Advanced Power Saving Mechanism in IEEE 802.16m Wireless Metropolitan Area Networks

Shiann-Tsong Sheu[+], Lu-Wei[+] Chen and Jenhui Chen*
Dept. of Communication Engineering, National Central University, Taoyuan 32054[+]
Dept. of Computer Science and Information Engineering, Chang Gung University, Taoyuan 333*
E-mail: stsheu@ce.ncu.edu.tw

***Abstract*—The mobile wireless metropolitan area networks (WMAN) architecture adopts power saving mechanism to prolong the battery lifetime of mobile devices. Due to the burst characteristic of non-real-time service, the exponentially growing sleep window, which is employed in the IEEE 802.16e and IEEE 802.16m, seems not the best approach in term of packet response time. To let the sleep window match the traffic pattern, base station (BS) should collect traffic information and then notify mobile station (MS) the appropriate sleep window size. As a solution, we propose an advanced power saving mechanism, namely A-PSM, which simply adjusts the sleep window according to the average packet inter-arrival time in order to improve the power saving capability. To reduce the negotiation overhead and accomplish the synchronization of sleep pattern between BS and MS, the information of measured inter-packet arrival time is piggybacked on every downlink packet sent from BS. Moreover, a parameter of tolerable delay is proposed to control the packet delay when the inter-packet arrival time suddenly becomes longer. As confirmed by the performance evaluation, the proposed A-PSM can easily achieve better power saving capability, as compared to the IEEE 802.16e and IEEE 802.16m under all kinds of traffic arrival rates.**

Keywords-Advanced power saving mechanism (A-PSM), IEEE 802.16e, IEEE 802.16m, wireless metropolitan area networks (WMAN)

I. INTRODUCTION

In order to extend the battery life of mobile station (MS) in the wireless metropolitan area networks (WMAN), the entire active period for an MS to transmit/receive data packets to/from base station (BS) should be bounded. Enhanced from the IEEE 802.16-2004 standard [1], which specifies the radio access protocol between the BS and a number of fixed subscriber stations (SSs), the IEEE 802.16-2009 [2] comprising of the IEEE 802.16e-2005 [3] protocol supports the power saving mechanism (PSM) and handover mechanism for MSs. Regarding different characteristics of traffic pattern and quality of service (QoS) requirement, two major PSMs, denoted as Type-I and Type-II, are defined to provide different sleep patterns for non-real-time and real-time services respectively. The latest progress under standardization is the IEEE 802.16m [4], which defines a new PSM for the advanced base station (ABS) and advanced mobile station (AMS). For the sake of brevity, the IEEE 802.16e Type-I PSM, 802.16e Type-II PSM and 802.16m PSM are denoted as PSMe-I, PSMe-II and PSMm, respectively.

The IEEE 802.16e BS uses the PSMe-I sleep pattern, which adopts fixed listening window and varying sleep window, to deal with the burst characteristic of non-real-time connections. The PSMe-I sleep pattern makes MS listen to channel in a more conservative manner. After each listening window, the sleep window is doubled from previous one till it reaches the specified maximum value or the sleep mode is deactivated. Moreover, during listening window, the traffic indication message would be broadcasted by BS to deactivate the sleep mode of designated MSs which should wake up to receive data packets from BS. On the other hand, the PSMe-II sleep pattern, which adopts fixed listening window and fixed sleep window, is used to deal with connections with more regular uplink/downlink traffic, such as voice and video traffic.

The IEEE 802.16m standard defines a common PSMm for both non-real-time and real-time services. After an AMS enters sleep mode, a sleep cycle, except for the first initial sleep cycle, shall consists of listening window and sleep window. The length of a sleep cycle is exponential doubled from initial sleep cycle and maintained at the final sleep cycle if there is negative indication in the advanced air interface traffic indication (i.e., AAI-TRF-IND) message. Upon a packet arriving at ABS, the AMS can check AAI-TRF-IND message during the listening window as the process of PSMe-I, and receive the buffered packet(s) without deactivating the sleep mode.

To improve the power saving capability, many ideas aiming to design an efficient PSM for WMAN have been proposed in the past years. Alternative PSM design, which combines different sleep patterns supported in standard to accommodate the traffic pattern of a session, have been proposed also [5] [6] [7] [8]. For example, the concept of using mixture of PSMe-I and PSMe-II sleep patterns has been considered [5] [6] [7] and the concept of employing two different PSMe-II sleep patterns for an MS has been introduced also [8].

In order to compromise the trade-off between power consumption and packet delay, the concept of controlling the sleep mode parameters to refine the standard PSMe-I sleep pattern has been proposed. For example, it has already been shown that the size of initial sleep window has significant impact on the active time, awake ratio and mean packet delay [5]. Therefore, authors of paper [5] proposed an efficient PSM to dynamically update the initial sleep window based on the estimated packet inter-arrival time during session lifetime. Since the packet arrivals can be monitored by the BS only, the BS has to send explicit sleep command to notify MS about the new initial sleep window. Intuitively, more frequent updates of sleep mode parameters will cause more bandwidth overhead on negotiations and also impact the overall power saving capacity. However, [5] does not explain how to synchronize states between BS and MS. Moreover, the produced sleep pattern, which still keeps the feature of binary-increasing sleep window, cannot precisely approximate the traffic pattern. It is still desired to have a novel PSM for the IEEE 802.16 system.

In our opinion, it is impractical for a host (such as BS) to conjecture the traffic pattern of a non-real-time service over the backbone network with best-effort feature. However, we can employ the statistical method to obtain the average packet inter-arrival time and the tolerable delay parameter to smooth the varying packet inter-arrival time. In this paper, we propose a new advanced power saving mechanism (A-PSM) to minimize the packet response delay, thereby combating

This study is conducted under the Advanced Wireless Broadband System and Inter-networking Application Technology Development Project of the Institute for Information Industry which is subsidized by the Ministry of Economy Affairs of the Republic of China.

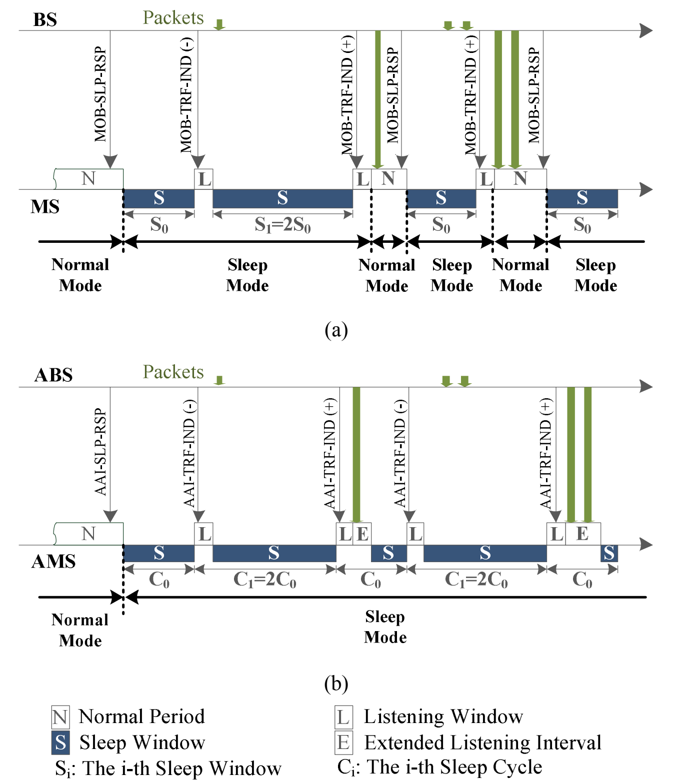

Fig. 1. An example of sleep mode operations: (a) PSMe-I of IEEE 802.16e and (b) PSMm of IEEE 802.16m.

potential power saving deterioration in IEEE 802.16e and 802.16m mobile networks.

The rest of the paper is organized as follows. A brief description of current IEEE 802.16e and IEEE 802.16m power saving mechanisms and their deficiency is provided in Section II, aiming to supply necessary background and motivate the discussions. The new advanced power saving mechanism (A-PSM) and numerical analysis are then elaborated in Sections III and IV respectively. The performance evaluations, discussions and suggestions are presented in Section V, followed by the conclusion remarks in Section VI, which completes the paper.

II. Sleep Operation in IEEE 802.16

A. IEEE 802.16e Sleep Mode Operation

The IEEE 802.16e standard provides PSMe-I for handling versatile non-real-time traffic pattern. Fig. 1(a) portrays an example of PSMe-I, where the BS sends an unsolicited MOB-SLP-RSP message to an MS to initiate the sleep mode. After negotiating the sleep parameters, MS enters sleep mode at the specified time frame and maintains for the initial sleep window (i.e., S_0), and then wakes up for an fixed interval, namely listening window (i.e., L), to receive the traffic indication message (i.e., MOB-TRF-IND). If there is no downlink data for the MS, the MS will receive the negative indication and then return to sleep for an extended sleep window which is doubled from the previous one. If the length of sleep window has reached the S_F, the sleep window will maintain at S_F until sleep mode is terminated. On the other hand, the MS will enter the normal mode if the positive indication is received. Let S_i denote the length of the i-th sleep window. We have

$$S_i = \min(S_0 \times 2^i, S_F), i \geq 0. \tag{1}$$

B. IEEE 802.16m Sleep Mode Operation

Fig. 1(b) also depicts the PSMm. Similarly, the ABS may initiate the sleep mode by issuing an unsolicited advanced air

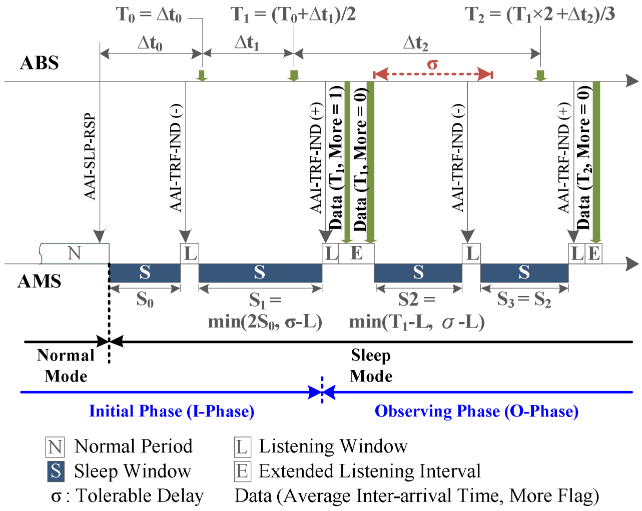

Fig. 2. An example of the proposed A-PSM.

interface sleep response message (i.e., AAI-SLP-RSP) to an AMS. The AAI-SLP-RSP message contains four major sleep parameters: initial sleep cycle (i.e., C_0), default listening window (L), final sleep cycle (i.e., C_F), and next sleep cycle flag (NSCF). Whenever the sleep mode is activated, the sleep cycle starts from C_0 to C_F in binary-increasing manner as the PSMe-I. Then, we have

$$C_i = \min(C_0 \times 2^i, C_F), i \geq 0. \tag{2}$$

However, if there is any downlink data arriving at ABS during sleep window, the ABS will send a positive indication to inform the addressed AMS during listening window. Upon the AMS obtaining this notification, the current length of sleep cycle shall be update to the new one according to the parameter NSCF, and the listening window is extended. The extended listening window is bounded by the current length of sleep cycle. The PSMm uses a same sleep parameter set to support both non-real-time and real-time services. In order to accommodate the non-real-time service, the NSCF shall be set to 0, and the subsequent sleep cycles are derived from (2). Contrarily, for real-time service, the NSCF shall be set to 1 and the sleep cycle is derived as following:

$$C_i = C_0. \tag{3}$$

It has been shown that the power saving capability of PSMm is better than the PSMe-I, but the average packet delay of a non-real-time service derived from the PSMm (NSCF=0) is longer than that of PSMe-I [9]. Again, it is still desired to have a new PSM to achieve superior power saving capability as well as lower mean packet delay.

III. The Advanced Power Saving Mechanism

Since this study focuses on non-real-time services, the proposed PSM is mainly compared with the PSMe-I and PSMm with NSCF=0. For the sake of brevity, all the ensuing discussions apply for power savings occurring on single non-real-time connection only, unless otherwise noted.

Due to the unpredictable traffic pattern of a non-real-time service, using binary-increasing sleep window is a sensible design, but by no means the most efficient one. Two drawbacks of adopting the binary-increasing sleep window for bursty traffic are: 1) the frequent listening windows would waste more power on receiving the negative traffic indication messages, and 2) the binary-increasing sleep window size would prolong the response time of the first packet arriving during sleep mode. Thus, the legacy designs of the PSMe-I and PSMm seem not so efficient to handle the varying traffic pattern. Moreover,

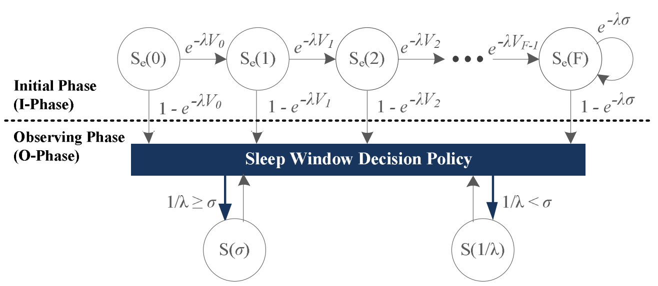

Fig. 3. State transition diagram for A-PSM.

because the packet inter-arrival time can be only observed by the ABS, the ABS has to send an AAI-SLP-RSP message to the corresponding AMS to dynamically adjust the sleep window.

Therefore, we propose the advanced power saving mechanism (A-PSM) to improve the power saving capability. Fig. 2 portrays an example of the proposed A-PSM, where the length of each sleep window can be dynamically adjusted according to the actual time instances of packets arriving at ABS. However, before the first packet arrives as the BS, the A-PSM will behave as legacy PSMe-I, where the sleep window exponentially grows from S_0 to a given tolerable delay (i.e., σ-L), where σ is the maximal packet response time configured by system operator. Correspondingly, a large value of σ is, a longer packet response time will be. The adopting of the binary-increasing sleep window at the early stage of growing sleep pattern is denoted as initial phase (I-Phase).

Upon new packets arriving at ABS during I-Phase, the inter-arrival time of packets is used by the ABS to determine the new sleep window size. Let T_i denote the average packet inter-arrival time (frame) observed from the first arriving packet to the i-th packet. We have

$$S_i = \begin{cases} \lceil \Delta t_0 \rceil & ,i=0, \\ \lceil (T_{i-1} \times i + \Delta t_i)/(i+1) \rceil & ,i>0, \end{cases} \quad (4)$$

where Δt_i represents the time interval between the i-th and (i-1)-th packets.

In order to synchronize the sleep window between the ABS and AMS, T obtained by (4) is carried on each downlink data packet and sent to the corresponding AMS. That is, whenever the AMS perceives a positive indication, it starts retrieving the piggybacked T until the AMS perceives that the transmission buffer of ABS becomes empty (i.e., the 'more' flag of the last downlink packet is set to 0). The adopting of the dynamic sleep window is denoted as observing phase (O-Phase).

IV. Numerical Analysis

Fig. 3 portrays the state transition diagram for the proposed A-PSM. Assume the traffic arrivals follow Poisson distribution with mean packet arrival rate λ. The probability of no traffic arrival during V_i is equal to $e^{-\lambda V_i}$, where V_i represents the i-th sleep vacation (i.e., $V_i = S_i+L$).

Whenever the AMS does not wake up in entire I-Phase, the AMS transits its state from the initial sleep state ($S_e(0)$) toward the final sleep state ($S_e(F)$), in which the subsequent sleep window is doubled until σ is reached, and then the sleep window will maintain at σ (i.e., V_F=σ). On the other hand, if traffic arrives at ABS in any sleep window during the I-Phase, ABS will wake up the AMS by sending the positive AAI-TRF-IND message in the subsequent listening window. Then, both ABS and AMS enter the O-Phase as soon as the AMS completes the data reception. We note that the ABS will calculate (4) and piggyback the result in data packet to inform AMS how long the next sleep window is. Moreover, the ABS and AMS keep staying in the O-Phase because the new sleep window size is always determined by min (T, σ). If the traffic arrivals follow Poisson distribution with mean packet arrival rate λ, the value of T will converge to $1/\lambda$ and the probability of staying at sleep states in I-Phase can be neglected. Therefore, the average sleep vacation, denote as V_{avg}, is given by

$$V_{avg} = \begin{cases} 1/\lambda, if\ 1/\lambda < \sigma, \\ \sigma\ , otherwise, \end{cases} \quad (5)$$

Thus, the average sleep window size S_{avg} is equal to V_{avg} -L.

In order to compare the performance of the legacy PSMe-I, PSMm and the A-PSM, the sleep ratio (SR), energy efficiency (EE), mean packet delay (MPD), and average energy consumption (AEC) are used as primary metrics.

A. Sleep Ratio (SR)

Let sleep ratio (SR) be the ratio of the total number of sleep frames to the total number of observed frames. Thus, we have

$$SR = \frac{S_{avg}}{V_{avg} + E[F_R]}, \quad (6)$$

where $E[F_R]$ represents the mean number of consecutive frames when an AMS receives the downlink data packets continuously. The $E[F_R]$ can be derived by

$$E[F_R] = (N^{V_{avg}} + N^R)E[X], \quad (7)$$

where $N^{V_{avg}}$ and N^R represent the average numbers of arrival packets during the average sleep vacation and during the average period of receiving downlink data packets respectively. Let $E[X]=1/\mu$ denote the mean service time of packets which follows the Exponential distribution with mean service rate μ. According to Little's Formula [10], $N^{V_{avg}}$ and NR can be derived from (8) and (9) respectively.

$$N^{V_{avg}} = \lambda V_{avg}. \quad (8)$$

$$N^R = \lambda E[F_R]. \quad (9)$$

By solving (8) and (9), we obtain the following equation for deriving the $E[F_R]$:

$$E[F_R] = \frac{\lambda V_{avg} E[X]}{1-\lambda E[X]} = \frac{\lambda V_{avg}}{\mu - \lambda}. \quad (10)$$

B. Energy Efficiency (EE)

Recall the AMS always turns its transceiver on at each listening window to check the AAI-TRF-IND message and keeps waking until there is no more packet destined to it. It is evident that frequent events of receiving negative AAI-TRF-IND message will waste much more power. The EE is defined as the ratio of the mean number of frames for packet reception to the mean number of AMS awaking frames (i.e., staying in listening window and extended listening window). Then, we have

$$EE = \frac{E[F_R]}{L + E[F_R]}. \quad (11)$$

C. Mean Packet Delay (MPD)

According to the vacation based power saving model, there are two major factors which may affect the packet delay. First, upon packets arriving at ABS during the average sleep vacation (V_{avg}), the AMS shall wait the residual sleep period, denoted as $D^{(S)}$, before waking up to receive them. For simplicity, we

TABLE I. Sleep Mode Parameters and Traffic Model

Parameter	Setting
Initial sleep window (S_0) (16e)	1 (frame)
Final sleep window (S_F) (16e)	256 (frames)
Initial sleep cycle(C_0) (16m)	2 (frames)
Final sleep cycle (C_F) (16m)	256 (frames)
Default listening window (L)	1 (frame)
Energy consumption of busy frame (E_R)	280 mW
Energy consumption of sleep frame (E_R)	10 mW
Energy consumption of state switch (φ)	1 mW
Frame duration	5 ms
Traffic model	Poisson
Mean service rate(μ)	1 (packet/frame)

assume these packets arriving at ABS during sleep vacation follow the uniform distribution. Therefore, we have

$$D^{(S)} = \frac{V_{avg}}{2}. \quad (12)$$

Secondly, when a packet arrives during a time frame where the AMS is receiving the buffered data packets, it still takes a mean waiting time before ABS transmits it to the AMS. By Pollaczek-Khinchin mean formula, the mean waiting time, denoted as $D^{(W)}$, is given by

$$D^{(W)} = \frac{E[X_r]}{1-\rho} = \frac{\rho E[X]}{2(1-\rho)}, \quad (13)$$

where $E[X_r]$ is the mean value of residual service time.

As a result, the expected value of MPD of proposed A-PSM can be derived from the following equation:

$$MPD = D^{(S)} + D^{(W)}. \quad (14)$$

D. Average Energy Consumption (AEC)

To compare the power saving capabilities for the PSMe-I, PSMm and the proposed A-PSM, the metric of average energy consumption (AEC) is considered. The expected AEC is derived by

$$AEC = \frac{E_S S_{avg} + E_R(L + E[F_R]) + 2\varphi}{V_{avg} + E[F_R]}, \quad (15)$$

where E_S represents the average energy consumption per frame when AMS stays in sleep window, E_R represents the average energy consumption per frame for receiving AAI-TRF-IND message and downlink data packets, and φ represents the energy consumption for switching the transceiver between the listening window and the sleep window.

V. PERFORMANCE EVALUATION

To concentrate on the performance of proposed A-PSM, an error-free channel condition is assumed in our simulation. The network under investigation consists of one ABS and one AMS, and one connection is established between ABS and AMS. Moreover, suppose the ABS has infinite buffer space, and thus always can buffer produced packets, regardless of how late the AMS wakes up to receive them. In addition, network only generates the downlink traffic in order to evaluate the impact from varied sleep patterns. The key sleep mode parameters and traffic parameters used in evaluation are listed in Table I. In the considered simulation model, the C_0 is set to 2 frames, where the first frame is used for an AMS to receive the traffic indication message and the following frame is used for an AMS to ensure at least one sleep frame or receive the downlink data packets, if any.

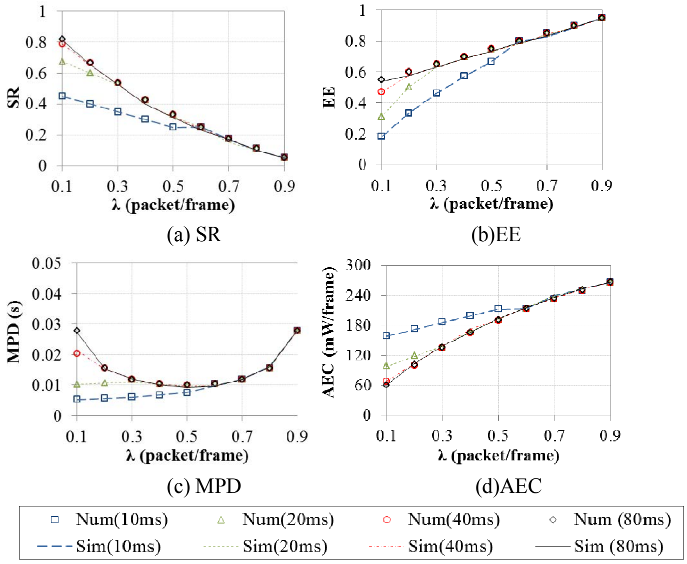

Fig. 4. SR, EE, MPD and AEC comparisons of A-PSC under different packet arrival rates and tolerable delay σ.

Here we assume only one packet can be served in one radio frame. To provide fair comparisons, the default listening interval of PSMe-I, PSMm and A-PSM are only used to receive the traffic indication message, and thus the length of default listening window is set to the minimal size (1 frame). As shown in the following figures, the simulation and numerical results of SR, EE, MPD and AEC are derived as functions of packet arrival rate (λ) which ranges from 0.1 to 0.9 in a step of 0.1.

Fig. 4 shows both simulation and analytical results of SR, EE, MPD and AEC over packet arrival rate for the proposed A-PSM with different tolerable delays σ. Fig. 4(a) depicts the SRs when σ is set to 10ms, 20ms, 40ms, and 80ms. The higher SR represents that AMS stays longer in sleep window. As expected, the SR decreases with traffic arrival rate and increases with releasing σ due to the shortened packet inter-arrival time and prolonged sleep window respectively. However, it can be observed that the results of each restricted σ are bounded by curve with σ=80ms. The reason is that the given delay constrain is higher than the average inter-arrival produced from λ. On the other hands, for instance, the SR with λ=0.1 and λ=40ms does not reach the highest value what it should have (i.e., SR=0.8) because the average inter-arrival time (i.e., 50ms) is larger than 40ms. Fig. 4(b) shows the EEs in terms of λ and the curves with different σ are also plotted. The higher EE means AMS receives less negative AAI-TRF-IND messages. As showed in Fig. 4(b), we observe that as λ and σ increases, the EE increases since the average inter-arrival time becomes shorter and the size of maximum sleep window becomes larger respectively.

Evidently, the packet response time has to be sacrificed for saving more power. We can observe from Fig. 4(c) that a large packet inter-arrival time (i.e., λ is small) will prolong MPD because the packet has higher probability arriving at ABS during a large sleep vacation. On the other hands, when λ=0.9, the heavy traffic load still may result ABS spends longer waiting time for delivering the newest arrival packet after emptying all of queuing packets prior of it. On the other hands, different σ will also impact different MPD for the same reason of Fig. 4(a) and Fig. 4(b). Evidently, in order to minimize the MPD, the σ shall be set to a small value. Fig. 4(d) shows results of AEC under different λ and σ. From Fig. 4, we cans understand easily both the relationship between traffic arrival rate and power saving capability and trade-off characteristic between power consumption and packet delay.

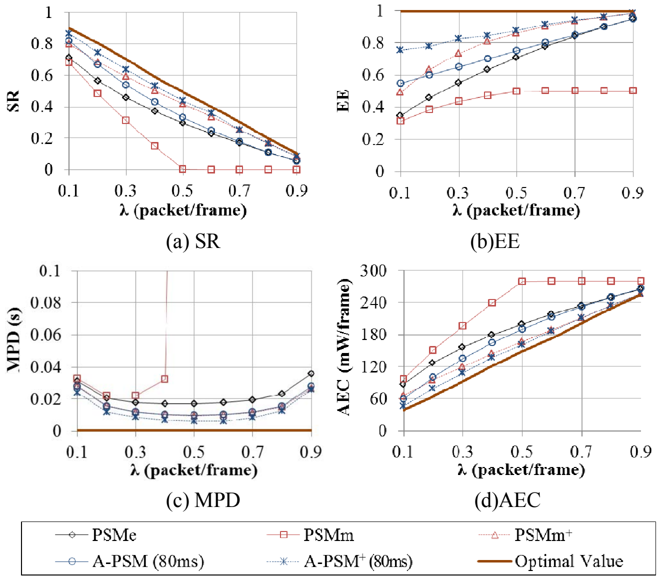

Fig. 5. SR, EE, MPD and AEC comparisons among PSMe-I, PSMm, and A-PSM under different packet arrival rates.

In order to estimate the improvement, we choose the curves of new A-PSM with σ=80ms to be the best results to compare with legacy PSMe-I and PSMm. In Fig. 4, we assume the listening window is only used for receiving AAI-TRF-IND message in order to provide fair comparisons. However, the assumption will impact evidently the power saving capability of PSMm. Thus, in Fig. 5, we further evaluate SR, EE, MPD and AEC of A-PSM and PSMm, where packets can be transmitted by ABS during default listening window, as notated A-PSM$^+$ and PSMm$^+$ respectively. In Fig. 5(a), the new A-PSM always results in better power saving efficiency than PSMe-I and PSMm. We note that SR approximated to 0 when λ is equal or larger than 0.5 because the AMS will keep waking and the sleep mode will alternate one default listening frame for perceiving AAI-TRF-IND message and one extended listening frame for receiving one packet. However, if the listening window can be used for receiving packet, our A-PSM$^+$ still results better SR, as compared with PSMe-I and PSMm$^+$.

Fig. 5(b) depicts EEs compared among A-PSM, A-PSM$^+$, PSMe-I, PSMm and PSMm$^+$. It can be observed that the EE of our A-PSM is better than PSMe-I and PSMm especially when λ is small (e.g., λ=0.1). The reason is that the sleep window of the proposed A-PSM will conform to the average inter-arrival time. On the other hands, the maximum EE of PSMm will be bounded to 0.5 when λ is equal or larger than 0.5 because only one extended listening frame occupies the initial sleep cycle (i.e., $C_0 = 2$). However, if the listening window can be used for receiving packet, our A-PSM$^+$ also results better EE compared with PSMe-I and PSMm$^+$.

As shown in Fig. 5(c), incoming traffic can experience a delay when the AMS is still asleep. The new A-PSM always results in a lower MPD then PSMe-I and PSMm; similarly the MPD of APSM$^+$ also better than PSMe-I and PSMm$^+$. As can be seen, the utilization of default listening window will impact the MPD of PSMm significantly. In this case, AMS always has insufficient time (only one frame) to receive all of data packets buffered at ABS. This is because the PSMm$^+$ results continuous rising MPD. Fig. 5(d) portrays the A-PSM outperform the PSMe-I and PSMm and the A-PSM$^+$ also outperform the PSMe-I and PSMm$^+$ in term of AEC.

In summary, comparison among those four subfigures that both the power saving capability and the mean packet delay improvement have achieved by the proposed A-PSM with large σ (i.e., σ=80ms). Moreover, the response time reduction the APSM can thus accomplish is better than PSMm, while the better power saving efficiency is maintained still. We also show the optimal values of SR, EE, MPD and AEC with Poisson arrival in respective subfigures. It can be observed clearly that our APSM$^+$ is nearer the optimal value than PSMm$^+$ and PSMe-I. Besides, considering that the state transition between ABS and AMS would be out of synchronization because the data bringing T is loss, the AMS could send AAI-TRF-IND-REQ defined in IEEE 802.16m standard to ABS for resynchronization.

VI. Conclusions and Future Work

In this paper, we have proposed an advanced power saving mechanism, namely A-PSM, to improve the power saving capability by dynamically adjusting the sleep window size. The key concept of A-PSM is to refer to the packet inter-arrival time for deriving the sleep window size. Such information is piggybacked on downlink packets to accomplish the synchronization of sleep window size between ABS and AMS. Moreover, the tolerable delay bound is introduced to control the packet delay caused from the prolonged packet inter-arrival time. Performance evaluation results and numerical results further confirm that the proposed A-PSM can improve the power saving capability, as compared to IEEE 802.16e PSMe-I and IEEE 802.16m PSMm.

For the future work, we will investigate different data traffic models and their combinations especially for more than two sessions. An efficient mechanism for adjusting sleep window will decrease the reception of the negative AAI-TRF-IND messages. In other words, if the sleep window can conform the packet inter-arrival time, the power saving efficiency will be much closer to the optimal results.

References

[1] IEEE Standard for Local and Metropolitan Area Networks-Part 16: Air Interference for Fixed Broadband Wireless Access Systems, IEEE Std. 802.16-2004, Jun. 2004.

[2] IEEE Standard for Local and Metropolitan Area Networks-Part 16: Air Interference for Fixed Broadband Wireless Access Systems, IEEE Std. 802.16-2009, May. 2009.

[3] IEEE Standard for Local and Metropolitan Area Networks-Part 16: Air Interference for Fixed Broadband Wireless Access Systems, Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigendum 1, IEEE Std. 802.16e-2005, Dec. 2006.

[4] DRAFT Amendment to IEEE Standard for Local and Metropolitan Area Networks-Part 16: Air Interface for Broadband Wireless Access Systems-Advanced Air Interface, IEEE Std. 802.16m/D10, Nov. 2010.

[5] S. Cho and Y. Kim, "Improving power savings by using adaptive initialsleep window in IEEE 802.16e," in Proc. IEEE VTC2007-Spring, Dublin, Ireland, Apr. 2007, pp. 1321 – 1325.

[6] S.-T. Sheu, Y.-C. Cheng, L.-W. Chen, J.-S. Wu, and J. Chang, "Listening interval spreading approach (LISA) for handleing burst traffic in IEEE 802.16e wireless metropoliten area networks," in Proc. IEEE VTC2008- Fall, Calgary, BC, Sep. 2008, pp. 1–5.

[7] L. Kong, G. K. W. Wong, and D. H. K. Tsang, "Performance study and system optimization on sleep mode operation in IEEE 802.16e," IEEE Transactions on Wireless Communications, vol. 8, no. 9, pp. 4518–4528, Sep. 2009.

[8] T.-C. Chen, J.-C. Chen, and Y.-Y. Chen, "Maximizing unavailability interval for energy saving in IEEE 802.16e wireless MANs," IEEE Transactions on Mobile Computing, vol. 8, no. 4, pp. 475–487, Apr. 2009.

[9] C.-Y. Chen, C.-H. Hsu, and K.-T. Feng, "Performance analysis and comparison of sleep mode operation for IEEE 802.16m advanced broadband wireless networks," in Proc. IEEE PIMRC 2010, Sep. 2010, pp. 1425 –1430.

[10] H. Kobayashi and B. L. Mark, System modeling and analysis: foundations of system performance evaluation. Upper Saddle River NJ: Prentice-Hall, 2009.