

Algorithm 1 Heuristic Dynamic Switching Off sector

```
Initialize the set of all sectors as 𝓑, and the set of sleeping
  sectors as 𝓑_off = ∅
while 𝓑 ≠ ∅ do
  Calculate the utility function values of sectors in set 𝓑,
  assume s_off as the sector with the minimum utility value
  Try to handover the users of sector s_off to the nearby
  sectors
  if all users of sector s_off can be handed over then
    𝓑_off = 𝓑_off + {s_off}
    Handover users of sector s_off to the nearby sectors,
    update the user association information of the network
    and the SINR of users
  else
    sector s_off remains active and the user association state
    remains the same as before
  end if
  𝓑 = 𝓑 − {s_off}
end while
```

To overcome the shortcoming of the heuristic algorithm, an expeditious and intelligent algorithm is then proposed as shown in Algorithm 2. The algorithm applies the utility function to classify the sectors into two different groups, and then a switch-off process is carried out to set all sectors in the group with relatively small utility to sleep mode. Upon the termination of the switch-off process, the algorithm determines whether to continue to classify the remaining active sectors and execute another switch-off process.

When the algorithm terminates, the sectors of set $\mathcal{D}$ are switched off, and the remaining sectors remain active until the next time spot of reconfiguration.

3.2 The Second-stage Sector Sleeping Scheme

If all sectors in $\mathcal{B}_{off}$ go to sleep mode, coverage hole may appear and therefore the blocking probability will be out of tolerance. Figure 4 shows a snapshot of simulation results obtained from the first-stage sector sleeping scheme, where any group of three sectors with opposite antennas is defined as a sector cluster. It can be seen from the figure that there exists some sector clusters with all three sectors being switched off, e.g., the sector cluster in blue color. Considering cases when new users arrive in such sleep sector clusters, they can only be associated to neighboring active sectors which are far away from the users with poor channel quality. Since the resource of each sector is limited, the demand of new users' minimal user rate may usually exceed the sectors' capacity. Therefore, new users in the blue area shown in Fig. 4 will usually be blocked as an example.

Algorithm 2 Progressive Dynamic Switching Off sector

1: Allow the sectors without any user association to sleep, initialize the set of sleeping sectors as $\mathcal{D}$, the remaining sectors constitute the set of candidate active sectors
2: According to the network state information of the present active sectors, calculate the utility function values of these sectors and sort the values incrementally
3: Denote P percentage of the sectors with relatively small utility values as can testing set $\mathcal{T}$ (the number of elements is N), the remaining sectors with relatively large utility values constitute the candidate active set $\mathcal{S}$, and initialize the number of sleeping sectors in this testing iteration as $off_{count} = 0$
4: **while** $\mathcal{T} \neq \emptyset$ **do**
5: Try to handover the users of the sector with the maximum utility in set $\mathcal{T}$ (denoted as M) to the nearby sectors
6: **if** all users of sector M can be handed over **then**
7: $\mathcal{T} = \mathcal{T} - \{M\}, \mathcal{D} = \mathcal{D} + \{M\}, off_{count} = off_{count} + 1$
8: Sector M can go to sleep, handover users of sector M to the nearby sectors, update the user association information of the network and the SINR of users
9: **else**
10: $\mathcal{T} = \mathcal{T} - \{M\}, \mathcal{S} = \mathcal{S} + \{M\}$
11: Sector M remains active and user association state remains the same as before, update the elements of sets
12: **end if**
13: **if** $off_{\text{count}}/N \geq \delta$ **then**
14: ruturn to step 2
15: **end if**
16: **end while**

In order to reduce the blocking probability, the second-stage sector sleep scheme will readjust the sectors' working mode in $\mathcal{B}_{off}$ as some sectors in $\mathcal{B}_{off}$ that may lead to coverage hole should not go to sleep. Firstly, the sleep sector clusters with all three sectors being switched off needs to be found. Secondly, one of the sectors in a sleep sector cluster from $\mathcal{B}_{off}$ should be removed from the sleep set. The second-stage sector readjusting scheme is presented in Algorithm 3. Upon the termination of the algorithm, sectors in $\mathcal{B}_{off,final}$ will go to sleep.

Algorithm 3 The second-stage sector readjusting scheme

1: Initialize $\mathcal{B}_{on,final} = \mathcal{B}_{on}$, $\mathcal{B}_{off,final} = \mathcal{B}_{off}$
2: **for** each $m \in \mathcal{B}_{off}$ **do**
3: Define sectors that in a same sector cluster with $\mathcal{B}_{off}(m)$ as $\mathcal{B}_{opposite}$
4: **if** $\mathcal{B}_{opposite} \cap \mathcal{B}_{on,final} = \emptyset$ **then**
5: $\mathcal{B}_{on,final} = \mathcal{B}_{on,final} + \mathcal{B}_{off}(m)$
6: $\mathcal{B}_{off,final} = \mathcal{B}_{off,final} - \mathcal{B}_{off}(m)$
7: **end if**
8: **end for**

It is suggested that sectors in $\mathcal{B}_{on,final}$ will reduce their electrical antenna downtilt to enlarge coverage area during the subsequent time interval. It is an effective way to reduce the coverage hole area. As the number of active sectors in each sector cluster differs, the electrical antenna downtilt adjustment can be done as follows.

1) If only one sector in a sector cluster will be active, its electrical antenna downtilt is β_1;

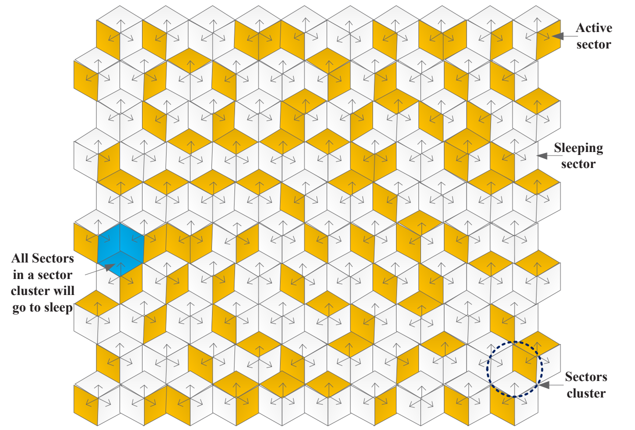

Fig. 4. A snapshot simulation results obtained form the first-stage BS sleeping scheme.

2) If two sectors in a sector cluster will be active, both their electrical antenna downtilt are β_2;
3) If there is no sector will go to sleep, all sectors stay their electrical antenna downtilt the same β_e.

where $\beta_e > \beta_2 > \beta_1$. The specific value of the electrical antenna downtilt are chosen to minimize the blocking probability.

3.3 User Association and Handover Method

When a new user arrives in a sleep sector cluster, for example the blue area in Fig. 4, the user needs to be handed over to other sectors, and a serving sector and RB should be selected. As mentioned before, at each time spot $*t^{(i)}, i = 0, ..., N$, a sector can be set to sleep mode as long as its associated users can be handed over to other sectors. The user handover scheme is summarized in Algorithm 4. We define the sector set $\mathcal{S}$ consisting of all the neighboring sectors of sector l as user k_ls candidate serving sectors. The user will selects a serving sector frrom $\mathcal{S}$ with higher channel quality and higher traffic load as well, aiming at concentrating traffic to these sectors and setting more sectors to sleep. We initialize the transmission rate as $r_s = 0$ and the allocated RB set as $\mathcal{R} = \emptyset$. Here a bandwidth protection margin $\varepsilon \in (0, 1]$ as in [8] is also introduced, which restricts the available RBs of the cells to $(1 - \varepsilon) \cdot N_{RB}$ in the execution phase of the user handover algorithm. This leaves some spare bandwidth at each sector to decrease the blocking probability of subsequent users entering the network and a larger ε means less sectors going to sleep. When the algorithm ends, if the candidate sector set $\mathcal{S} \neq \emptyset$, the user k_l can access to sector i^* and the RBs in $\mathcal{R}$ are allocated to it. Otherwise, there is no sector that has enough resource to the user k_l, andthe user k_l can't be handed over, which means the sector l will stay active mode in the time interval. During the time interval, when a new user arrives at the SCN, the user association algorithm is similar to the user handover algorithm except the following two points. The user will select the serving sector with higher channel quality and lower traffic load in order to balance the traffic load of the SCN to reduce system blocking probability. Besides, there is no protection margin in user association algorithm (i.e. $\varepsilon = 0$).

Algorithm 4 The user handover algorithm

```
while S ≠ ∅ do
    l* = arg max_{l∈S} H̄_{k,l} · L_l, r_s = 0, R = ∅
    while r_s < r_min and Σ_i Σ_{k_l*} α_{k_l*,i} < N_RB do
        i* = arg max_i (1 − Σ_{k_l*} α_{k_l*,i}) H_{k,i,l*}
        R = R + {i*}, r_s = r_s + B · γ_{k,i*,l*}
    end while
    if r_s >= r_min and Load_{i*} ≤ (1 − ε) then
        Break;
    else
        S = S − {l*}
    end if
end while
```

TABLE 1
Simulation Parameters

Parameter	Value
Bandwidth(W_b)	10 MHz
Number of RB(N_{RB})	50
Minimum user rate demand(R_{min})	1 Mbps
Maximum transmission power(P_{max})	41 dBm
Thermal noise	-174 dBm/Hz
Channel model	ITU mirco-cell scenario in [12]
Power conversion efficiency η	0.38
Standard deviation of shadowing(σ_ξ)	4dB
ϕ_{3dB} θ_{3dB}	70° 15°
SLL_{az} SLL_{el} SLL_o	20dB 20dB 20dB
A_o	17dBi
β_e β_2 β_1	12° 10° 8°
α β	0.3 0.7

3.4 Performance Evaluation

In this section, simulation analysis on the performance in terms of energy saving and blocking probability will be presented. The main simulation parameters [11] are given in Table 1.

For the first-stage progressive algorithm, the threshold and the percentage can be generally set as δ=0.5, $P = 0.5$ for simplicity. Considering that adaptive thresholds and percentages matching the traffic variation can further enhance the efficiency and performance of this scheme in real scenarios, hence we can have the adaptive version of the progressive scheme. Note that these thresholds and percentages can be obtained by other methods in reality, such as the historical statistics about the network resource utilization and the anticipative necessary network resource based on some traffic prediction techniques. The bandwidth protection margin ε was set to 0.6 for both first-stage algorithm and the scheme is executed every 15 minutes. Given varying traffic intensities during a whole day, the performance in terms of active BS numbers and blocking probability are depicted in Fig. 5 and Fig. 6, respectively. It can be seen from Fig. 5 that the number of active sectors tracks the variation of traffic profile very well. As a comparison between the first-stage progressive and heuristic algorithms, the former can switch off more sectors than the latter.

It is because that the progressive algorithm classifies the sectors into two different groups and handles each group on its own characteristics, thus guarantees that sectors with similar characteristics can be handled fairly. It ensures a higher probability for sectors with relatively small utility to be switched off. With the second-stage readjusting algorithm which aims to provide approximately seamless coverage, the resulted number of active sectors from both switch-off algorithms are very close. Furthermore, for

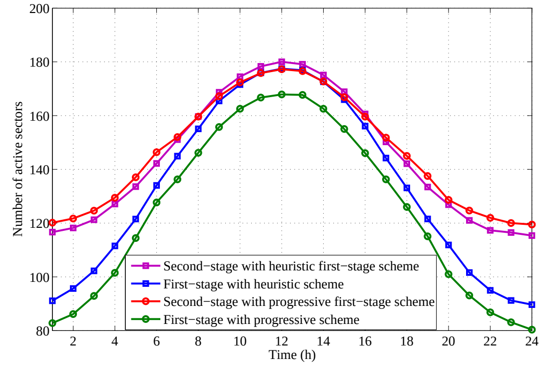

Fig. 5. The active BSs' number of two schemes versus time.

low and moderate traffic intensities, the two-stage scheme with the progressive first-stage algorithm switches on slightly more sectors than the one with the heuristic first-stage algorithm, while for high traffic intensity, a contrary result was obtained.

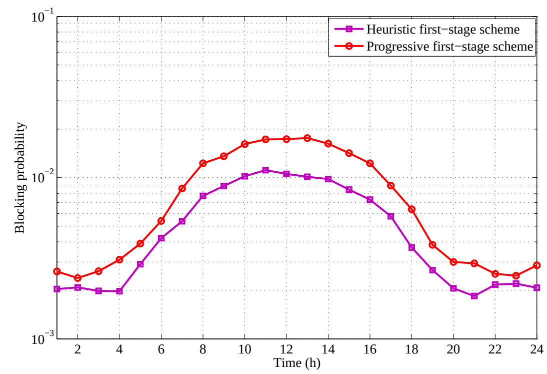

Fig. 6. The blocking probability versus time.

Figure 6 depicts the simulation results of blocking probability by the two first-stage algorithms. It can be seen from the figure that the blocking probability is slightly decreasing with the incremental traffic intensity from the beginning, which is because more sectors will be in active mode when more users arrive in the SCN and the coverage hole is relative small. However, the blocking probability increases significantly when the traffic intensity is high. The reason is that more users in the SCN demand more resources to satisfy their minimum rate requirements,and thus some users are blocked due to the limited resource. As shown in the figure, the average blocking probability is around 0.01, which can satisfy the quality of service requirement of general communication services, and the progressive first-stage scheme can switch off more sectors, while having a slightly impact on the network blocking probability.

Figure 7 depicts the remarkable difference of execution time of the two proposed schemes. Averagely, the scheme with progressive first-stage algorithm takes about one third time of the scheme with heuristic algorithm, which indicates that the progressive algorithm can reduce the network signaling overhead to a great extent and can quickly reconfigure the working mode of all sectors to accommodate communication traffic. It is because that the progressive scheme avoids unnecessary traversal of some sectors and can adaptively decide when to stop the switching off process.

The impact of bandwidth protection margin ε on the perfor-

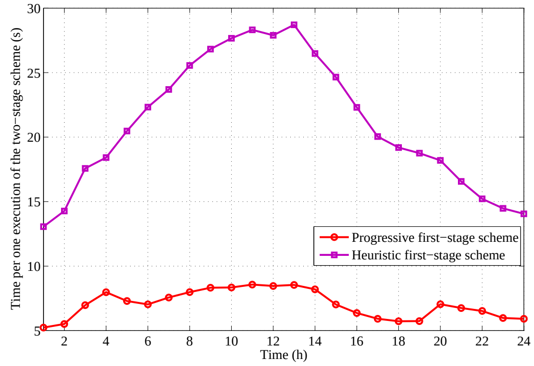

Fig. 7. The time per one execution of the proposed schemes versus time.

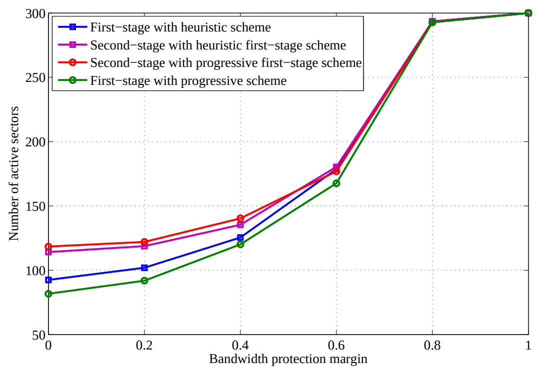

Fig. 8. The average number of active sectors of the proposed schemes under different bandwidth protection margin.

mance of the proposed schemes are depicted in Fig. 8-10. Figure 8 shows the average numbers of active sectors with different ε. It is obvious that the number of active sectors increases with ε. The reason is that the less bandwidth for the current users, the more sectors need to be active to meet users' demand. For the first-stage scheme, when ε is low, the progressive scheme can switch off more sectors. As the ε increases, the difference between the two first-stage schemes decreases. In the extreme case when $\varepsilon = 1$ which indicates that no sector can accept any user, the results of the two first-stage schemes become the same and no sector can be switched off. Besides, under the action

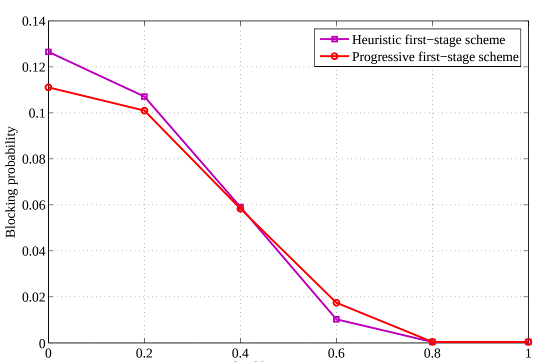

Fig. 9. The average blocking probability of the proposed schemes under different bandwidth protection margin.

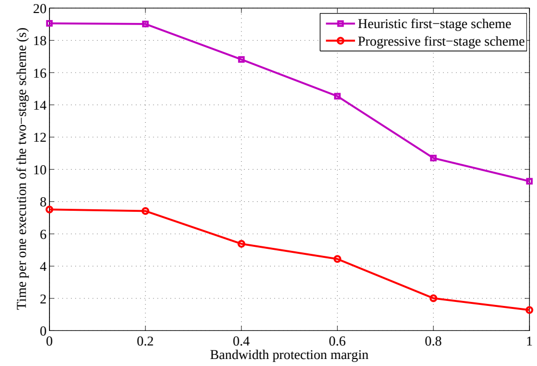

Fig. 10. The time per one execution of the proposed schemes under different bandwidth protection margin.

of the second-stage readjusting algorithm, the numbers of active sectors by the two schemes are quite close. Figure 9 shows that the results of average blocking probability with different ε by the two first-stage schemes are similar. With less sectors switched off, the blocking probability will decrease. Figure 10 shows the downward trend ofexecution time with increasing ε. According to the proposed schemes, a sector can be switched off if and only if all its users can be successfully handed over. Otherwise, once a user cannot be handed over, the associated sector remains active and the subsequent process terminates, hence the time is saved. As ε increases, the opportunity that a user can be handed over successfully decreases, so more time can be saved. Therefore, in real scenarios the parameter ε must be carefully tuned in order to balance among energy saving, coverage guarantee and network response time.

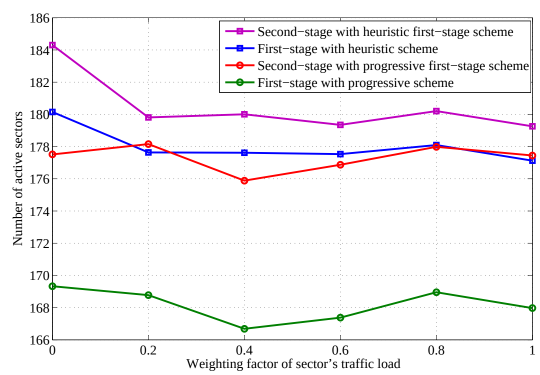

Fig. 11. The average number of active sectors of the proposed schemes under different weighting factor of sector's traffic load.

Figure 11-13 show the impact of weighting factor α of sector's traffic load on the active sector number, blocking probability and execution time, respectively. It can be seen from Fig. 11 and Fig. 12 that varying α has no significant affect on the number of active sectors and blocking probability, both of which have fluctuation within a small range. For the impact on execution time as shown in Fig. 13, there is a more significant trend that the execution time decreases with α. Specifically, when α takes a relatively big value, which means that in the utility function more weight to the traffic load term is given, the execution time is obviously shorter. When α takes a moderate value, which means a comparable attention is paid to both terms in the utility function, the variation of execution

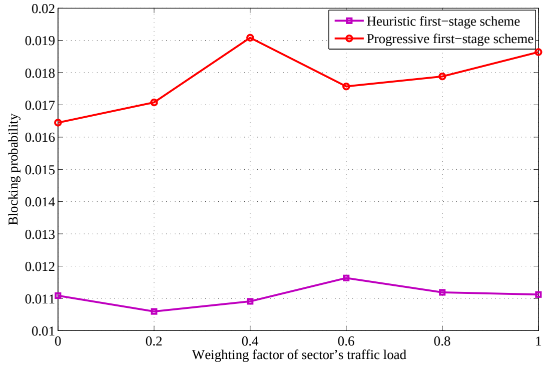

Fig. 12. The average blocking probability of the proposed schemes under different weighting factor of sector's traffic load.

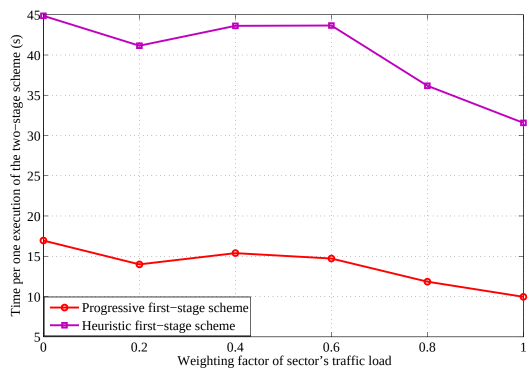

Fig. 13. The time per one execution of the proposed schemes under different weighting factor of sector's traffic load.

time is considerably small. Hence, a reasonable α can be chosen to adjust the network response time, while having slight impact on energy saving and network performance.

Figure 14 shows the results of blocking probability with different time intervals. It can be seen from the figure that the blocking probability increases with the time interval τ. The reason is that the proposed two-stage schemes can better track the traffic variation if the time interval of performing the schemes is shortened. At the same time, the system overhead will increase due to frequent switching on-off operations. Therefore, there is a tradeoff between system overhead and system performance, which

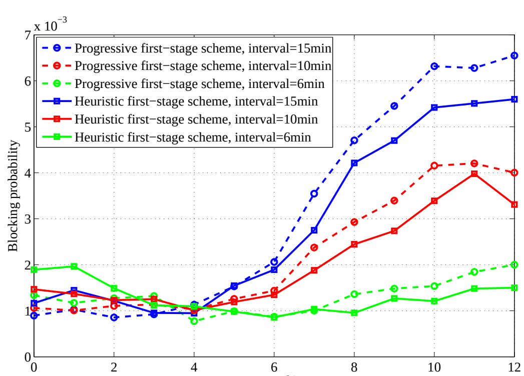

Fig. 14. The blocking probability of the proposed scheme under different time interval.

can be dynamically adjusted according to use scenarios.

4 Conclusion

In this paper, two sector sleeping schemes have been proposed for SCNs to dynamically and periodically adjust sectors' working mode, i.e. active mode and sleep mode, for the purpose of energy saving. Both of the schemes consist of two stages, including the first-stage switching off stage and second-stage readjusting stage. The two schemes differ in the first stage, i.e. the heuristic algorithm and progressive algorithm. Furthermore, a user association and handover scheme is also proposed to optimize the selection of serving sectors and bandwidth resource. The results of simulation analysis indicate that the number of active sectors well matches the traffic variation in the time and space domain while guaranteeing a tolerable blocking probability, validating the feasibility of the schemes. Particularly, the complexity of the progressive first-stage scheme is much lower than the heuristic one, enabling much more prompt network respond to the traffic variation. Besides, the progressive scheme can lead to a similar result of energy saving while slightly deteriorates the blocking probability as compared with the heuristic scheme. The simulation results also imply that the there exist tradeoffs among performances of energy saving, blocking probability and system response while setting the bandwidth protection margin, weighting factor and time interval. How to balance these parameters in real scenarios will be one of our future work.

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