Sleep Scheduling in IEEE 802.16j Relay Networks

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Abstract—Power saving for mobile stations (MSs) is one of the most critical issues in IEEE 802.16j relay networks. To reduce power consumption of MSs, IEEE 802.16j borrows the sleep mode of 802.16e, but new parameters are introduced. Up to now, no previous work has addressed the sleep scheduling problem in IEEE 802.16j networks. Therefore, this paper proposes an energy-efficient, standard-compliant sleep scheduling scheme which involves relay stations (RSs) and realizes spatial reuse on RS transmissions to minimize energy consumption of MSs while guaranteeing their QoS. The main idea of the proposed scheme is to interleave the sleep patterns of MSs and exploit spatial reuse on MS-RS transmissions to reduce resource consumption while enlarging the available frame space. Comprehensive simulation has been conducted to verify the effeteness of our scheduling scheme. It shows that our scheme can serve more requests of MSs while increasing their sleep ratios.

Keywords—802.16j, power saving, sleep mode, spatial reuse, green wireless networks

I. INTRODUCTION

IEEE 802.16-2009/16m [1, 2] has been considered as one of the most promising approaches for supporting mobile and broadband wireless access. In succession to IEEE 802.16, IEEE 802.16j [3] *Multi-hop Relay* is proposed to extend coverage and improve throughput. Like most wireless networks, power saving is a critical issue for *mobile stations* (MSs). In IEEE 802.16-2009, three types of *power saving classes* (PSCs) are defined for flows with different QoS characteristics. Each PSC consists of a sequence of interleaved listening and sleep windows and can support one or more flows in an MS with similar QoS characteristics at the same time. Thus, an MS can turn off its radio interface to save power when all its PSCs are in their sleep windows. To support sleep mode in IEEE 802.16j relay networks, the existing IEEE 802.16 sleep mode is reused and new parameters are introduced to IEEE 802.16j.

In an IEEE 802.16j relay network, two types of *relay stations (RSs)* are defined. One is called the transparent RS if it is not noticed by MSs, and the other is the non-transparent RS. Transparent RSs can help relay data to MSs to improve network throughput while non-transparent RSs can help increase the BS's coverage. In this paper, we focus on transparent RSs because their resources are managed by the BS and are thus easier to implement than non-transparent ones.

In previous researches, much work [4-6] has been done on sleep scheduling of multiple IEEE 802.16 MSs, which are directly connect to a central *base station (BS)*. However, none of those researches consider how to manage the sleep patterns of MSs in IEEE 802.16j relay networks. By deploying IEEE 802.16j transparent relays, MSs in the cell edge can have better link quality, and concurrent transmissions of multiple links become possible. This architecture helps increase overall network capacity and the data rates of MSs. It also reduces the power consumption of MSs. In such a relay network, how to select the path for MSs (directly to the BS or via RS) and how to schedule the concurrent transmission of multiple BS-MS/RS-MS links need to be addressed. In addition, existing power saving schemes proposed in IEEE 802.16e cannot be directly applied to IEEE 802.16j networks. In this work, we study the sleep scheduling problem in IEEE 802.16j transparent relay networks. We propose a standard-compliant, energy-efficient sleep scheduling scheme in IEEE 802.16j networks. This scheme can avoid resource collision among MSs by interleaving their sleep patterns and exploit spatial reuse on MS-RS transmissions. Thus, more MSs can be served and they can still enjoy high sleep ratios.

II. RELATED WORK

In the literature, reference [7] has shown that with sleep mode and 802.16j RSs, MSs' power consumption can be significantly reduced. The work [8] proposes a hybrid sleep operation under the idle mode to save MSs' power. However, all of them do not employ the PSCs of 802.16 for further power saving, so the performance of energy conservation is limited. The study [9] proposes a scheme with power control and relay selection to save MSs' energy. Recently, some works [4]–[6] and [14] have studied the PSC scheduling of MSs. Reference [6] proposes a tank-filling scheme which can guarantee MSs' traffic delay and enhance MSs' request satisfaction. However, these works do not consider using RSs. To the best of our knowledge, this is the first work that addresses the sleep scheduling problem for IEEE 802.16j transparent relay networks with RSs.

III. PRELIMINARIES

A. IEEE 802.16j Networks

In a IEEE 802.16j network, the resource is represented by a frame. In each frame, it composes a downlink subframe and an uplink subframe. In the downlink subframe, there are two types of zones: *access zone* and *transparent zone*, as shown in Fig. 1. The access zone is used for *access links* which are the communication links from BS to RSs ("BS-RS" for short). The transparent zone is used for *transparent links* which is the communication links from BS to MSs ("BS-MS" for short) and from RS to MSs ("RS-MS" for short). The lengths of access zone and transparent zone may be varied frame-by-frame according to the total transmission lengths of BS-RS, BS-MS, and RS-MS. Note that BS-MS and RS-MS transmissions may exploit spatial reuse to improve transmission efficiency.

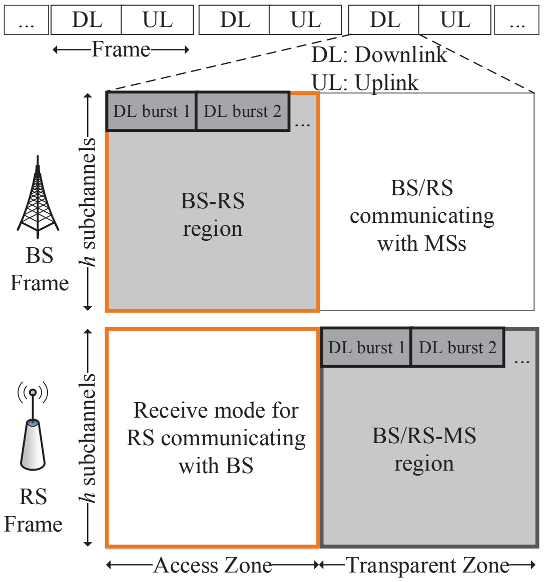

Fig. 1. The downlink subframe sturcute of IEEE 802.16j

B. *Problem Definition*

We are given an 802.16j network with one BS, *m* RSs, and *n* MSs. We assume that the distance between any two nodes can be estimated by measuring their received signal strength. The m RSs are denoted as $RS_1, RS_2, ...RS_m$ and the BS is sometimes written as RS_0. The downlink path of each MS_i is denoted by P_i, where $P_i \in \{RS_0, ..., RS_m\}$, which means that the transmission way come directly from BS or indirectly from RS. Each MS_i has a data arrival rate of β_i bits/frame and each piece of arrival data has a delay bound of D_i frames. Our goal is to assign each MS_i a PSC of Type II (as shown in Fig .2), including a sleep cycle T_i^S, a listening window T_i^L, and a start-offset T_i^O, such that $T_i^S \le D_i$ and the sum of sleep ratios of all MSs is maximized, i.e.,

$$max \ \sum_{i=1...n} \frac{(T_i^S - T_i^L)}{T_i^S}. \tag{1}$$

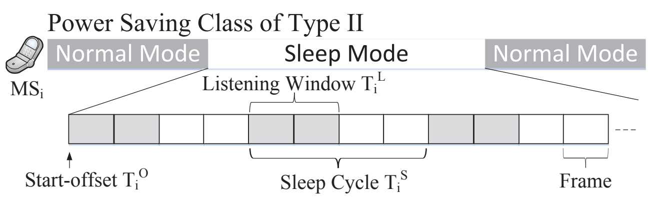

Fig. 2. Illustration of the PSC of Type II for an MS.

IV. THE PPROPOSED SCHEME

To solve the problem, we design an energy-efficient sleep scheme to schedule MSs' transmission and determine their sleep parameters, i.e., T_i^S, T_i^L, and T_i^O, i=1..n. The proposed scheme is composed of three procedures: path selection, determination of T_i^S, and determination of T_i^O and T_i^L. Path selection is to choose an energy conserving path for each MS. For the determination of T_i^S, the idea is to make each MS's sleep cycle an integer multiple of others'. This helps MSs to interleave their listening windows to avoid resource contention. Lastly, the determination of T_i^O and T_i^L exploits RSs and spatial reuse on BS-MS and RS-MS transmissions to save frame space. Thus, more MSs may be served by the network and more MSs can turn off their radio interfaces to save energies. The details of the scheme are described as follows.

A. *Path Selection*

For each MS_i's possible path P_i, let $R_{i,j}^A$ and $R_{i,j}^T$ be the transmission rates of its access link (i.e., BS-RS_j link) and transparent link (i.e., RS_j-MS_i link), respectively. Note that $R_{i,j}^A = 0$ if $j = 0$. Then, we set path P_i to the one that causes the minimal time to transmit one bit, i.e.,

$$P_i = \arg\min_{RS_j} \left\{ \frac{1}{R_{i,j}^A} + \frac{1}{R_{i,j}^T} \right\}. \tag{2}$$

B. *Determination of T_i^S*

To decide T_i^S of each MS_i, we first sort MSs by their delay bounds. Without loss of generality, let $D_1 \le D_2 \le ... \le D_n$. Suppose that $T_1^S = T_{basic}$ is known and $T_1^S \le D_1$, we set T_i^S, i = 2...n, as follows:

$$T_i^S = T_{i-1}^S \times \left\lfloor \frac{D_i}{T_{i-1}^S} \right\rfloor, \forall i = 2..n. \tag{3}$$

Note that Eq. (3) implies $T_i^S \le D_i$ for all MS_i, which guarantees the arriving data of each MS_i to meet its delay bound D_i. Also, Eq. (3) ensures T_i^S to be an integer multiple of T_{i-1}^S for i = 2..n, which can interleave MSs' listening windows to avoid resource competition. In addition, T_1^S is the basic cycle and the sleep schedule repeats after T_n^S/T_1^S basic cycles (this will be clear later on).

C. *Determination of T_i^O and T_i^L*

Before deciding T_i^O and T_i^L of MS_i, we first define $C_{i,i'}$ as an indicator to represent whether or not paths P_i and $P_{i'}$ are conflict. $C_{i,i'} = 1$ if the transparent link of P_i is interfered by that of $P_{i'}$; otherwise, $C_{i,i'} = 0$. The value of $C_{i,i'}$ can be derived by applying the scheme in [12], so we omit this part. As a result, the number of conflict paths of P_i is $\sum_{i'=1..n,\, i' \ne i} C_{i,i'}$.

Now, we classify MSs into classes. Each class consists of the MSs with the same cycle length, T_i^S. For each MS in the same class, we calculate its bandwidth requirement per cycle, denoted as BR_i, by $BR_i = AR_i + TR_i$, where $AR_i = \frac{\beta_i \times T_i^S}{R_{i,j}^A}$ is the required bandwidth in the access zone (in frames) and $TR_i = \frac{\beta_i \times T_i^S}{R_{i,j}^T}$ is the required bandwidth in the transparent zone (in frames). We then sort the MSs in each class according to their BR_i in an increasing order because the MSs with lighter bandwidth requirements may have more opportunities to utilize the frame space. In case that there is a tie, we will give priority to the one with the least total number of conflict paths because such an MS will have more opportunities to receive data concurrently with other RS-MS transmissions. After sorting MSs in each class, we also partition *n* MSs into conflict-free groups, denoted by $\hat{G}_1, \hat{G}_2, ..., \hat{G}_Q$ $(1 \le Q \le n)$. Basically, we group MSs in a greedy way, i.e., selecting MSs for each group from shorter cycle classes to the long cycle classes and from higher priority MSs to lower priority MSs in a class.

Recall that our goal is to maximize the total sleep ratio of MSs, i.e., $max \sum_{i=1..n} \frac{(T_i^S - T_i^L)}{T_i^S}$. Thus, we try to reduce MSs' listening windows so as to both increase their sleep ratios and reserve the maximum available frame space. The key idea to achieve both goals is via spatial reuse by overlaping the frame use of the transparent links which are conflict-free. The details are described below.

Let R_k, $k = 1..T_n^S$, be the available frame space of frame k (in frames). Initially, we set $R_k = 1$, $k = 1..T_n^S$. For each frame k, we use $G_{k,q}$ to represent the group of MSs which belong to group $\hat{G}_q$ and are allocated resource in frame k; initially, $G_{k,q} = \emptyset$, q=1..Q. In addition, we use $0 \le GTR_{k,q} \le 1$ (in frames) to represent the total allocated frame size for the RS-MS transmissions of $G_{k,q}$; initially, $GTR_{k,q} = 0$.

Then, we determine T_i^O and T_i^L of MS_i sequentially from the shortest cycle class to the longest cycle class and from MSs with the highest priorities in each class. We define two functions: $W(i,f)$ and $N(i,f)$, where $W(i,f)$ evaluates the amount of listening frames of MS_i per cycle with start-offset f and $N(i,f)$ represents the number of frames in $W(i,f)$ which only allocate resource to MS_i. Specifically, we find the best start-offset f^* by function $W(i,f)$ for MS_i, i.e.,

$$f^* = arg\ min_{f=1..T_i^S}\{W(i,f)\}. \tag{4}$$

In case of there is a tie, we use function $N(i,f)$ to help to choose the best start-offset. $W(i,f)$ is expressed as follows:

$$W(i,f) = min_{f'}\left\{f' - f + 1 \middle| \sum_{k=f..f'} FillingFS(k,i) \ge BR_i\right\}, \tag{5}$$

where $f' \ge f$ and $FillingFS(k, i)$ represents the filling frame space of frame k for MS_i, which includes bandwidth allocated to MS_i's access link and transparent link, i.e., $FillingFS(k,i) = AR_{i,k}^{Fill} + TR_{i,k}^{Fill}$, where $AR_{i,k}^{Fill}$ and $TR_{i,k}^{Fill}$ are defined as follows:

$$AR_{i,k}^{Fill} = \begin{cases} AR_i & , if\ AR_i \le R_k\ and\ BR_i \le R_k + GTR_{k,q} \\ R_k & , if\ AR_i > R_k\ and\ \gamma < GTR_{k,q} \\ \alpha & , otherwise \end{cases},$$

$$TR_{i,k}^{Fill} = \begin{cases} TR_i & , if\ AR_i \le R_k\ and\ BR_i \le R_k + GTR_{k,q} \\ TR_i \times \frac{R_k}{AR_i} & , if\ AR_i > R_k\ and\ \gamma < GTR_{k,q} \\ \gamma & , otherwise \end{cases}. \tag{6}$$

where α is $\frac{AR_i}{AR_i + TR_i}(R_k + \mathrm{GTR_{k,g}})$, and γ is $\frac{TR_i}{AR_i + TR_i}(R_k + \mathrm{GTR_{k,g}})$ and $BR_i = AR_i + TR_i$. Here, AR_i and TR_i are the required frame resource of MS_i in access link and transparent link, respectively. Fig. 3 presents possible cases that MS_2 share frame 1 with MS_1 with spatial reuse, where both MS_1 and MS_2 are conflict-free. After above steps, each MS_i has its best start frame f^*. Here, if MS_i has more than one best start frames f^*, we use the predefined function $N(i,f)$ to choose one that causes the least number of frames which only allocate resource to MS_i, i.e.,

$$f^{**} = arg\ min_{f^*}\{N(i,f^*)\}, \tag{7}$$

where

$$N(i,f^*) = \sum_{k=f^*..f^*+W(i,f^*)-1} \lfloor R_k \rfloor. \tag{8}$$

Note that $\lfloor R_k \rfloor = 1$ means that the frame k has not been allocated before. Thus, we calculate the total number of unallocated frames from frame f^* to $(f^* + W(i,f^*) - 1)$ which will be the number of increased allocated frames caused by MS_i if MS_i uses f^* as the start-offset.

After conducting the best frame f^{**} and the best listening window $W(i, f^{**})$, we set $T_i^O = f^{**}$ and $T_i^L = W(i,f^{**})$. Then, we allocate frame space for MS_i and update $GTR_{k,q}$, and $G_{k,q}$, $k = l \times T_i^S + f^{**} .. l \times T_i^S + (f^{**} + W(i,f^{**}) - 1)$, $l = 1..\frac{T_n^S}{T_i^S} - 1$, accordingly, where $MS_i \in \hat{G}_q$. These operations will repeat until the allocation of all MSs is done or all frame space is exhausted.

Through above operations, we can find the best start-offset for MSs which can not only reduce their listening windows but also fully utilize the frame resource and thus help the BS to serve more MSs. For further optimization, we can choose a best basic cycle length $1 \le T_{basic} \le D_1$ to further improve MSs' sleep ratios.

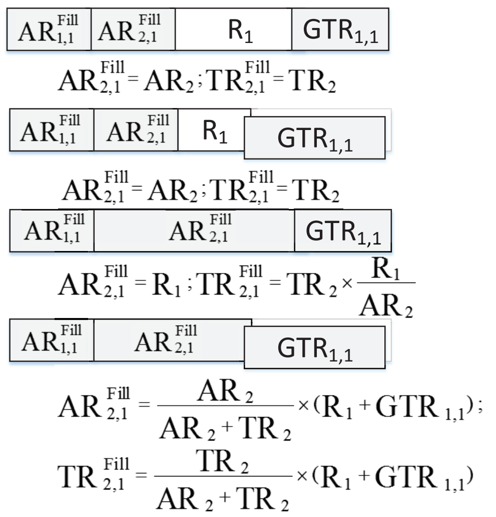

Fig. 3. Possible results of allocating resource for MS_2 with spatial reuse (assume $T_1^l = 1$ and $MS_1, MS_2 \in \hat{G}_1$)

Below, we give an example as shown in Fig. 4. There are 6 *MSs* (i. e., MS_i, $i = 1..6$) and they are partitioned into conflict-free groups, where MS_1 and MS_2 are in group $\hat{G}_1$, MS_4 and MS_5 are in $\hat{G}_2$, and both MS_3 and MS_6 directly connect to the BS. The bandwidth requirement of access zone and transparent zone of MSs are (AR_1, TR_1)=(0.1, 0.1), (AR_2, TR_2)=(0.3, 0.2), (AR_3, TR_3)=(0, 0.2), (AR_4, TR_4)=(0.3, 0.1), (AR_5, TR_5)=(0.2, 0.2) and (AR_6, TR_6)=(0, 2.6). We use $R[q, w]$ to represent the available frame space of the w-th frame in the q-*th* basic cycle, where $q = 1..T_n^S / T_{basic}$, and $w = 1..T_{basic}$. Initially, $R[q, w] = 1$ for all q and w. Then, we first choose $T_1^O = 1$ (for MS_1, T_i^o=1 or 2 is the same). Consequently, we allocate AR_1 and TR_1 into $R[q, 1]$ and update $R[q, 1]$ = 0.8 accordingly. For MS_2, we allocate AR_2 and TR_2 in frame, because MS_1 and MS_2 are in same group $\hat{G}_1$ and $N(2, 1) = 0$. Then we update $R[q, 1]$ = 0.4. For MS_3, because $N(3, 1) = N(3, 3) = 0$ which is better than $N(3, 2) = N(3, 4) = 1$, we set T_3^O = 1. Then, we update $R[1, 1]$ and $R[3, 1]$ by 0.2. For MS_4, we choose T_4^O = 2 because $W(4, 1) = 2 > W(4, 2) = 1$. After updating $R[1, 2]$ and $R[3, 2]$ by 0.6, a new non-zero group $G_{2,2}$ is formed. Next, we choose frame 2 as T_5^O and allocate MS_5 into frame 2 (in this case, MS_5 is added to $G_{2,2}$); then, $R[1, 2]$ and $R[3, 2]$ is updated by 0.3. Finally, for MS_6, both frames 2 and 3 result in the minimal cost, i.e., $W(6, 2) = W(6, 3)$ = 6. In the end, we set T_6^O = 2 due to $N(6, 2) = 1 < N(6, 3) = 2$, *i.e.,* $T_6^O = 2$ can fully utilize the frame space.

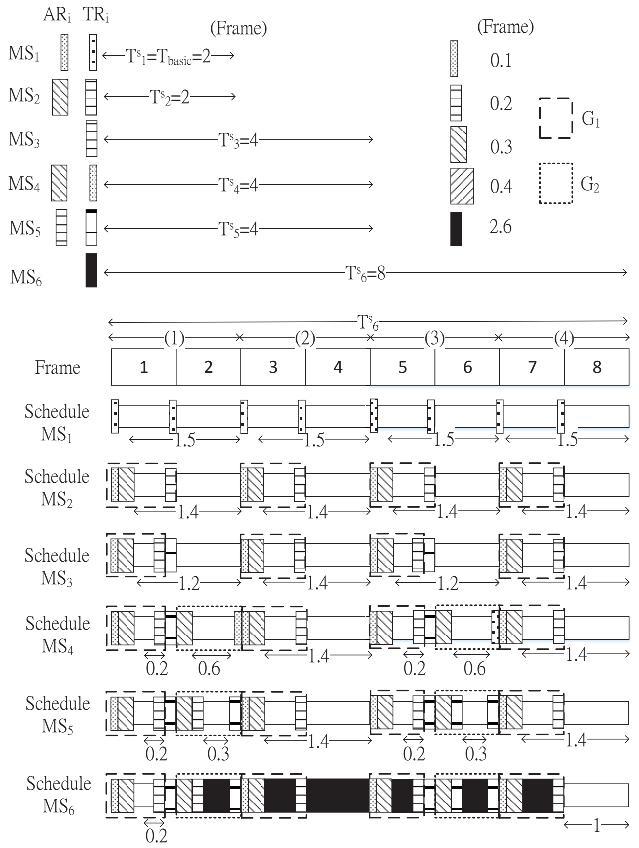

Fig. 4. Example of scheduling

Based on the rules described above, we can recursively determine all MSs' sleep cycles T_i^S, listening windows T_i^L, and offsets T_i^O in polynomial time.

V. SIMULATION RESULT

Using C# language, we develop a simulator to verify the effeteness of our scheduling scheme. Table 1 shows the default parameters in our simulator. We consider two types of traffics: voice and video streams. A voice stream and a video stream are with requests of 64 kbps and 300 kbps, respectively [9]. Each MS has one voice or one video stream randomly. The network consists of one BS, multiple RSs and MSs, where RSs are uniformly deployed inside the 1/2 coverage range of the BS to get the best performance gain and MSs are randomly deployed inside the BS's coverage. The number of RSs is ranged from 0 to 16 and the number of MSs is ranged from 10 to 210. Note that in the simulator, we adopt the *empirically based path loss model* [11] which covers most common terrains.

Table 1: The parameters in our simulator.

Parameter	Value
Channel bandwidth	10 MHz
Frame duration	5 ms
Path loss model	Empirically based path loss model [11]
Antenna height	BS: 30m, RS: 10m, MS: 2m
Transmitter power	BS: 20W, RS: 10W
Shadowing effect	8.2 db [11]
Thermal noise	-120dBm [11]
Request size	Voice (64 kbps), Video (300 kbps) [10]
Traffic delay	35 ~ 225 ms [13]

Table 2: Modulation and coding schemes (MCSs) [9].

Level	MCS	Data carried by a slot	Minimum SINR threshold
1	QPSK 1/2	48 bits	6 dBm
2	QPSK 3/4	72 bits	8.5 dBm
3	16QAM 1/2	96 bits	11.5 dBm
4	16QAM 3/4	144 bits	15 dBm
5	64QAM 2/3	192 bits	19 dBm
6	64QAM 3/4	216 bits	21 dBm

We compare our scheme against the **Tank-Filling (TF)** scheme [6], which has the best performance on power saving in IEEE 802.16e networks. Specifically, the **TF** scheme allocates resource to MSs sequentially by their delay bounds and fulfills the frame space to minimize MSs' active periods. Note that the **TF** scheme does not support relay stations, so we adopt our path selection strategy for **TF** scheme, denoted as **Modified-TF** scheme, to make it work successfully in the 802.16j relay network.

We consider two performance metrics: (i) sleep ratio: the ratio of sleep windows (i. e., $T_i^S - T_i^L$) over the sleep cycle T_i^S and (ii) successful-to-sleep probability: the probability to succeed in determining MSs' sleep patterns to meet their requests. Note that each experiment is averaged by at least 10000 simulation results.

A. Sleep Ratio

We first evaluate the sleep ratio of MSs under different number of MSs, which is as shown in Fig. 5(a), where the number of RSs is 3. Clearly, the sleep ratios of all schemes decrease when the number of MSs increases. When the number of MSs is lower than 30, the sleep ratios of all schemes are similar because the resource (i. e., frame space) is sufficient to serve all MSs. When the number of MSs is higher than 30, our scheme has higher sleep ratio than both **TF** and **Modified-TF** schemes, because our scheme can exploit spatial reuse to potentially enlarge the frame space; thus, more MSs can have short listening periods. From Fig. 5(a), it shows that our scheme can increase 10% and 15% of sleep ratio as compared with **Modified-TF** and **TF** schemes, respectively.

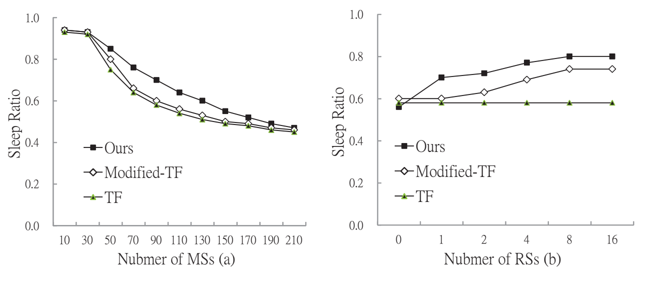

Fig. 5. (a)The sleep ratio of MSs under different number of MSs, where there are 3 RSs; (b) The sleep ratio of MSs under different number of RSs, where there are 90 MSs.

We then measure the sleep ratio of MSs under different number of RSs. As shown in Fig. 5(b), we can see that the sleep ratio of our scheme and **Modified-TF** scheme increase when the number of RSs increases because each MS has more choices to select a proper RS to serve its request. On the other hand, the sleep ratio of **TF** scheme is not affected by the number of RSs because it does not consider the existence of RSs. When the number of RSs is more than or equal to 1, our scheme has a higher sleep ratio than **Modified-TF** because our scheme can enlarge the frame space by exploiting spatial reuse. We also observe that when the number of RSs is more than 8, increasing the number of RSs has slight effect on MSs' sleep ratio because more RSs may arise more interference. From Fig. 5(b), our scheme can increase 10% and 25% of MSs' sleep ratio compared with **Modified-TF** and **TF** scheme, respectively.

B. Successful-to-Sleep Probability

Next, we investigate the successful-to-sleep probability of MSs. When the successful probability is 1, it means that the scheme can completely satisfy the requests of all MSs and make all MSs to sleep successfully. Fig. 6(a) shows the successful-to-sleep probability of all schemes under different number of MSs, where the number of RSs is 3. Clearly, the successful-to-sleep probability of all schemes decreases when the number of MSs increases because the network is getting saturated. In addition, our scheme has higher successful-to-sleep probability than other schemes because it can fully utilize the frame space by exploiting concurrent transmissions. From Fig. 6(a), our scheme can increase 10% and 12% of MSs' successful-to-sleep probability compared with the **Modified-TF** scheme and **TF** scheme, respectively.

Fig. 6(b) shows the successful-to-sleep probability of all schemes under different numbers of RSs, where the number of MSs is 90. Clearly, the successful-to-sleep probabilities of our scheme and **Modified-TF** scheme increase when the number of RSs increases. This is because the RSs can help to increase the network capacity. When the number of RSs is larger than or equal to 1, our scheme has a higher successful-to-sleep probability because it can employ the spatial reuse to fully utilize the frame space. From Fig. 6(b), our scheme can increase 10% and 25% of MSs' successful-to-sleep probability as compared with **Modified-TF** scheme and **TF** scheme, respectively.

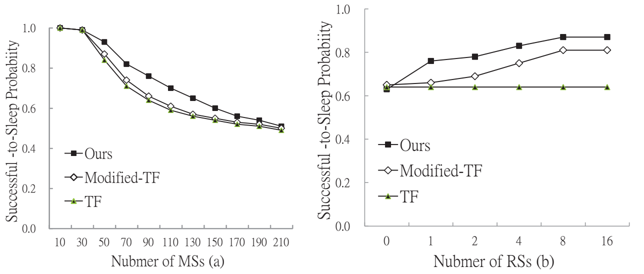

Fig. 6. (a) The successful-to-sleep of MSs under different number of MSs, where there are 3 RSs; (b) The successful-to-sleep of MSs under different number of RSs, where there are 90 MSs.

VI. CONLCUSION

In this paper, we have addressed the sleep scheduling problem in IEEE 802.16j networks. An energy efficient sleep scheme is proposed to tackle the problem. By interleaving the active periods of MSs and exploiting spatial reuse on RS-MS transmissions, simulation results have shown that our scheme can serve more MSs' requests while maintain better sleep ratios than previous work.

VII. ACKNOWLEDGMENT

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