

A New Energy Saving Mechanism in IEEE 802.16e/m

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Abstract

To extend lifetime of battery-powered mobile device before its recharging in broadband wireless access networks, power saving mechanism in MAC (medium access control) has become a significant design issue. Basically, a power saving mechanism is manipulated by adjusting operating parameters such as the minimum sleep interval (T_{min}) and the maximum sleep interval (T_{max}). In this paper, we propose a new energy saving mechanism for IEEE 802.16e/m to get maximized energy saving by dynamically changing sleep interval T based on traffic rate of serving service. The proposed mechanism also tries to minimize overheads transmitted between Mobile Subscriber Station (MSS) and Base Station (BS) by eliminate MOB-SLP-REQ/RSP messages. The value of sleep interval T is chosen by BS instead of MSS in WiMAX 802.16e standard and is sent to an MSS via MOB-TRF-IND message. The MSS only uses constant sleep interval T value in a successive sleep interval sequence until next transaction from awake mode to sleep mode. The new mechanism also does not use MOB-SLP-REQ/MOB-SLP-RSP that causes more energy consumption because of staying in waiting stage. This mechanism can be applied for Power Saving Class (PSC) I and PSC II by changing T corresponding delay requirement of service. The analytical results and simulation show that the proposed mechanism gains more than 36% of energy saving in maximized saving mode or 23% in optimized energy saving mode if it keeps response time changed a little in compared with the current standard of sleep mode mechanism.

Keywords: Maximized energy saving, dynamical sleep mode, optimized sleep interval, 802.16e/m.

1. Introduction

The explosive growth of the Internet over the last decade has led to an increasing demand for high-speed ubiquitous Internet access. Broadband Wireless Access (BWA) is increasingly gaining popularity as an alternative "last mile" technology in this domain. Following the successful deployments of the fixed WiMAX IEEE 802.16-2004 [1] networks, the Mobile WiMAX technology IEEE 802.16e-2005 [2] enables pervasive and ubiquitous high-speed connectivity to meet the ever-increasing demand for broadband Internet. The IEEE 802.16e-2005 is designed to support Mobile Subscriber Station (MSS) moving at vehicular speed in licensed bands and amendment for broadband wireless access. The IEEE 802.16e architecture provides enhancements to IEEE 802.16-2004 to support mobility and real-time applications such as video stream or Voice over IP (VoIP) in mobile environment with high data rate and stability.

Since an MSS is powered by a battery with limited capacity, a power saving mechanism is one of critical concerns in designing the medium access control (MAC) layer for MSS. IEEE 802.16e introduced three kinds of sleep mode operation named

power saving classes (PSCs) of types I, II and III. PSC I is recommended for Best Effort (BE) and non-real time variable rate (NRT-VR) traffics, PSC II is recommended for unsolicited Grant service (UGS) and real time variable rate (RT-VR) traffics, and PSC III is recommended for management operation and multicast connections. Each PSC class differs from the others by their parameters, procedures of activation and deactivation and policies of MSS availability for data transmission.

The basic principle of a power saving mechanism is to implement sleep mode operation to minimize MSS power consumption. In general, an MSS has two modes: awake mode and sleep mode, shown in Figure. 1. The sleep mode operations of PSC I and PSC II in the IEEE 802.16e standard are to alternate awake mode and sleep mode. In sleep mode, there is two stages: sleep stage in which the MSS does not communicate with its serving BS and listening stage in which the MSS wakes up to check there is any packets BS wants to send (by checking MOB-TRF-IND message). After sending and receiving all packets, an MSS needs to switch from awake mode to sleep mode by sending a sleep request message (MOB-SLP-REQ) which includes information such T_{min} , T_{max} , listening interval L and so on to its serving BS to get approval. If the serving BS accepts the sleep request from MSS, it sends the MSS a response message (MOB-SLP-RSP) which includes the beginning time of the sleep mode (T_s), T_{min} , T_{max} , L and so on. After receiving the MOB-SLP-RSP, the MSS starts sleep mode operation.

During sleep mode operation, a listening interval is between two successive sleep intervals. An MSS needs listening for a while to be sure if there is any packet transmitting to it. Sleep mode duration consists of sleep intervals and listening intervals as in Figure 1. In 802.16e, the sleep intervals are defined as follows: At the first sleep interval, a minimum sleep interval T_{min} is used. After the first sleep interval, an MS switches into a listening interval to wait for a MOB-TRF-IND message. This message indicates addressed traffic that BS buffered for the MSS during previous sleep interval. The value of MOB-TRF-IND determines next MSS's reaction. The negative MOB-TRF-IND message means that there is not any packet serving BS want to send. When an MSS receives a negative MOB-TRF-IND message, it goes to the next sleep interval whose duration is double from the preceding sleep interval. This process repeatedly continues until the sleep interval reaches to T_{max} and then next sleep interval keeps unchanged. In j-th listening interval, if serving BS sends the MSS a positive MOB-TRF-IND message, the MSS leaves sleep mode and wakes up to process packets. We call the duration of first sleep interval $T_1=T_{min}$, then the duration of j-th sleep interval is

$$T_j = \min\{2^{j-1}T_{min}, T_{max}\} \quad (1)$$

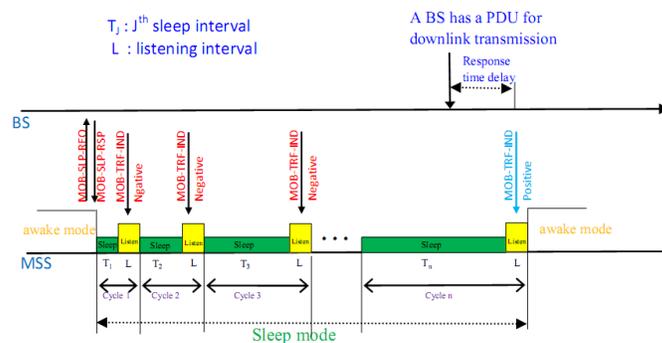


Figure 1. Standard Sleep Mode in IEEE 802/16e

2. Related Work

Numerous studies evaluated the PSCs in IEEE 802.16e. Y. Xiao and Y. Zhang [3][4][5] proposed an analytical model of PSC I and investigated the energy consumption of IEEE 802.16e for both uplink and downlink traffic. L. Kong *et al* [6] proposed a theoretical framework based on the semi-Markov to design an optimal sleep mode selection scheme so as to maximize the energy efficiency in a mobile WiMAX system while providing a certain QoS guarantee. In [7][8][9] the authors use Markov-chain model to analyze both energy consumption and response delay in PSC I of IEEE 802.16e affected by relative size of these two operating parameters. In [3]-[9] the traffic pattern characteristics follow Poisson distribution whereas some authors consider the other traffic patterns such as Erlang distributed interarrival time [10] and Hyper-Erlang distributed interarrival time [11]. In [12] the paper has established a general approach for analyzing queueing models with repeated in homogeneous vacations. In [13] Zhanqiang also used a discrete-time Geom/G/1 queueing model with a close-down time and multiple vacations is built in the paper. By employing an embedded Markov chain method, the average queue length and the average sojourn time of the system model are derived.

Based on the previous studies, several researchers [14][15][16][17] attempted to deploy adaptive power saving mechanisms in the IEEE 802.16e system by dynamically adjust initial and final sleep interval according to the average traffic overload or the remaining energy stage. In [18] a statistical sleep window control approach is proposed to improve the energy efficiency of a mobile station with non real-time downlink traffic. See [19] and [20] for attempts to adopt power saving mechanism for Voice over IP (VoIP) traffic and multiple real-time connections. As the last enhancements of the power saving in IEEE 802.16e, Eunju Hwang *et al* [21] has propose a new sleep mode scheme called the *power-saving mechanism with periodic traffic indications* where a traffic indication (TRF-IND) message is periodically sent at the beginning of every constant TRF-IND intervals.

From studying power saving mechanism in IEEE 802.16e, we have realized some cons of it. A problem of standard sleep mode PSC I is to always use the fixed T_{\min} and fixed T_{\max} for various traffic types. It is not always good for all traffic rates. Another problem of PSC I is waiting time. It is so "conservative". An MSS has to send MOB-SLP-REQ message and wait to receive MOB-SLP-RSP if it wants transiting from awake mode to sleep mode. During waiting time, the MSS consumes the energy by staying in awake mode. Furthermore, the MSS also need energy for sending and receiving MOB-SLP-REQ/RSP messages. Another case might happen in the MSS's waiting time is to BS does not accept because of packets came in that time. In this case, the MSS must send sleep request message again in other time. It significantly increases overheads in sleep mode procedure. These problems motivated us to introduce a new sleep mode mechanism for IEEE 802.16e/m.

In this paper, we propose a new sleep mode mechanism named *maximized energy saving* (MES) mechanism without using MOB-SLP-REQ/MOB-SLP-RSP messages. The main characteristic of MES mechanism is to the length of sleep interval is determined by BS and based on the serving traffic rate. The serving BS takes traffic interarrival time into account to choose the value of sleep interval so that the MSS consume minimum energy in sleep mode. The value T of sleep interval is sent in MOB-TRF-IND message whenever MSS is in listening interval or there is not any packet in its buffer.

The rest of this paper is organized as following. In Section 3, we introduce the performance analysis of sleep mode operation for PSC I in IEEE 802.16e. Section 4 describes our proposed MES mechanism and section 5 shows the results of comparison between standard sleep mode and our proposal. The final section 6 is the conclusions about new mechanism and future works.

3. Power Saving Mechanism in IEEE 802.16e/m

This section introduces the operation of the power saving mechanism for PSC I in IEEE 802.16e and its analytical model. It is based on the work of Y. Xiao [3].

In this paper, we use the notation $E[.]$ to stand the mean/average function. Let n and D denote the number of sleep intervals and the duration of a successive sequence of sleep intervals in sleep mode, respectively. E_S , E_L denote the energy consumption units per unit time in the sleep interval and the listening interval, respectively. R denotes the frame response time which is defined as the delay a frame destined to an MSS has to wait before it is delivered.

We assume that the arrival of frames destined to an MSS follow a Poisson distribution with rate λ . It means, the inter arrival time is distributed according to an exponential law with parameter $1/\lambda$. Let e_j denote the event that there is at least one packet arrival during the monitor period j . Note that in our definition, listening intervals are also belong to the sleep mode. We have

$$\Pr(e_j = true) = 1 - e^{-\lambda(T_j+L)} \quad (2)$$

The term $\Pr[n=j]$ represents the probability of success in the exact j -th iteration, which is also the probability of failure in iteration 1 to $j-1$ and success in the j -th. The number of sleep cycles is an independent random variable.

$$\Pr(n = 1) = \Pr(e_1 = true) = 1 - e^{-\lambda(T_1+L)} \quad (3)$$

For $n \geq 2$, we have

$$\begin{aligned} \Pr(n = j) &= \Pr(e_1 = false; \dots; e_{j-1} = false; e_j = true) \\ &= \prod_{i=1}^{j-1} \Pr(e_i = true) \Pr(e_j = true) \\ &= e^{-\lambda \sum_{i=1}^{j-1} (T_i+L)} (1 - e^{-\lambda(T_j+L)}) = \sum_{j=1}^{\infty} e^{-\lambda \sum_{i=1}^{j-1} (T_i+L)} - \sum_{j=1}^{\infty} e^{-\lambda \sum_{i=1}^j (T_i+L)} \end{aligned} \quad (4)$$

From the equations (3) and (4), we can calculate an important quantity. It is the calculation of the expected value of n , that is, $E[n]$. Since, the value of n ranges from 0 to ∞ , so

$$E[n] = \sum_{j=1}^{\infty} j \Pr(n = j) = \sum_{j=1}^{\infty} j e^{-\lambda \sum_{i=1}^{j-1} (T_i+L)} - \sum_{j=1}^{\infty} j e^{-\lambda \sum_{i=1}^j (T_i+L)} \quad (5)$$

Similarly, each cycle has length of T_j+L . Therefore, the expected duration of a sequence of sleep mode cycles is calculated by:

$$\begin{aligned}
 E[D] &= \sum_{j=1}^{\infty} \Pr(n = j)(j^{\text{th}} \text{ cycle duration}) = \sum_{j=1}^{\infty} \Pr(n = j) \sum_{k=1}^j (T_k + L) \\
 &= \sum_{j=1}^{\infty} e^{-\lambda \sum_{i=1}^{j-1} (T_i + L)} \sum_{k=1}^j (T_k + L) - \sum_{j=1}^{\infty} e^{-\lambda \sum_{i=1}^j (T_i + L)} \sum_{k=1}^j (T_k + L)
 \end{aligned} \tag{6}$$

The energy consumption for j-th cycle is $E_j = \sum_{k=1}^j (T_k E_S + L E_L)$. Hence, the expected energy consumption of a sequence of sleep mode cycles is modeled as:

$$\begin{aligned}
 E[\text{Energy}] &= \sum_{j=1}^{\infty} \Pr(n = j) E_j = \sum_{j=1}^{\infty} \Pr(n = j) \sum_{k=1}^j (T_k E_S + L E_L) \\
 &= \sum_{j=1}^{\infty} e^{-\lambda \sum_{i=1}^{j-1} (T_i + L)} \sum_{k=1}^j (T_k E_S + L E_L) - \sum_{j=1}^{\infty} e^{-\lambda \sum_{i=1}^j (T_i + L)} \sum_{k=1}^j (T_k E_S + L E_L)
 \end{aligned} \tag{7}$$

It's assumed that the frame causing escape from the sequence of sleep mode cycles will arrive at any moment during the last cycle with uniform probability. The length of j-th cycle is $(T_j + L)$. The expected frame response time is defined as:

$$\begin{aligned}
 E[R] &= \sum_{j=1}^{\infty} \Pr(n = j) (T_j + L) / 2 \\
 &= \frac{1}{2} \sum_{j=1}^{\infty} e^{-\lambda \sum_{i=1}^{j-1} (T_i + L)} (T_j + L) - \frac{1}{2} \sum_{j=1}^{\infty} e^{-\lambda \sum_{i=1}^j (T_i + L)} (T_j + L)
 \end{aligned} \tag{8}$$

4. Maximized Energy Saving Sleep Mode in IEEE 802.16e/m

4.1. Algorithm to get Maximized Energy Saving for Sleep Mode IEEE 802.16e/m

Based on the above analysis, we can see that these parameters T_{\min} , T_{\max} are main factors affecting on the energy consumption and frame response time (delay). In general, each pair of (T_{\min}, T_{\max}) gives different results of energy consumption. So, if the value of T_{\min} and T_{\max} are limited in a given range, we certainly choose a pair (T_{\min}, T_{\max}) which causes energy consumption is minimal correspond to a certain λ . The algorithm to choose $(T_{\min-\lambda}, T_{\max-\lambda})$ is below:

```

START
  For tmin=  $T_{\min}, 2^1 T_{\min}, 2^2 T_{\min}, \dots, T_{\max}$ 
    For tmax=tmin,  $2^1 t_{\min}, 2^2 t_{\min}, \dots, T_{\max}$ 
      If (getEnergy(tmin, tmax,  $\lambda$ )(*) < min_energy)
        Tmin_λ=tmin; Tmax_λ=tmax;
        min_energy=getEnergy(*)(tmin, tmax,  $\lambda$ );
      end
    end
  end
END

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(*): follows the equation (7)

By scanning all possible cases of (T_{\min}, T_{\max}) , we can choose the best case which has minimum energy consumption for given λ . So, let denote $\psi(\lambda)$ is a function whose output is a pair $(T_{\min-\lambda}, T_{\max-\lambda})$ so that energy consumption calculated by (7) is minimal. $\psi(\lambda)$ looks like below:

$$\Psi(\lambda) = \begin{cases} (T_{\min,1}, T_{\max,1}) & \text{if } \lambda \leq \lambda_1 \\ (T_{\min,2}, T_{\max,2}) & \text{if } \lambda_1 < \lambda \leq \lambda_2 \\ \dots & \\ (T_{\min,n}, T_{\max,n}) & \text{if } \lambda_{n-1} < \lambda \leq \lambda_n \\ (T_{\min,n+1}, T_{\max,n+1}) & \text{if } \lambda_{n+1} < \lambda \end{cases} \quad (10)$$

To compare new mechanism in this paper with standard sleep mode mechanism studied in Xiao work, we chosen $T_{\min}=1$, $T_{\max}=1024$, $L=1$. Sleep energy consumption and listening energy consumption are chose based on [7], $E_S=30$, $E_L=1$. We consider λ in range of $[0.001; 0.2]$. Based on the algorithm (9) we have following function $\psi(\lambda)$

$$\Psi(\lambda) = \begin{cases} (256,256) & \text{if } 0.0010 \leq \lambda \leq 0.0016 \\ (128,128) & \text{if } 0.0016 < \lambda \leq 0.0058 \\ (64,64) & \text{if } 0.0058 < \lambda \leq 0.0194 \\ (32,32) & \text{if } 0.0194 < \lambda \leq 0.0601 \\ (16,16) & \text{if } 0.0601 < \lambda \leq 0.1672 \\ (8,8) & \text{if } 0.1672 < \lambda \leq 0.2 \end{cases} \quad (11)$$

There is an interesting thing in the results. We can recognize that it has $T_{\min}=T_{\max}$ for given λ to get minimum energy consumption. It means that we always get a pair $T_{\min}=T_{\max}$ corresponding to given λ so that the energy consumption by (7) is minimal. To validate our results in other cases, we will provide other experimental results in cases of $E_S \neq 30$ in section 5 of this paper.

4.2. Proposed Mechanism for Maximized Energy Saving (MES)

Unlike standard PSC I sleep mode, our proposed mechanism does not use MOB-SLP-REQ/RSP to get sleep permission from BS. The mechanism lets BS choose the best sleep interval T for served MSS. An MSS uses constant sleep interval T send from its serving BS via MOB-TRF-IND message in a successive sequence of sleep mode cycles. Our new proposed mechanism operates as following: after transmitting all packets in buffer, BS calculates the mean λ based on the packets it has received in a given duration Δt . By using function $\psi(\lambda)$, BS chooses the most suitable T ($T=T_{\text{suitable}}$ or $T= T_{\text{suitable}} /2$ will be explained in section 5) for an MSS and sends via MOB-TRF-IND message. The MSS receives the MOB-TRF-IND message and switches to sleep mode operation. The MSS sleeps in the first sleep interval with length of T and listens in short time L to check if there is any packet sent to by seeing MOB-TRF-IND is positive or negative. The next sleep interval is still T instead of 2T as in standard sleep mode. The value T is

constant in the same sequence of sleep intervals until next transaction from awake mode to sleep mode. The new proposed energy saving mechanism is depicted in Figure 2.

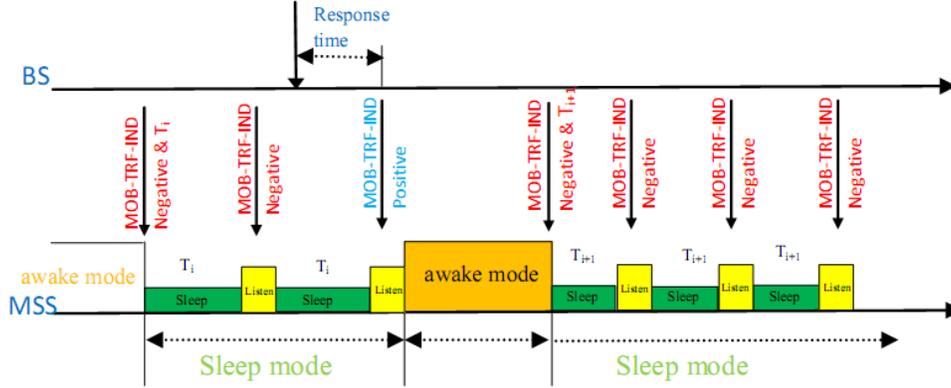


Figure 2. MES Sleep Mode Mechanism for IEEE 802.16e/m

In case of $T_{\min}=T_{\max}=T$, the formula (5)-(8) are rewrote as following. Let p equal to $e^{-\lambda(T+L)}$. Then n is a geometric random variable. For $j \geq 1$, we have

$$\Pr(n = j) = p^{j-1}(1-p) \quad (12)$$

$$E[n] = \sum_{j=1}^{\infty} j \Pr(n = j) = \sum_{j=1}^{\infty} (j-1)p^{j-1}(1-p) = \frac{p}{1-p} \quad (13)$$

$$\begin{aligned} E[D] &= \sum_{j=1}^{\infty} \Pr(n = j) \sum_{k=1}^j (T_k + L) \\ &= \sum_{j=1}^{\infty} p^{j-1}(1-p) j(T+L) = \frac{1}{p} \sum_{j=1}^{\infty} jp^j(1-p)(T+L) = \frac{T+L}{1-p} \end{aligned} \quad (14)$$

$$\begin{aligned} E[\text{Energy}] &= \sum_{j=1}^{\infty} \Pr(n = j) \sum_{k=1}^j (T_k E_s + LE_L) \\ &= \sum_{j=1}^{\infty} p^{j-1}(1-p) j(T E_s + LE_L) = \frac{1}{p} \sum_{j=1}^{\infty} jp^j(1-p)(T E_s + LE_L) = \frac{T E_s + LE_L}{1-p} \end{aligned} \quad (15)$$

$$\begin{aligned} E[R] &= \sum_{j=1}^{\infty} \Pr(n = j) (T_j + L) / 2 \\ &= \frac{1}{2} \sum_{j=1}^{\infty} p^{j-1}(1-p)(T+L) = \frac{(T+L)}{2} \end{aligned} \quad (16)$$

5. Performance Evaluation

The WiMAX industry has seen much enthusiasm in the last five years, as measured by the number of device vendors taking part in producing WiMAX devices. Each WiMAX-device vendor differs from the others by their parameters such as energy consumption in sleep state and active stage. To check our MES algorithm in various

kind of WiMAX device, we change the value of E_L in range [10; 30]. Figure 3 shows the results. We use the following parameters $T_{min}=1$, $T_{max}=1024$, $L=1$, $E_S=1$, $E_L=[10; 25]$. The results show that the MES algorithm always can choose the best pair (T_{min} ; T_{max}) so that energy consumption in sleep mode is minimal. The results also give us $T_{min}=T_{max}=T_{suitable}$.

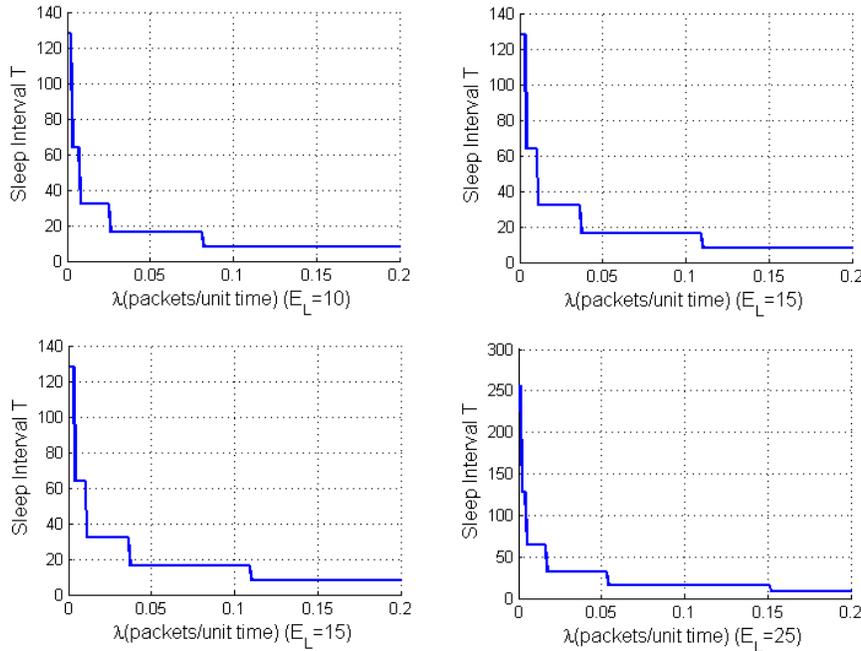


Figure 3. MES Algorithm in Case of Changing E_L ($T_{min}=T_{max}=T$)

We have made a simulation using MATLAB to validate our proposed mechanism. We also analytical evaluate and compare new mechanism with standard sleep mode in IEEE 802.16e. In both simulation and analytical evaluation, we use follow parameters: $T_{min}=1$, $T_{max}=1024$, $L=1$, $E_S=1$, $E_L=30$. Based on MES algorithm, we choose the sleep interval T equals to $T_{suitable}$ or a half of $T_{suitable}$ in case of running services need to get better response time. The total simulation time is 10^9 unit times. Figure 4 shows simulation and analytical result of energy consumption. We can see that both simulation and analytical results are nearly same.

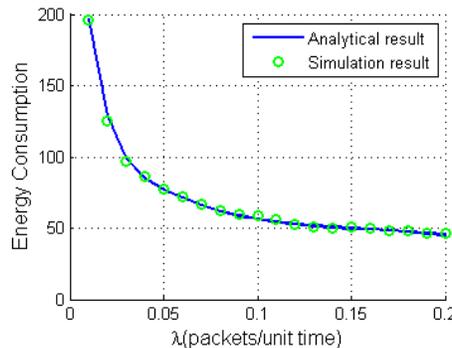


Figure. 4. Analytical Result vs. Simulation Result ($T=T_{suitable}$)

In case of $T=T_{suitable}$, Figure 5 shows the comparison results between standard sleep mode and our scheme for IEEE 802.16e/m. Figure 6 shows energy saving of our scheme in comparison with standard sleep mode. The formula of energy saving is

$$\text{Energy saving}(100\%) = \frac{\text{Energy}_{PSM} - \text{Energy}_{MES}}{\text{Energy}_{PSM}} \times 100\% \quad (17)$$

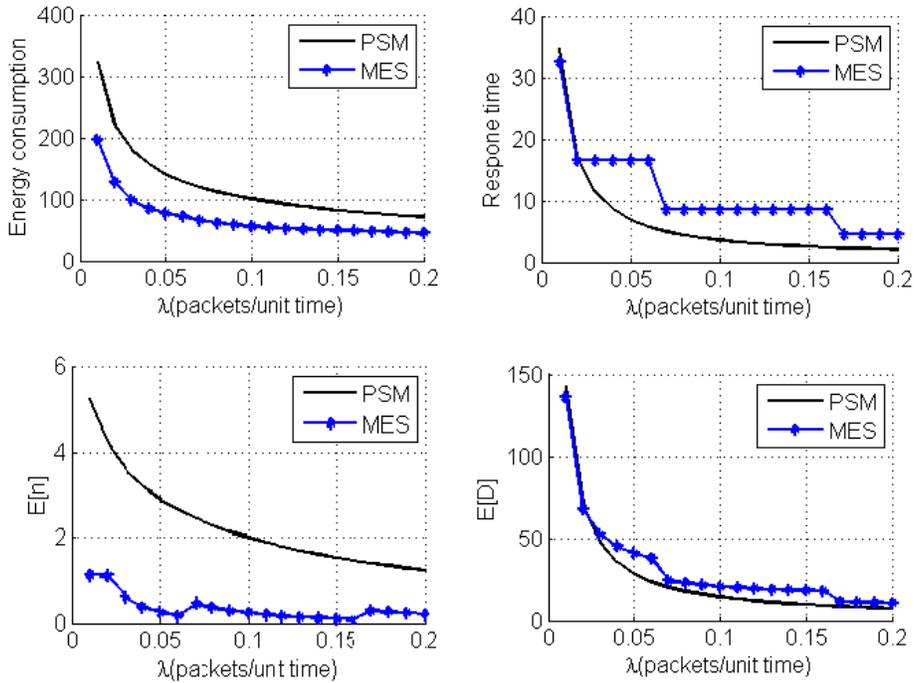


Figure 5. PSM vs. MES ($T=T_{suitable}$)

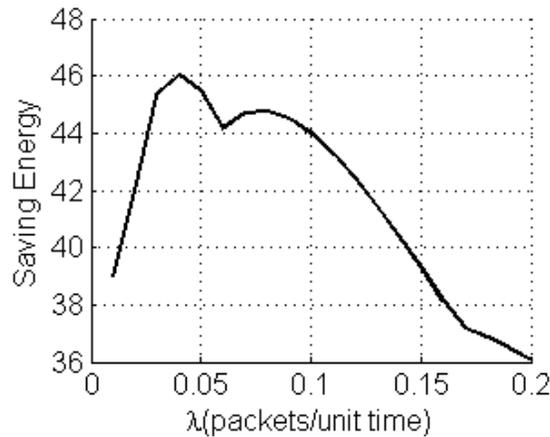


Figure 6. Energy Saving ($T=T_{suitable}$)

We can see in the Figure 6, the MES mechanism has saved energy more than 36%. The response time, however, is also increased. From the formula (16), the frame response time is $(T+L)/2$. So, in case of $T=T_{\text{suitable}}/2$, we get both better energy consumption result and response time result. These Figures below show the results in case of $T=T_{\text{suitable}}/2$

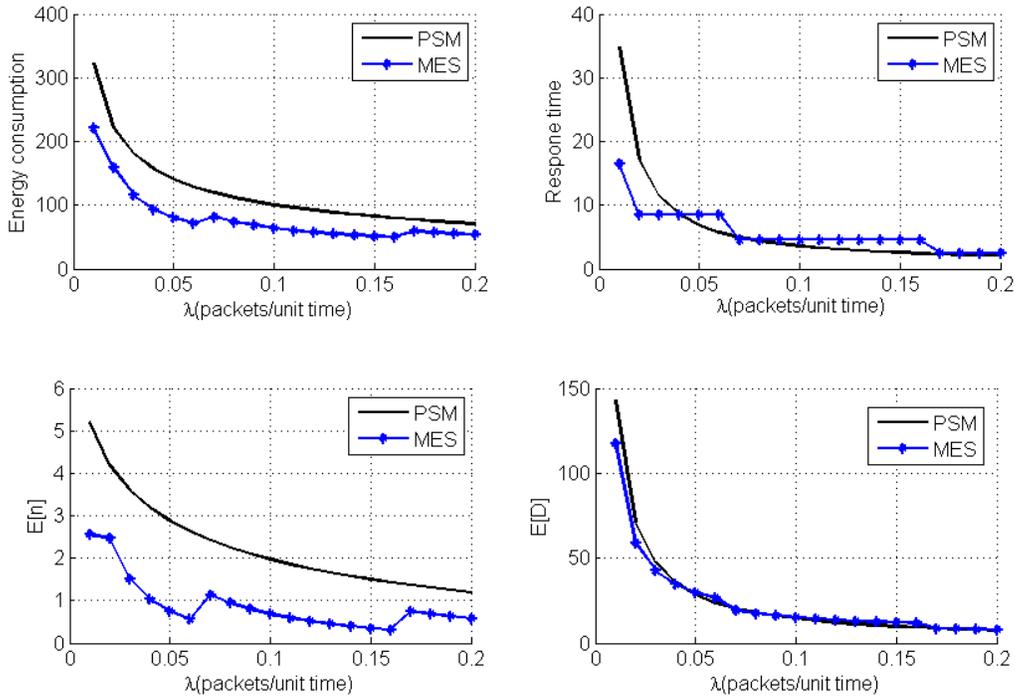


Figure 7. PSM vs. MES ($T=T_{\text{suitable}}/2$)

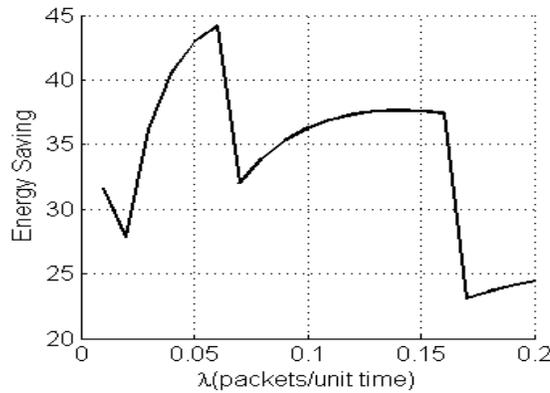


Figure 8. Energy Saving ($T=T_{\text{suitable}}/2$)

6. Conclusions

In this paper, we have proposed a new energy saving mechanism without MOB-TRF-REQ/RSP by using dynamical sleep interval corresponding to variation of traffic rates. The proposal lets BS decide which sleep interval time is suitable for MSS by observing average

packet arrival time. The new mechanism does not reduce the tasks of MSS in sleep mode but also it reduces overheads and waste time to get sleep approval. The analytical model and simulation results showed that our mechanism has much more energy saving in comparison with standard sleep mode 802.16e. Our mechanism is flexible and can be applied for both PSC I and PSC II in IEEE 802.16e/m by changing the length of sleep interval available for response time requirement. In near future, we will make more experiments in real systems or with other simulation tools such as OPNET or NS-2 to validate the proposed mechanism.

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