Integrated Power-Saving Scheduling for IEEE 802.16e Networks

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Abstract *- The mobility of IEEE 802.16e introduces an important issue for battery-powered mobile station to extend the operational lifetime. Although the sleep-mode operation in power management helps to increase the life of mobile station by saving energy consumed, since the sleep-mode operation is not fully integrated with the scheduling mechanism, the energy-saving efficiency is not utilized due to the reciprocal effect between the connections. In order to effectively use the channel bandwidth and provide energy efficiency for wireless mobile station, this research developed a scheduling method, in attempt to provide energy saving based on the premise of different service delayed restrictions.*

Keywords: IEEE 802.16e, PSC, Sleep-mode, Power-saving.

1. Introduction

In recent years, IEEE 802.16 has been standardized for WiMAX technique to provide a solution for the next generation broadband wireless access networks. The original IEEE 802.16 standard only supported fixed broadband wireless access. The emerging IEEE 802.16e standard has enhanced the original standard with mobility so that the mobile subscriber station (MSS) can be movable during service. However, although this protocol can provide better throughput and transmission distance than the traditional WiFi access, the mobile device would consume more power for communication. Consequently, power management has become an important issue for the mobile device. Furthermore, due to the promising mobility capability, energy saving is a significant issue in IEEE 802.16e.

In IEEE 802.16e, in order to extend the operating time of mobile device, an MSS is permitted to repeatedly switch from normal mode (i.e., wake-mode) to sleep-mode whenever it is not communicating with a base station (BS). Hence, the MSS can temporarily close the radio frequency component and enter the sleep-mode when the data transmission is not carried out. However, if a large number of connections are established between MSS and BS, the MSS operation state would be affected by the interaction among the power saving mechanisms of those connections. The operation state of a MSS can be switched to sleep-mode only when all the connections in the MSS expect to enter the sleep-mode. Comparing with the single connection MSS, multi-connection is less likely to be switched to a sleep-mode. The reason is that operation among power saving-classes and their schedule mechanisms has no cooperative relationship. Therefore, the effect of power-saving mechanism operation is not obvious.

Many studies have evaluated the power-saving in IEEE 802.16 communication systems. [2] [5] investigated the protocol and control mechanism. [1] proposed a novel model to investigate the energy consumption of IEEE 802.16e by considering the message delivery from BS to MSS. [3] analyzed the energy consumption by considering both the incoming frames and outgoing frames since the instants of terminating sleep-mode by incoming or outgoing traffics are different. These studies only considered the power-saving class (PSC) Type I and Type II [6] sleep-mode, and the analytical models were evaluated for average energy consumption and the average response delay of awakening MAC SDUs. Although many studies have evaluated the performance of sleep-mode, none conducted performance analysis on PSC type III nor proposes the schedule scheme for PSC type III.

This study introduced an integrated power saving schedule scheme, called IPSS. Distinguished from previous studies, IPSS is a novel MSS-based schedule scheme. Furthermore, to efficiently manage energy consumption in IEEE 802.16e, the sleep interval and wake interval of MSS are directly specified by the base station. This study modeled the sleep-mode operation of

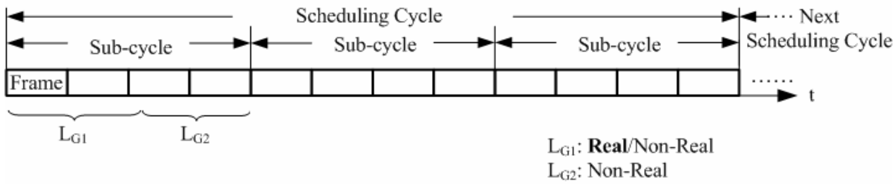

Figure 1. An example of the two levels MSS-based IPSS scheme

the proposed IPSS scheme, and evaluated its average power consumption.

The remainder of this paper is organized as follows. Section 2 provides a brief description of the sleep-mode in IEEE 802.16e. Section 3 describes the scheme presented in the literature designed to improve the IEEE 802.16e energy management. Section 4 presents the analytical model for IPSS scheme. Section 5 describes the results of the evaluation simulations. Finally, Section 6 concludes this study.

2. Overview of the sleep mode in IEEE 802.16e

The IEEE 802.16e protocol defines three power-saving classes (PSC), which are differed by their parameters set, procedures of definition/activation/deactivation, and policies of MSS availability for data transmission [5]. In IEEE 802.16e, MSS in the wake-mode can transmit/receive data according to base station's scheduling, whereas in the sleep-mode, it is absent from the serving base station during the pre-negotiated intervals. Before switching to the sleep-mode from the wake-mode, the MSS needs to inform the base station using a sleep request message. After receiving the sleep response message from the base station with parameters initial-sleep window ($T_{\min}$), final-sleep window ($T_{\max}$), listening window (L) and start time, the MSS can enter the sleep-mode.

In PSC Type I (PSC I), the duration of sleep interval in the n-th cycle is given by [3]:

$$T_n = \begin{cases} T_{\min},\ n = 1 \\ Min\left(2^{n-1} \cdot T_{\min},\ T_{\max}\right),\ n > 1 \end{cases}$$

The sleep window size basically increases binary exponentially. If the MSS continues in the sleep-mode, this process is repeated as long as the sleep window does not exceed $T_{\max}$, whereas it remains fixed when the duration of sleep window reaches $T_{\max}$. Otherwise, the MSS returns to the wake-mode if there are frames arriving at base station for the MSS, and vice versa.

The PSC of Type II (PSC II) is recommended for the connections of UGS, rtPS service connection. Unlike PSC I, PSC II uses constant sleeping window size instead of doubling sleep interval. Moreover, the MSS may send or receive any SDUs during its listening interval (i.e., L), hence the short data messaging transmission or reception can be carried out without interruption of sleep-mode on the MSS. The potential waste of switch cost can thus be avoided.

In PSC Type III (PSC III), the length of sleep period is predefined. The MSS simply sleeps for the predefined period of time, and then returns to normal operation. Type III is the simplest sleep-mode in PSC. The base station can activate the PSC operation of a MSS by sending a MOB-SLP-RSP. And then MSS deactivation of PSC after the expiration of sleep window. In other words, base station can dynamically manage the MSS sleep interval in accordance with the network condition.

3. Proposed Method

The scheduling method of BS has significant effect on the power consumption of MSS, and the usage time of power is important to the success proceeding of service. Therefore, in order to use the power of MSS effectively and enhance the usage efficiency of WiMAX network channel, this study proposed a scheduling method, called the Integrated Power Saving Schedule (IPSS).

As shown in Figure 1, IPSS uses two-level scheduling strategy. Its scheduling cycle can be divided into scheduling cycle and sub-scheduling cycle, of which scheduling cycle is n times of the sub-scheduling cycle, and the sub-scheduling cycle is m times of the frame (n, m are integers). Service flow that needs real-time service, i.e. UGS, ertPs, rtPs, would be schedule once for every sub-scheduling cycle (short schedule interval), while non-real-time service, i.e. nrtPs, BE, is scheduled once for every scheduling cycle (long schedule interval).

Although it is specified in IEEE 802.16 standard that each service flow could send bandwidth request to each base station independently, when the base station replies to the bandwidth grant, it still treats MSS as the basic

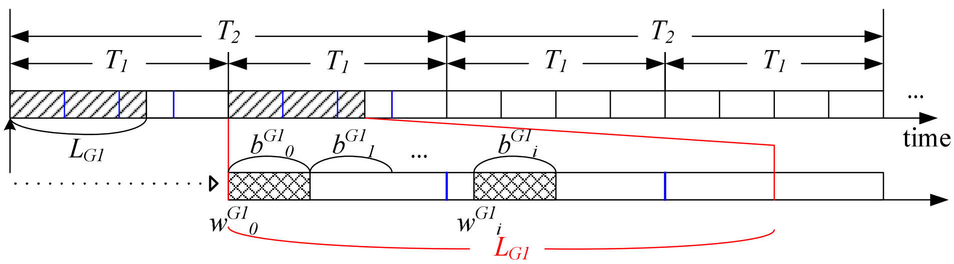

Figure 2. The scheduling of G1 in the next T1 cycle at the starting point of the previous T1 cycle

unit, and the scheduling unit of MSS determines the distribution of bandwidth (instead of responding to the service flow individually). To enhance the power usage efficiency of the mobile station, IPSS also uses MSS as the basic unit when scheduling.

Before scheduling, IPSS divides the MSS connecting to BS into 2 groups: group 1 (G_1) includes the MSS that needs real-time service (i.e. MSS with UGS, ertPs or rtPs connection), and other MSSs (i.e. MSS only in nrtPs, BE connection) are in group 2 (G_2). T_1, T_2 are the time lengths of sub-scheduling cycle and scheduling cycle, respectively. IPSS scheduler conducts scheduling following the steps below:

Step1: compute the time period for the next T_1 at the starting of the previous sub-scheduling cycle, and the time period for the next T_2 at the starting of the previous scheduling cycle, then the channel usage time, L_{G1}, L_{G2}, allocated to G_1,G_2 in a sub-scheduling cycle.

Step2: Compute the bandwidth assigned to each MSS, and assign the wake-up time of MSS.

The sub-scheduling cycle period, is given by:

$$T_1 = m \cdot T_f,\ m = \arg\max_i (i \cdot T_f \le \text{delay constraint}),\ i \in N \qquad (1)$$

and the scheduling cycle period, is given by:

$$T_2 = n \cdot T_1,\ n \in N \qquad (2)$$

With T_1 as a basic cycle, IPSS would schedule the MSS of G_1 after each T_1 cycle, then schedule the MSS of G_2 after n T_{L1} cycle. After obtaining the time period of T_1 cycle, the scheduler would compute the access time of station of G_1 in sub-scheduling cycle. Then, base on the minimal reserved data rate, the length of T_1 cycle is proportionally assigned to stations of G_1 and G_2:

$$L_{G1} = T_1 \times \frac{\sum_{i}^{\text{flow in G1}} R^{i}_{min}}{\sum_{i}^{\text{flow in G1,G2}} R^{i}_{min}} \qquad (3)$$

Where, R^i_{min} is the minimal reserved data rate for the service flow i.

Then the time length in T_1 cycle for G_2, is calculated by:

$$L_{G2} = T_1 - L_{G1} \qquad (4)$$

After passing each T_2 cycle, the IPSS would allocate the L_{G2} time period left in n T_1 to stations of G_2.

After computing the allocation areas of the scheduling cycle, sub-scheduling cycle, and bandwidth, IPSS then computes the time point w_i for waking-up of MSS in each cycle, and the time interval b_i for accessing the channel. IPSS would notify the MSS of the time and length of the next access after each wake-up of MSS, as shown in Figures 2 and 3.

For the reserved bandwidth, as shown in Figure 2, IPSS first calculates the MSS of G_1, the allocated length of access time in T_1 is based on the proportion of the minimal reserved data rate. For example, MSS i has number of flow j, and then MSS i can reserve to access time of b^{G1}_i:

$$b^{G1}_i = L_{G1} \times \frac{\sum_{j}^{\text{flow in MSS } i} R^{j}_{\min}}{\sum_{j}^{\text{flow in G1}} R^{j}_{\min}} \qquad (5)$$

The following equation is used to compute the relative time for MSS to start accessing the channel, wherein the relative time is the expected wake-up time of MSS with each T_2 as the starting point, using the length based on T_2 cycle. For example, MSS 0, which is the first MSS of group 1, can be transmitted after T_1 period. And MSS i, which is the i^{th} MSS of group 1, can be transmitted after T_1 cycle plus the total time of MSSs reserved time in group 1 before MSS i coming.

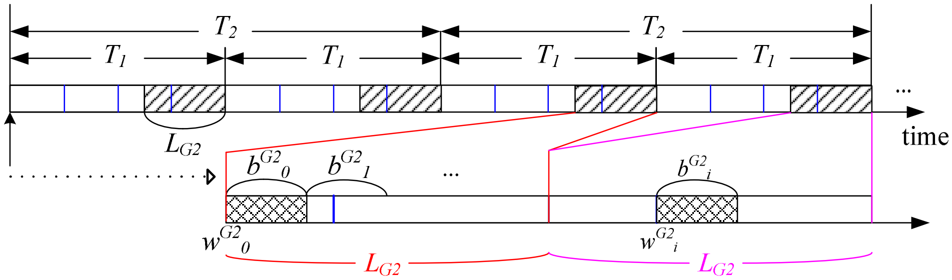

Figure 3. The scheduling of G2 in the next T2 cycle at the starting point of the previous T2 cycle

$$w^{G1}{}_0 = T_1 \quad (6)$$

$$w^{G1}{}_i = w^{G1}{}_{i-1} + b^{G1}{}_{i-1} = T_1 + \sum_{m=0}^{i-1} b^{G1}{}_m \quad (7)$$

The allocation of stations of G_2 is similar to that of G_1, as shown in Figure 3. First, the accessing time length allocated to stations in G_2 within the T_2 cycle is computed, then Eq. (8) is used to differentiate the time allocated to each station.

$$b^{G2}{}_k = (n * L_{G2}) \times \frac{\sum_i^{flow\ in\ MSS\ k} R^i_{\min}}{\sum_i^{flow\ in\ G2} R^i_{\min}} \quad (8)$$

Then, Eqs. (9) and (10) are used to compute the relative time for MSS to start accessing the channel. For example, MSS 0, which is the first MSS of group 1, can be transmitted after T_2 cycle plus L_{G1} period. And MSS i, which is the i^{th} MSS of group 2, can be transmitted after T_2 cycle plus the total time of MSSs reserved time in group 2 before MSS i coming. Because the time of group 2 reserved is L_{G2} period, MSSs of group 2 sometimes need to wake up at two T_1 cycles.

$$w^{G2}{}_0 = T_2 + L_{G1} \quad (9)$$

$$w^{G2}{}_i = T_2 + L_{G1} + \left\lfloor \frac{\sum_{k=0}^{i-1} b^{G2}{}_k}{L_{G2}} \right\rfloor \times T_1 + (\sum_{k=0}^{i-1} b^{G2}{}_k)\% L_{G2} \quad (10)$$

In summary, when allocating the frames, IPSS would first select MSS that requires real-time QoS for scheduling (the MSSs of group 1), then select the rest of MSS by order. If there is extra bandwidth, it would then schedule the MSS without the need for real-time QoS (the MSSs of group 2).

4. Analytical Model

Before the analysis, the environmental hypothesis is defined as follows:

(1) λ represents the average packet arrival rate. The distribution probability model of packet arrival is based on *Poisson* probability distribution, thus, the inter-arrival rate of packet is index distribution, and the arrival of each packet at time of [0, T] is evenly distributed (assumed that the packet length is fixed).

(2) For convenience of analysis, it is assumed that there is only one service flow between each MSS and base station, there are M MSS require real-time QoS, and N MSS do not need real-time QoS. Each is independent.

(3) It is assumed that the base station and MSS have no limitation on buffer capacity.

(4) It is assumed that there is no incident of packet loss during data transmission.

In terms of computation for energy, the following discusses the power-saving by station of group 1 in T_2 cycle. In [0,T_2], the MSS in group 1 would wake-up once in each T_1 cycle, thus the MSS of G_1 的 would wake-up n times, among which the time length of transmission after wake-up is L_{G1}, allocated proportionally based on the data rate. Since the M MSS would use the same data rate for transmission, the time allocated to each G_1 is $(1/M) \times L_{G1}$, and the remaining time is maintained at the sleep-mode. Since the wake-up mechanism for the sleep-mode is in basic unit of frame, only when the entire frame is in the sleep-mode would it enter the sleep-mode. For power-saving effect, the ratio of the actual sleep time to the total time is used to evaluate the effectiveness of the sleep. The equation is written as follows:

$$\varepsilon_{rt} = \frac{\left(m - \left\lceil \frac{\frac{1}{M} \times L_{G1}}{T_f} \right\rceil \right) \times T_f \times n}{T_2} \quad (11)$$

Where, the length of L_{G1} is allocated for MSS under the same base station.

It is assumed that the MSS of G_1 and G_2 uses the same distribution model, L_{G1} is allocated based on the ratio of G_1, G_2 for T_1, hence, the lengths of L_{G1} and L_{G2} are written as below:

$$L_{G1} = \frac{M}{M+N} \times T_1 \tag{12}$$

$$L_{G2} = \frac{N}{M+N} \times T_1 \tag{13}$$

According to Eqs. (1), (2), and (12), Eq. (11) can be rewritten as:

$$\varepsilon_{rt} = \frac{m - \left\lceil \dfrac{m}{M+N} \right\rceil}{m} \tag{14}$$

The following discusses the power-saving of stations of group 2 in T_2 cycle. In $[0,T_2]$, the MSS of group 2 would only wake up once, and proceed with transmission within the predefined length of wake-up time; it remains in the sleep-mode in the rest of the time. The allocation method is to combine the lengths of all L_{G2} in the T_2 cycle, and allocate proportionally. Thus, the wake-up time allocated to each G_2 is $(1/N) \times n \times L_{G2}$ (pro rata), and the remaining time is in the sleep-mode. The equation for evaluating the effectiveness of sleep is as follows:

$$\varepsilon_{nrt} = \frac{\left(m \times n - \left\lceil \dfrac{\frac{1}{N} \times n \times L_{G2}}{T_f} \right\rceil \right) \times T_f}{T_2} \tag{15}$$

According to Eqs. (1)(2)(13), Eq.(15) can be rewritten as:

$$\varepsilon_{nrt} = \frac{m \times n - \left\lceil \dfrac{m \times n}{M+N} \right\rceil}{m \times n} \tag{16}$$

As for the overall power-saving effect, there are a total of $M+N$ stations. If considering the ratio of the sum of the sleep time of each station to the total wake-up time for evaluating the effectiveness of sleep, the equation is written as below:

$$\varepsilon_{total} = \frac{\left(m - \left\lceil \dfrac{\frac{1}{M} \times L_{G1}}{T_f} \right\rceil \right) \times T_f \times n \times M + \left(m \times n - \left\lceil \dfrac{\frac{1}{N} \times n \times L_{G2}}{T_f} \right\rceil \right) \times T_f \times N}{(M+N) \times T_2} \tag{17}$$

Lastly, according to Eqs. (1), (2), (12) and (13), Eq. (17) can be rewritten as follows:

$$\varepsilon_{total} = \varepsilon_{rt} \times \frac{M}{M+N} + \varepsilon_{nrt} \times \frac{N}{M+N} \tag{18}$$

The following uses analytical equation to evaluate the effective of power-saving by IPSS. Simulation experiment was conducted to validate the accuracy of the results.

5. Numerical Results

This section presents the effect of Integrated Power Saving Schedule. In this study, the parameters were M = 50, N = 50, with mean of Poisson λ=25. Figure.4 shows the analysis of sleeping ratio with group 1, the influence of delay constraint is more obvious than the number of n because the MSS of group 1 needs to wake up at each T_1 cycle. Therefore, the MSS of group 1 is not influenced by different numbers of n. Figure 5 shows the analysis of sleeping ratio with group 2. As seen, the sleeping ratio increases as the delay constraint and the number of n increase. This is because the MSS of group 2 can aggregate more packets to transmit wake-up time at once. Figure 6 shows the analysis of sleeping ratio with group 1 and group 2. The sleeping ratio is better when the number of n and the delay constraint grow.

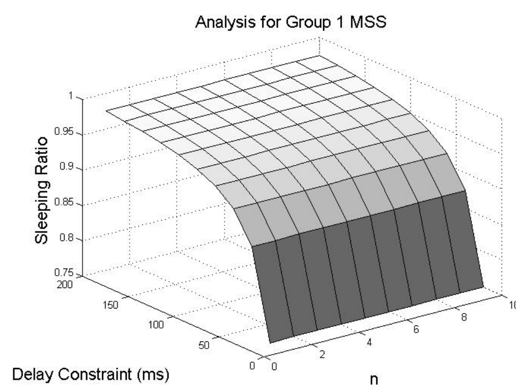

Figure 4. Analysis of sleeping ratio with group 1

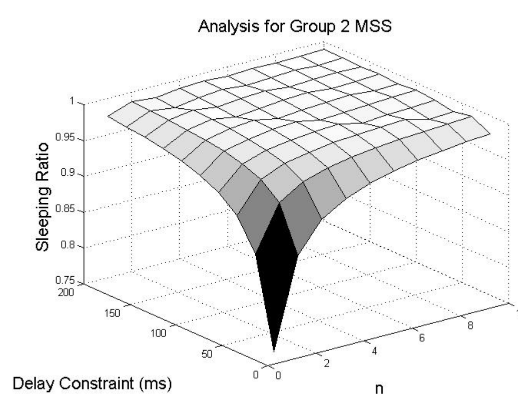

Figure 5. Analysis of sleeping ratio with group 2

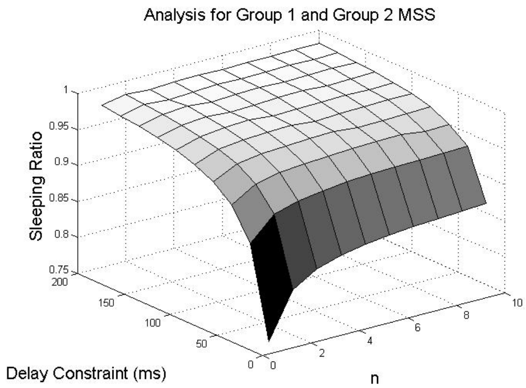

Figure 6. Analysis of sleeping ratio with group 1 and group 2

Figure 7 shows the ratio of power-saving with analysis and simulation. In this case, T_f and T_1 are set to 5 ms and 20 ms, respectively (i.e., m = 4) and other parameters are the same as above. In order to satisfy QoS requirement, the MSS in group1 needs to wake up in each T_1 cycle, whereas that in group 2 only needs to wake up once in each T_2 cycle. The MSS of group 1 needs to wake up at least a T_f time in a T_1 cycle, so the sleeping ratio is about to 3/4. Figure 7 shows that the analysis model matches with the simulation results, and the sleeping ratio increases with *n*. However, the performance of power-saving mechanism can longer reach a better performance when the value of *n* increases to a certain degree. According to the initially evaluated result, the value of *n* is recommended to be set between 3 and 8.

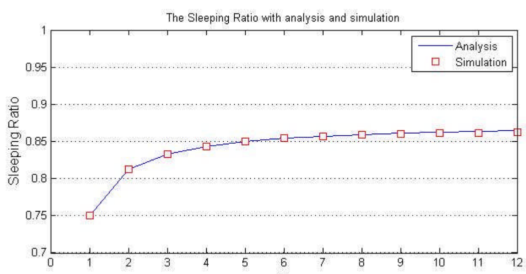

Figure 7. The sleeping ratio with analysis and simulation

6. Conclusions

This study proposed an energy-saving mechanism of the emerging IEEE 802.16e standard. This paper evaluated the IPSS scheme via analytical and numerical results. After the comparative study on the sleep-mode operation, the results showed that the pre-negotiation based IPSS scheme could carry out adaptive switching according to the application QoS requirement and network condition.

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