A New Adaptive Energy Management Scheme in IEEE 802.16e Mobile WiMAX

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Abstract

Energy management strategy is an indispensable component in the emerging IEEE 802.16e mobile WiMAX because Mobile Subscriber Stations are normally powered by a rechargeable battery. In this paper, we propose a new energy saving scheme by adjusting the sleep windows adaptively. Simulation results indicate that the new policy is able to reduce power consumption significantly with much less increased packet delay.

1. Introduction

With the support for mobility capability in the latest specification, the IEEE 802.16 Working Group is attempting to develop high-bandwidth and high-capacity standards for Broadband Wireless Access (BWA). The IEEE 802.16 standard defines the physical (PHY) layer and Medium Access Control (MAC) layer [1, 2]. Given that Mobile Subscriber Stations (MSSs) are usually powered by a rechargeable battery, it is of great significance to develop an efficient mechanism for conserving energy in wireless networks, to maximize the lifetime of mobile stations and to enhance network resilience.

In order to manage limited power efficiently, a sleep mode operation is specified in the IEEE 802.16e MAC protocol. In the literature, the sleep strategy has been discussed in [3] [4]. The two studies solely focus on analyzing the standardized sleep mode and no new strategy is proposed to further reduce power consumption. In this paper, we present a new energy saving policy. The simulation result demonstrates that the proposed scheme is able to reduce energy consumption significantly with minor penalty delay.

2. Standardized Sleep Mode in IEEE 802.16e

Before entering sleep mode, the MSS sends a request message MOB-SLP-REQ to the BS. Upon receiving the request, the BS replies with the response message MOB-SLP-RSP, which indicates the initial-sleep window $T_{\min}$, final-sleep window $T_{\max}$ and listening window L. Upon receiving MOB-SLP-RSP, the MSS enters into sleep mode.

We now focus on the sleep mode mechanism. The duration of the first sleep interval T_1 is equal to the initial-sleep window $T_{\min}$. After the first sleep interval, the MSS transits into a listening state and listens to the traffic indication message MOB-TRF-IND broadcast from the BS. This message indicates whether there has been traffic addressed to the MSS during its sleep interval T_1. If it is negative, the MSS continues in sleep mode after the listening interval L. Otherwise, the MSS will return to wake mode. We term the sleep interval and its subsequent listening interval as a cycle. If the MSS continues in sleep mode, the new sleep interval will be double the length of the preceding sleep interval. This process is repeated as long as the sleep interval does not exceed the final-sleep window $T_{\max}$. If the MSS has reached $T_{\max}$, the length of the sleep interval will remain $T_{\max}$. The length of sleep window in the n^{th} cycle is given by

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$$T_n = \begin{cases} T_{\min} & , n=1 \\ \min(2^{n-1}T_{\min}, T_{\max}) & , n>1 \end{cases} \quad (1)$$

For the sake of presentation, we let $T_{\max} = T_{N_{\max}-1} = 2^{N_{\max}-1}T_1$. This also indicates that the maximum number of sleep windows before reaching the final-sleep window is $N_{\max}$. We define the set of all possible lengths of sleep window as $\{T_1, T_2, \cdots, T_{N_{\max}-1}\}$.

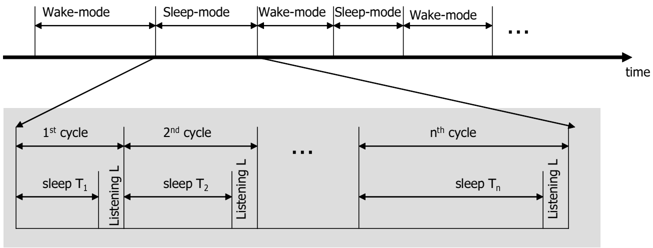

Figure 1 Wake mode and sleep mode transition in the IEEE 802.16e

Fig. 1 shows the wake mode and sleep mode of an MSS. It may be seen that the MSS alternates between wake mode and sleep mode throughout its lifetime.

3. A New Adaptive Energy Management Mechanism

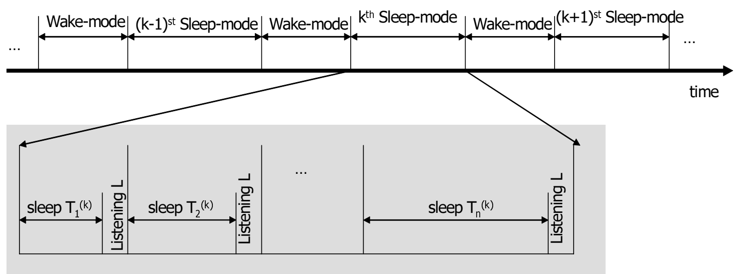

Figure 2 Enhanced energy management mechanism in IEEE 802.16e

We term a sleep and the immediate next sleep mode as *neighboring sleep modes*. Fig. 2 shows the indices of all sleep modes during an MSS's lifetime. During the k^{th} sleep mode, an MSS experiences a number of sleep windows before sleep mode termination. We define the duration of all sleep windows as the set $\{T_1^{(k)}, T_2^{(k)}, \cdots, T_n^{(k)}\}$ for the k^{th} (*k =1,2,…*) sleep mode, where $T_i^{(k)}$ (*i=1,2,…,n*)denotes the i^{th} sleep window.

In the enhanced scheme, the initial-sleep window during the k^{th} sleep mode is set as $T_1^{(k)}$, instead of $T_{\min}$ as specified in the standard. The reasoning behind this setting is as follows. In the standard, the length $T_{\min}$ is fixed without considering the traffic pattern. The MSS's termination of sleep mode during the n^{th} sleep window implies that this sleep window is not suitable for the sleep length for this specific sleep mode. From a statistical point of view in the long run, the average duration of the sleep window right before the last sleep window (i.e.$T_{n-1}^{(k-1)}/2$) is suitable. Furthermore, using the moving average in a number of previous consecutive neighboring sleep modes, the initial-sleep window $T_1^{(k)}$ should be more appropriate. We assign the initial-sleep window $T_1^{(k)}$, which is equal to the moving average of q previous average sleep windows coming next to the last sleep window. Since $T_{n-1}^{(k-i)}/2$ is the average length of the sleep window right before the final-sleep window in the $(k-i)^{th}$ sleep mode, we have

$$T_1^{(k)} = (T_{n-1}^{(k-1)}/2 + T_{n-1}^{(k-2)}/2 + \cdots + T_{n-1}^{(k-q)}/2)/q = (\sum_{i=1}^{q} T_{n-1}^{(k-i)})/2q \quad (2)$$

where q is a positive integer. In the above equation, $T_{n-1}^{(k-i)}/2$ is set as $T_{n}^{(k-i)}/2$ if $n=1$. When $T_1^{(k)}$ is smaller than $T_{\min}$, $T_1^{(k)}$ is set as $T_{\min}$. When $T_1^{(k)}$ is greater than $T_{\max}$, $T_1^{(k)}$ is set as $T_{\max}$. Moreover, after the calculation in equation (1), $T_1^{(k)}$ may not be exactly one of the values in the set $\{T_1, T_2, \cdots, T_{N_{\max}-1}\}$. In such a case, we choose

$$T_1^{(k)} = \begin{cases} T_i, & |T_1^{(k)} - T_i| < |T_1^{(k)} - T_{i+1}| \\ T_{i+1}, & |T_1^{(k)} - T_i| \geq |T_1^{(k)} - T_{i+1}| \end{cases} \quad (3)$$

where $i = 1, 2, \cdots, N_{\max} - 1$.

In summary, the enhanced energy management mechanism is presented as follows. An MSS defines a variable to store the updated initial-sleep window length. Whenever the MSS enters sleep mode, it chooses the first sleep window $T_1^{(k)}$ based on the equation (1). After the first sleep interval, the MSS enters a listening state. If MOB-TRF-IND indicates in the negative, the MSS continues in sleep mode. The next sleep window will be twice the size of the preceding sleep interval if $2 \times T_1^{(k)}$ is no more than $T_{\max}$. Otherwise, the next sleep window remains fixed at $T_{\max}$. This process is repeated until sleep mode is terminated. It is clear that only the first length of sleep window length differs from the scheme in IEEE 802.16e, which implies that our proposed scheme is compatible with the standardized energy management scheme in IEEE 802.16e.

Let $\varepsilon^{(k)}$ denote the consumed energy in the k^{th} sleep mode during an MSS's lifetime. Then, the average consumed energy during sleep mode is expressed as

$$\bar{\varepsilon} = \lim_{k\to\infty} (\varepsilon^{(1)} + \varepsilon^{(2)} + \cdots + \varepsilon^{(k)})/k \quad (4)$$

Let $D^{(k)}$ denote the delay in the k^{th} sleep mode during an MSS's lifetime. Then, the average delay during a sleep mode period is given by

$$\bar{D} = \lim_{k\to\infty} (D^{(1)} + D^{(2)} + \cdots + D^{(k)})/k \quad (5)$$

4. Numerical Results

We choose the following default parameters: $L=1$, $T_{\min}=1$ and $T_{\max}=1024$. The consumed energy units are set as $E_L = 0.045W$ and $E_S = 1.5W$ [5]. In what follows, we employ m_d-stage Erlang distributed downlink packet inter-arrival time t_d and m_u-stage uplink packet inter-arrival time t_u. Specifically, the pdf is expressed as

$$f_{t_k}(t) = \frac{(m_k \lambda_k)^{m_k} t^{mk-1}}{(m_k - 1)!} e^{-m_k \lambda_k t}; \quad k \in \{d, u\} \quad (6)$$

Fig. 3 shows the reduced energy consumption and introduced extra delay in our proposed mechanism with different downlink traffic processes. This example demonstrates the condition that only downlink traffic process is considered. We let $\varepsilon_{802.16e}$ and $\varepsilon_{\text{Enhanced}}$ denote the energy consumption in the standard IEEE 802.16e and in our proposed scheme, respectively. The saved energy consumption is then expressed as $(\varepsilon_{802.16e} - \varepsilon_{Enhanced})/\varepsilon_{802.16e}$. Similarly, we let $D_{802.16e}$ and D_{Enhanced} denote the packet delay in the two schemes respectively. The extra delay introduced by the proposed scheme is expressed as $(D_{\text{Enhanced}} - D_{\text{802.16e}})/D_{\text{802.16e}}$. For ease of comparison, we have employed an identical scale on the y-axis for the two subfigures. The saved energy and extra delay decreases as the traffic arrival rate increases. The comparison indicates that power consumption can be reduced significantly. i.e., for $\lambda_d = 0.02$, the saved energy can be 37%. We also notice that the introduced extra delay is around 25% under the same condition, which is much smaller than the percentage with respect to the saved energy and indicates the advantage of our proposed strategy. Under other identical conditions, the percentage of saved energy is always higher than that of extra delay. Furthermore, the sleeping mechanism is standardized for best effort and non-realtime services, which is insensitive to a small increase in packet delay. As a result, with respect to the tradeoff between energy consumption and delay, our proposed scheme outperforms the standard scheme in IEEE 802.16e.

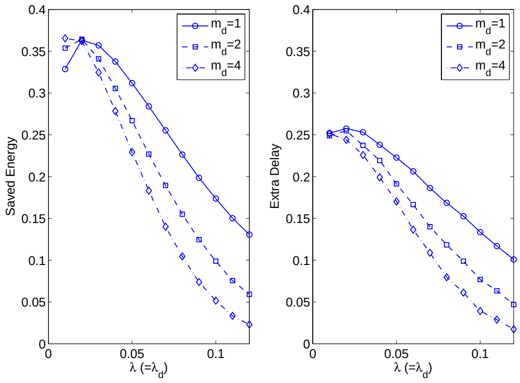

Figure 3 Saved energy and extra delay with different downlink traffic processes

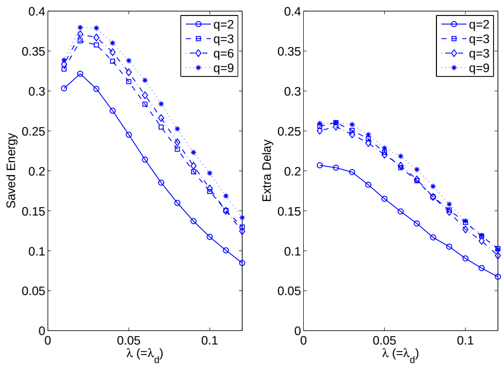

Figure 4 Saved energy and extra delay with different q

Fig. 4 shows the effect of q on the saved energy and extra delay. It may be seen that various q could achieve different energy consumption and also delay in the enhanced scheme. $q=2$ is able to reduce power consumption substantially with acceptable delay tradeoff. After $q \geq 3$, there is an insignificant discrepancy with ever larger q in terms of energy consumption and packet delay. Consequently, the value of q is unnecessarily too large. For example, q can be chosen as 3 in this example.

5. Conclusion

An enhanced energy management mechanism is proposed by choosing the sleep window size adaptively. The scheme is able to reduce energy consumption significantly, and the introduced packet delay is much lower than the percentage of saved energy. Under identical situations in the proposed strategy, the percentage of saved energy is always higher than that of introduced extra delay.

Reference

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