

Adaptive Power Saving Mechanism Considering the Request Period of Each Initiation of Awakening in the IEEE 802.16e System

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Abstract—Performance of the IEEE 802.16e power management is mainly affected by two operating parameters: the minimum sleep interval (T_{min}) and the maximum sleep interval (T_{max}), in sleep-mode operation. To enhance the performance, this letter proposes a new power saving mechanism, which adaptively controls these parameters by considering the request period of each initiation of awakening (T_{int}). The numerical analysis and simulation results show that this mechanism can achieve better energy conservation with reasonable response delay of Medium Access Control (MAC) Service Data Units (SDUs) than the standard operation.

Index Terms—IEEE 802.16e, power management, energy, sleep-mode.

I. INTRODUCTION

THE IEEE 802.16e (mobile WiMAX) [1] specifies sleep-mode and wake-mode for efficient power management of a Mobile Subscriber Station (MSS). In power management, energy conservation is the prime goal, but attention should also be paid to the reduction of response delay of awakening Medium Access Control (MAC) Service Data Units (SDUs). When an MSS attempts to transmit data traffic to a Base Station (BS) (*MSS initiation of awakening*), awakening of the MSS can be initiated without response delay due to the fact that it is self-operational. On the other hand, when a BS attempts to transmit data traffic to an MSS (*BS initiation of awakening*), a MAC SDU for awakening of the MSS can only be transferred to it during listening intervals so that response delay can occur [2]. Consequently, a power saving mechanism need to be properly managed in consideration of these operating conditions.

In sleep-mode, an MSS conserves energy by powering down during sleep intervals and only powering up during listening intervals [1]. Thus, the reduction of the total number of listening intervals included in each sleep cycle is the key for energy conservation. The number of sleep cycles is affected by the request period of each initiation of awakening (T_{int}) and two operating parameters: the minimum sleep interval (T_{min}) and the maximum sleep interval (T_{max}) [3], [4]. In addition, there is a tradeoff relationship between energy consumption and response delay [4]. Therefore, since requests to initiate

awakening are not controllable, manipulating the values of the two parameters is an efficient way of reaching target performance in various operating conditions.

As far as we are aware of, however, earlier studies on power management have mainly dealt with standard operation [2]–[4] and presented power saving mechanism without simultaneously considering the aforementioned operating parameters [5]. Therefore, this letter proposes a new power saving mechanism, which adaptively controls the two operating parameters by reflecting the previous T_{int} . The benefit of this proposal is to save energy by maintaining a fewer number of sleep cycles while keeping reasonable response delay.

II. ADAPTIVE POWER SAVING MECHANISM (APSM)

Let us observe the effects of the relative size of T_{min} and T_{max} compared to T_{int} on performance of power management. For example, if the parameters are set to smaller values compared to T_{int} , response delay may be lower but more energy consumption is expected because the smaller T_{min} and T_{max} can induce more sleep cycles. On the other hand, if the parameters are set to larger values, higher energy conservation can be achieved but more response delay is expected. Thus, we can achieve a higher efficiency of power management within a lower response delay if we control T_{min} and T_{max} adaptively by taking T_{int} into account.

Now, we will explain how APSM operates using Fig. 1. T_{MIN} [T_{MAX}] is the smallest [largest] value that T_{min} [T_{max}] can take. T_f is the final sleep interval in the previous sleep-mode. During one sleep-mode operation, if there is no initiation of awakening in each sleep cycle, the size of operating sleep interval doubles from the size of the previous sleep interval until reaching T_{max} . When an initiation of awakening occurs, T_{min} and T_{max} are newly updated based on the following policies: (1) If T_f is equal to T_{MIN} and T_{min} is smaller than T_{max} , then T_{max} is regarded as a relatively larger size compared to T_{int} . Thus, T_{max} is updated and becomes half of the T_{max} in the previous operation. (2) Or, if T_f is equal to T_{max} and T_{max} is smaller than T_{MAX} , T_{max} is regarded as a relatively smaller size compared to T_{int} and the T_{max} doubles. (3) Otherwise, T_{min} is updated to half of T_f .

By applying the proposed parameter decision mechanism in the IEEE 802.16e power management, the average number of sleep cycles can be maintained at as few as possible with reasonable response delay of awakening MAC SDUs under various T_{int} . Thus, this mechanism can also reduce energy consumption. The following section will show numerical analysis based on its operating policy.

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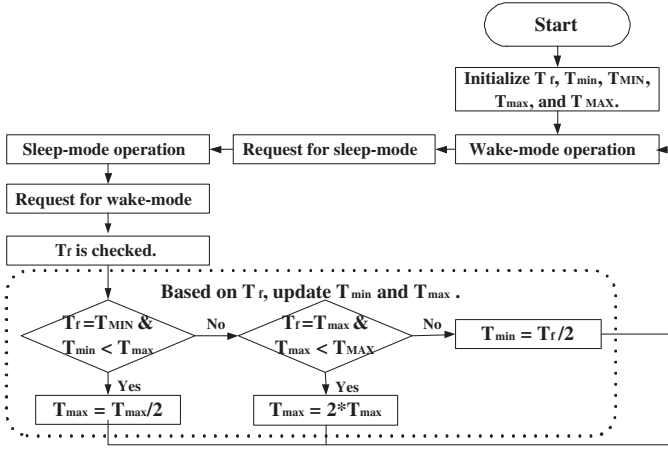


Fig. 1. Operating procedure of the proposed APSM.

III. ANALYTICAL MODELS

This section presents an analytical model to evaluate the proposed mechanism. Each MAC SDU for awakening of an MSS is assumed to arrive at it with Poisson process with rate λ . The request period (inter-arrival time) of an initiation of awakening is exponentially distributed with mean $1/\lambda$, equal to the average request period of initiations of awakening (T_I). According to the standard sleep-mode operation [1], the duration of the k^{th} sleep interval is obtained by:

$$T_k = \min [2^{k-1} T_{\min}, T_{\max}], \text{ for } 1 \leq k. \quad (1)$$

The duration of the k^{th} sleep cycle is given by:

$$C_k = T_k + L, \quad (2)$$

where L is the duration of listening interval.

The probability that there is no initiation of awakening during C_k is then obtained by:

$$P_k = e^{-\lambda C_k}, \quad 1 \leq k \leq M, \quad (3)$$

where $T_{MAX} = 2^{M-1} T_{MIN}$.

Thus, the probability that there is at least one initiation of awakening during C_k is $1 - e^{-\lambda C_k}$.

The probability that there is at least one initiation of awakening in the k^{th} sleep cycle during one sleep-mode is given by:

$$P_k^S = \sum_{a=0}^{k-1} P_a \cdot (1 - P_k) = e^{-\lambda \sum_{a=0}^{k-1} C_a} (1 - e^{-\lambda C_k}). \quad (4)$$

In order to analyze the performance of APSM, we apply the two dimensional Markov chain. Let $\pi_{i,j}$ be the steady state probability when $T_{max} = 2^{M-1-i} \cdot T_{MIN}$ ($0 \leq i \leq M-1$), and the size of operating sleep interval during overall sleep-mode operation, $T_j = 2^j \cdot T_{MIN}$ ($0 \leq j \leq M-i-1$). We have the following steady state equations.

For $j = 0$, we have

$$0 = \pi_{i,j}(-1) + \pi_{i,j+1}(1 - P_j), \quad (5)$$

where $i = 0$,

$$0 = \pi_{i-1,j}(1 - P_j) + \pi_{i,j}(-1) + \pi_{i,j+1}(1 - P_{j+1}), \quad (6)$$

where $1 \leq i \leq M-3$,

$$0 = \pi_{i-1,j}(1 - P_j) + \pi_{i,j}(-1) + \pi_{i+1,j}(1 - P_j), \quad (7)$$

where $i = M-2$, and

$$0 = \pi_{i,j}(-1 - P_j) + \pi_{i-1,j}(1 - P_j), \quad (8)$$

where $i = M-1$.

For $1 \leq j \leq M-i-3$, we have

$$0 = \pi_{i,j-1}(P_{j-1}) + \pi_{i,j}(-1) + \pi_{i,j+1}(1 - P_{j+1}), \quad (9)$$

where $0 \leq i \leq M-3$,

For $j = M-i-2$, we have

$$0 = \pi_{i,j-1}(P_{j-1}) + \pi_{i,j}(-1) + \pi_{i,j+1}(1 - P_{j+1}) + \pi_{i+1,j}(1 - P_j), \quad (10)$$

where $i = 0$, and

$$0 = \pi_{i,j-1}(P_{j-1}) + \pi_{i,j}(-1) + \pi_{i+1,j}(1 - P_j), \quad (11)$$

where $1 \leq i \leq M-3$.

For $j = M-i-1$, we have

$$0 = \pi_{i,j-1}(P_{j-1}) + \pi_{i,j}(-1 - P_j), \quad (12)$$

where $0 \leq i \leq M-2$.

For brevity, $\pi_{i,j}$ values out of the range ($0 \leq i \leq M-1$ and $0 \leq j \leq M-i-1$) take the value zero.

Then, we also have the normalization equation:

$$\sum_{i=0}^{M-1} \sum_{j=0}^{M-1+i} \pi_{i,j} = 1. \quad (13)$$

The average number of sleep cycles in overall sleep-mode operation is then obtained by:

$$E[n] = \sum_{i=0}^{M-1} \sum_{j=0}^{M-1+i} \pi_{i,j} \sum_{k=j+1}^{\infty} k \cdot P_k^S. \quad (14)$$

The average response delay of awakening MAC SDUs in BS initiations of awakening is given by:

$$E[R] = \sum_{i=0}^{M-1} \sum_{j=0}^{M-1+i} \pi_{i,j} \sum_{k=j+1}^{\infty} P_k^S \cdot \frac{C_k}{2}. \quad (15)$$

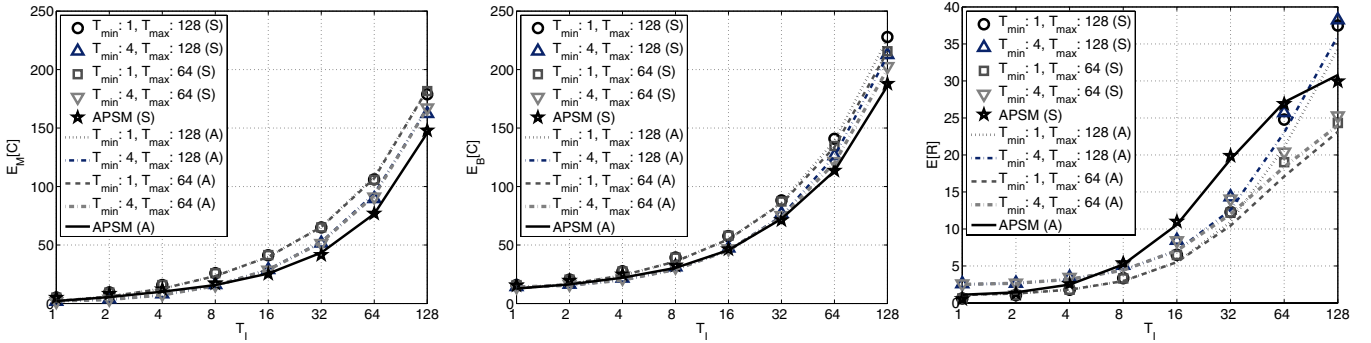
The average energy consumption in BS initiations of awakening is given by:

$$E_B[C] = \sum_{i=0}^{M-1} \sum_{j=0}^{M-1+i} \pi_{i,j} \sum_{k=j+1}^{\infty} P_k^S \sum_{a=j+1}^k (T_a E_S + L E_L), \quad (16)$$

where E_S is the consumed energy per 1 unit of time during sleep intervals, and E_L is the same during listening intervals.

The average energy consumption in MSS initiations of awakening is achieved by subtracting the consumed energy during the average response delay from $E_B[C]$. So, it is obtained by:

$$E_M[C] = \sum_{i=0}^{M-1} \sum_{j=0}^{M-1+i} \pi_{i,j} \sum_{k=j+1}^{\infty} P_k^S \sum_{a=j+1}^{k-1} (T_a E_S + L E_L) + \sum_{i=0}^{M-1} \sum_{j=0}^{M-1+i} \pi_{i,j} \sum_{k=j+1}^{\infty} P_k^S \frac{T_k E_S}{2}. \quad (17)$$



(a) The average energy consumption in MSS initiations of awakening (b) The average energy consumption in BS initiations of awakening (c) The average response delay time of awakening MAC SDUs in BS initiations of awakening

Fig. 2. Performance comparison between APSM and standard operation (T_I : the average request period of initiations of awakening, S: simulation, A: analysis).

IV. PERFORMANCE EVALUATION

This section evaluates the performance of APSM with the following parameters: $L = 1$ unit of time, $E_S = 1$, and $E_L = 10$, $T_{MIN} = 1$ unit of time, and $T_{MAX} = 64$ units of time ($M=7$). Simulation results are obtained with the following assumption: 1) Each interarrival time of awakening MAC SDU is set to sleep time during one sleep-mode, and 2) Wake-mode is not considered.

The average energy consumption in MSS initiations of awakening ($E_M[C]$) and that in BS initiations of awakening ($E_B[C]$) are shown in Fig. 2 (a) and (b), respectively. From the results of $E[n]$ in Fig. 3, $E_M[C]$ and $E_B[C]$ under APSM are smaller than that under the standard operation, due to the reduced $E[n]$. As T_I increases, the degrees of enhancement of $E_M[C]$ and $E_B[C]$ also increase because APSM maintains the $E[n]$ as low as possible, while the standard operation simply comes to increase $E[n]$. As shown in Fig. 2 (c), APSM produces a slightly longer average response delay time for awakening MAC SDUs ($E[R]$) than the standard operation only in the middle range of T_I . This is mainly due to the decreased $E[n]$.

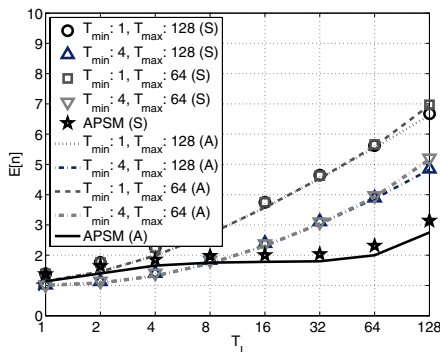


Fig. 3. The average number of sleep cycles in overall sleep-mode operation.

In addition, we show the average number of sleep cycles ($E[n]$) in sleep-mode in Fig. 3. In most ranges of T_I , except in the low value range, APSM produces smaller $E[n]$ than the standard sleep-mode operation. This implies that our mechanism can adaptively pursue the current state of request period of each initiation of awakening while the standard operation can not. Consequently, our proposed APSM can save much more energy than the standard operation. The benefit of this mechanism is especially revealed when T_I is in the higher value range.

V. CONCLUSION

In this letter, we proposed an adaptive power saving mechanism for the IEEE 802.16e systems. Contrary to the standard mechanism, APSM adaptively decides the sizes of T_{min} and T_{max} by taking into account the request period of initiation of awakening in the previous sleep-mode operation. Our analytical and simulation results showed that the proposed mechanism had better performance in energy consumption by minimizing the average number of sleep cycles. In addition, the efficiency of energy saving compensated for the deterioration of response delay.

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