On the Power Consumption of 802.16e Listening State

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Abstract: - Energy consumption strategy is crucial to the future of Broadband Wireless Access (BWA). In order to manage limited battery power efficiently, the IEEE 802.16e standard defines the sleep mode operation in its MAC protocol to maximize the lifetime of Mobile Station (MS) and to enhance the network capability. In this paper, we analytically investigate the power consumption of listening state and sleep state operations of IEEE 802.16e. A Mobile Station goes to sleep mode when there is no data to send or receive with the Base station (BS). After a Mobile Station stays in sleep state for a pre-defined time, it wakes up and transits to listening state periodically to check if the Base Station has any buffered downlink traffic destined to the Mobile Station itself. Although the listening interval is shorter than sleep interval, the power consumption should consider both listening state and sleep state operations. Our proposed model and numerical results prove the listening state may consume up to 90% of the total power consumption in some case.

Key-Words: - WiMAX, Power consumption, Listening state, Sleep mode, 802.16e.

1 Introduction

With the mature of IEEE 802.11 wireless local area network (WLAN), we have the ability to access high speed internet connection at any location. However, WLAN does not support high-speed mobility functions. During the past years, the mobile devices have become more popular, and a ubiquitous internet access network is feasible. The Worldwide Interoperability for Microwave Access (WiMAX) [1, 2] has been designed for fixed and mobile broadband network through broadband radio access technology. In order to combine the fixed (802.16d) and mobile (802.16e) systems, the authors [3] have presented the coexistence and spectrum sharing study as an initial step toward beyond 3G.

WiMAX achieves high mobility with the Orthogonal Frequency Division Multiple Access (OFDMA) air interface, Adaptive Modulation and Coding (AMC) modulation and Multi-Input Multi-Output (MIMO) antenna technologies. Due to the high speed moving capability, the Mobile Station need to use battery as its major power source, and therefore the power management becomes a very important issue. From the hardware perspective, radio frequency (RF) module dominates the power consumption of MS, and how/when to turn off the RF module is the main concern of power saving. For this reason, the 802.16e defines the sleep mode operation for the MS to extend battery lifetime.

Sleep mode is a state in which an MS conducts pre-negotiated periods of absence from the Serving Base Station air interface. Under the 802.16e sleep mode operation, an MS starts to sleep for a fixed amount time, called initial-sleep window, then wakes up to listening state if the BS has any buffered downlink traffic destined to itself. If there

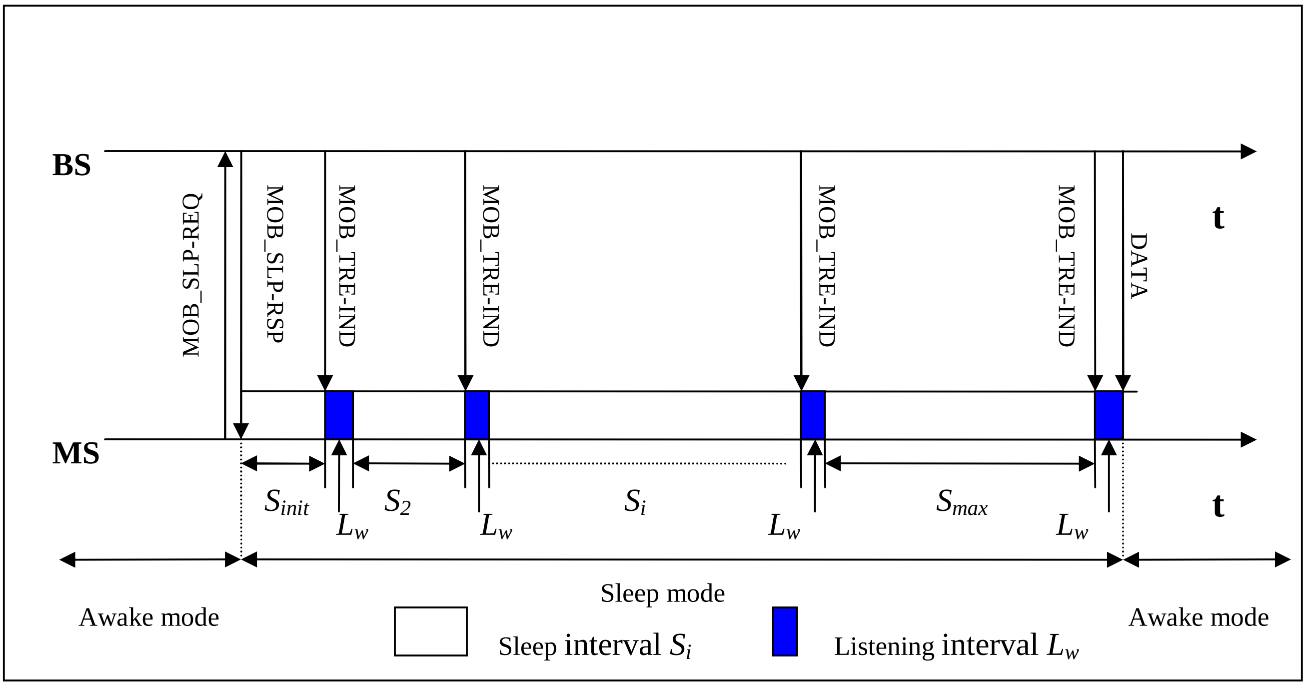

Fig. 1: Illustration of the listening state and sleep state operations in Type I

is no such traffic, MS adjusts the sleep window size and goes to sleep state again. Otherwise, it enters the awake mode. Sleep mode is intended to minimize MS power usage and decrease usage of Serving BS air interface resources. Implementation of sleep mode is optional for the MS and mandatory for the BS.

There are three types of Power Saving Classes, which differ by their parameter sets, procedures of activation/deactivation, and policies of MS availability for data transmission. Power Saving Classes of Type I is recommended for Best Effort (BE) and non-real-time variable rate (NRT-VR) type, Power Saving Class of Type II for unsolicited grant service (UGS) and real-time variable rate (RT-VR), and Power Saving Class of Type III [4] for management operation and multicast connections, respectively.

When in Power Save Class of Type I, the sleep window is exponentially increased from the minimum value of initial-sleep window to the maximum value of final-sleep window (Fig. 1). Power Save Class of Type II has a fixed-length sleep window (Fig. 2). Power Save Class of Type III allows for a one-time sleep window and the length is equal to final-sleep window.

In the literature, Chung [5] divides the handset system into three units (data receiving, data processing and user interface). One of the power saving mechanisms is to make some of the units switch between active and sleep state. Jang [6] presents a model to adapt the length of sleeping period according to the traffic status. The authors in [7] evaluate the effect of initial sleep window, final sleep window and average inter-arrival time of MAC frame on the performance of power saving. Xiao [8, 9] propose an analytical mode of Type I and investigate the power consumption of 802.16e, including the incoming and outgoing frames.

[8] and [10] have studied the operation of sleep mode that is specified in MAC protocol. Han [11] has evaluated the sleep mode operation in terms of average energy consumption and average frame response delay. Under the assumption of Poisson traffic, Seo[12] constructs the queuing models with multiple vacations to analyze the power consumption and the delay which consists of queuing delay and serving time. Yang [13] mentions the awake mode action requires not only signaling transactions but also consumes great amount of energy.

[14]-[18] presented a sleep mode interval control algorithm that takes into consideration downlink/uplink traffic pattern and the mobility of the mobile station. Jeong and Jeon [19] extended the sleep period update scheme which multiplies the sleep period by a real number q>1 instead of doubling it.

In [20]-[23], the initial sleep interval and maximum sleep interval are adaptive according to

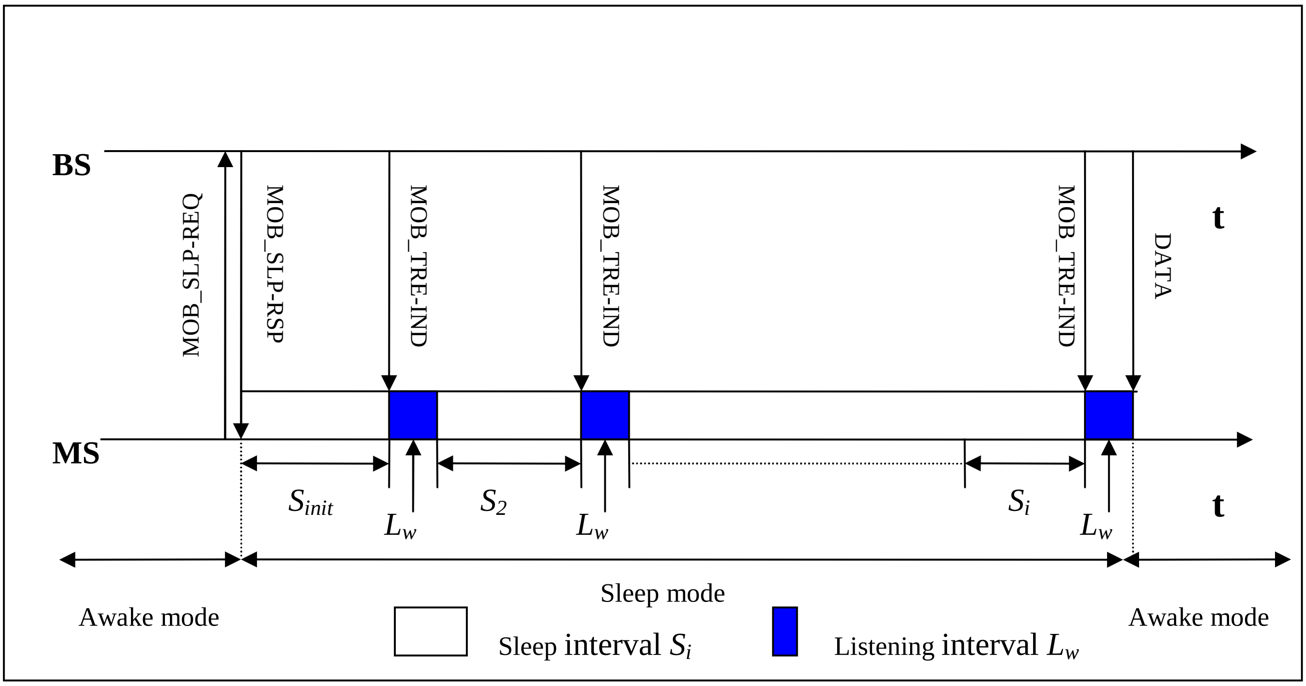

Fig. 2: Illustration of the listening state and sleep state operations in Type II

the traffic condition. All of the previous works did not take any attention for the listening state.

In this paper, we develop a simple but precise model, which is capable of investigating the listening state and sleep state operations of IEEE 802.16e. The rest of paper is organized as follows, Section 2 introduces the overview of listening state and sleep state operations in IEEE 802.16e. We present analytical models for Power Saving Class of Type I and II in Section 3. In order to observe the effect of listening state on power management, we present the performance evaluation result in Section 4. Finally, we conclude this paper in Section 5.

2 Overview of listening state and sleep state operations in IEEE 802.16e

After the MS registers with a specific BS, it can be one of two operational modes, awake mode and sleep mode, as is illustrated in Fig. 3. The time is always divided into cycles, and each cycle includes the awake mode and sleep mode. If the MS has data to send or receive, it is in the awake mode. Otherwise, it will enter the sleep mode. The sleep mode involves two operating intervals, a sleep interval and the following listening interval. During the sleep interval, the MS may take off some physical operation components in order to save its battery power energy. During the listening interval, the MS shall synchronize with the BS and wait the traffic indication message (MOB_TRF-IND) from the serving BS to decide whether to stay in awake mode or go back to sleep mode.

There are two formats for the MOB_TRF-IND messages, depending on the FMT field (1 bit). If FMT = 0, MOB_TRF-IND message contains the Traffic Indication Bitmap, and BS notifies to the MS with the sleep ID (SLPID) bitmap whether to stay awake or go back to sleep. If FMT = 1, MOB_TRF-IND message includes the Basic CID(Connection Identifier) of MS which have to go to the awake mode. If MOB_TRF-IND exists with a positive signal through bitmap or basic CID, or if the MS did not receive MOB_TRF-IND message during the listening interval, the MS shall remain in awake mode and terminate the sleep mode.

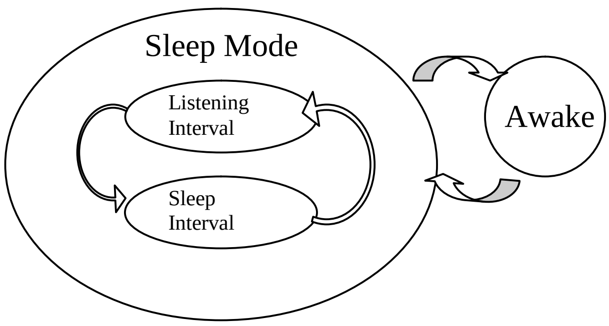

Fig. 3: The cycle of Awake mode and Sleep mode

In detail, the defined sleep algorithm operates as follows.

(a) When the MS cannot find any data to send or receive, it recognizes that it must go to a sleep mode.
(b) Before entering the sleep mode, the MS shall inform the BS using a sleep request (MOB_SLP-REQ) message for permission. The MS may retransmit MOB_SLP-REQ message if it does not receive the MOB_SLP-RSP message within the defined timer.
(c) MS will receive approval through MOB_SLP-RSP message from BS. The MOB_SLP-RSP message contains power saving class type, sizes of initial-sleep window (S_{init}), sizes of listening window, size of final-sleep window base, and sizes of final-sleep window exponent.
(d) The MS allocates the parameters received from the BS so that MS can come into sleep state for an interval defined by S_{init}. When this sleep interval finishes, the MS wakes up to listening state. During the listening interval, the MS listens to a traffic indication (MOB_TRE-IND) to decide whether to enter awake mode or go back to sleep state. When the MS senses a positive MOB_TRF-IND message indication, it will enter the awake mode. Otherwise,
(e) Power Saving Class of Type I ： If the MS decide to stay in the sleep state, it shall double the preceding sleep internal. This process is repeated as long as the sleep interval does not exceed the final-sleep window (S_{max}). If the MS has reached S_{max}, it shall keep the sleep interval as fixed S_{max}.
(f) Power Saving Class of Type II ： If the MS decide to stay in the sleep state, the new sleep internal is the same as last sleep internal (S_{init}). This process is repeated until MS receives the positive signal of MOB_TRE-IND.
(g) Power Saving Class of Type III ： All sleep intervals are the same size and equal to final-sleep window (S_{max}).

The length of sleep interval in the *i*-cycle is given as follows ：
(a) Power Saving Class of Type I

$$S_i = \begin{cases} S_{init} & i = 1 \\ \min(2^{i-1} S_{init}, S_{max}) & i > 1 \end{cases} \quad (1)$$

(b) Power Saving Class of Type II
$S_i = S_{init}$

(c) Power Saving Class of Type III
$S_i = S_{max}$

The MS can go from the sleep mode to awake mode when the MS has some uplink Protocol Data Units (PDUs) to the BS during sleep mode by itself. In such case (Fig. 4), the MS can wake up prematurely to send a bandwidth request message to the BS for uplink transmission and terminate the sleep mode. Therefore, from the viewpoint of power saving, the longer sleep interval can have better power management performance. On the other hand, if the BS has some PDUs to transmit to the MS during sleep mode, the BS need to wait to transmit the PDUs until the start time of coming listening state in the MS. It will have some additional response time delay.

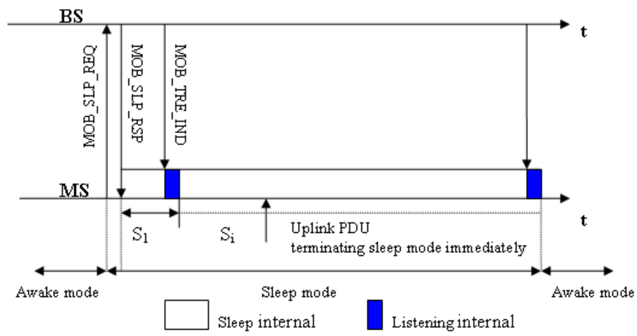

Fig. 4: Uplink PDU

802.16e also defined the idle mode to save more energy, and support for it is optional in WiMAX. Idle mode allows the MS to completely turn off and to not be registered with any BS and yet receive downlink broadcast traffic. The BSs are divided into logical groups called paging groups. The MS is assigned to a paging group by the BS before going into idle mode, and the MS periodically wakes up to update its paging group. The purpose of these groups is to offer a contiguous coverage region in which the MS does not need to transmit in the UL, yet can be paged in the DL if there is traffic targeted at it. The paging groups should be large enough so that most MSs will remain within the same paging group most of the time, and small enough such that the paging overhead is reasonable.

When downlink traffic arrives for the idle mode MS, the MS is paged by a collection of base stations that form a paging group. Idle mode saves more power than sleep mode, since the MS does not even have to register or do handoffs. Idle mode also benefits the network and BS by eliminating handover traffic from inactive MSs.

Figure 5 [2] shows an example of four paging groups defined over multiple BS arranged in a hexagonal grid. A BS may be a member of one or more Paging Groups.

Currently, we do not have any power information of IEEE 802.16e system in listening state and sleep state. Borrowing data from 802.11, we find out the power consumption in receiving state is much larger than sleep state. Although the listening interval is a very short period in 802.16e, we shall consider this 802.11 power consumption factors to increase the accuracy of 802.16e power consumption. We find out the listening state may consume up to 90% of the total power consumption from our proposed model in some case.

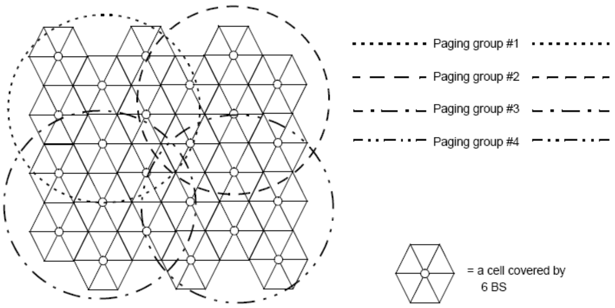

Fig. 5: Paging-groups example

3 Analytical model

From the description in the previous section, we know that there are some parameters, related to the power saving mechanism, which can be adaptively configured. We will develop the mathematical formulas to describe the power consumption of Power Saving Class of Type I and II, respectively, and apply different values to these parameters according to the different services.

3.1 Power Saving Class of Type I

According to standard of Type I, the timings of performing switches between listening window and sleep window are based on four major parameters as shown below (Table 1). When the MS send a MOB_SLP-REQ message for sleep request, the BS shall respond with the MOB_SLP-RSP message with relevant parameters.

Table 1:
The major parameter formats of MOB_SLP-RSP of Type I

Syntax	Size
initial-sleep window	8 bits
listening-window	8 bits
final-sleep window base	10 bits
final-sleep window exponent	3 bits

In the first sleep interval, a minimum sleep window is used and the first sleep window size is called initial-sleep window (S_{init}), measured in frames. The listening window (L_w) is assigned duration of MS listening window (measured in frames and fixed). Each subsequent sleep window is doubled until a final-sleep window size is reached, and then the sleep interval is maintained at the final sleep window until MS wakes up. The final-sleep window base is an assigned final value for the sleep interval. The final-sleep window exponent is also a factor by which for the final-sleep window base is multiplied in order to calculate the final-sleep window.

The following formula is used to calculate the final-sleep window (S_{max}).

Final-sleep window (S_{max})
= final-sleep window base x $2^{(\text{final-sleep window exponent})}$

Here, we focus on two power consumption areas, listening interval and sleep interval. First, we assume the MS shall transit to awake mode when its sleep window size reaches the final-sleep window (S_{max}). Let n denote the *i*-th sleep interval before the MS goes to the awake mode. S_i denotes the length of the *i*-th sleep interval. E_S denotes the consumed energy units per frame in sleep interval. E_L denotes the consumed energy units per frame in listening interval. *TPS* denotes the total power consumption in all sleep intervals. *TPL* denotes the total power consumption in all listening intervals. *TTL* is the total power consumption in one sleep mode cycle. We have

$$TTL = TPS + TPL \qquad (2)$$

According to the definition of sleep mode operation, S_i , the duration of the *i*-th of sleep interval, is obtained in each step as follows.

$$S_1 = S_{init}$$
$$S_i = 2 S_{i-1}, \qquad n \ge i > 1$$

Consumed energy of the MS during all sleep intervals is given by

$$\begin{aligned} TPS &= \sum_{i=1}^{n} E_S S_i \\ &= E_S \ (S_{init} + 2\, S_{init} + \dots + 2^{n-1} S_{init}) \\ &= E_S \ (2^n - 1)\, S_{init} \qquad (3) \end{aligned}$$

The total power consumption in all listening intervals is

$$TPL = \sum_{i=1}^{n} E_L L_w = n \ E_L \ L_w \qquad (4)$$

Let α represents the rate of E_L / E_S. We can rewrite equation (4) to

$$TPL = n E_L L_w = n \alpha E_S L_w \quad (5)$$

Finally, the total power consumption (*TTL*) in one sleep mode cycle is

$$TTL = TPS + TPL$$
$$= E_S (2^n - 1) S_{init} + n \alpha E_S L_w \quad (6)$$

3.2 Power Saving Class of Type II

Unlike Type I, the sleep windows of Type II are the same size as initial windows. Sleep windows are interleaved with listening windows of fixed duration. According to standard, the timings of performing switches between listening window and sleep window are based on three parameters as shown below (Table 2).

In this Type II, BS and MS can freely exchange data packets during listening window and the MS does not need to leave sleep mode. This type is useful for handling services with constant bit rate. For real-time services, data rate is not specified by the maximum data rate and a little bit delay is tolerable. So the MS is allowed to wake up for listening window to transmit/receive data packets to/from BS and then enter sleep mode.

Table 2:
The major parameter formats of MOB_SLP-RSP of Type II

Syntax	Size
initial-sleep window	8 bits
listening-window	8 bits
Start frame number for first window	6 bits

The notations are the same as Type I.

(a) E_S : the consumed energy units per frame in sleep interval.
(b) E_L : the consumed energy units per frame in listening interval.
(c) S_{init} : size of the initial-sleep window.
(d) L_w : size of listening window.
(e) *TPS* : the total power consumption in all sleep intervals.
(f) *TPL* : the total power consumption in all listening intervals.
(g) *TTL* : the total power consumption in one sleep mode cycle.
(h) n : the *i*-th sleep interval before the MS goes to the awake mode.
(i) α : the rate of E_L / E_S

The total power consumption in all sleep intervals is

$$TPS = \sum_{i=1}^{n} E_S S_{init}$$

and, the total power consumption in all listening intervals is

$$TPL = \sum_{i=1}^{n} E_L L_w$$

Finally, the total power consumption in one sleep mode cycle is

$$TTL = TPS + TPL$$
$$= \sum_{i=1}^{n} E_S S_{init} + \sum_{i=1}^{n} E_L L_w$$
$$= n (E_S S_{init} + E_L L_w)$$
$$= n E_S (S_{init} + \alpha L_w)$$

4 Performance evaluation

In this section, we present the performance metrics analysis for Power Saving Class of Type I and II. In order to investigate the numerical result for each Type, we need to determine the frame time used throughout this paper. Normally, the frame length is assumed to 5 msec, and we will choose this value for our study.

4.1 Power Saving Class of Type I

Power Saving Class of this type is recommended for connections of Best Effort (BE), Non-real-time variable rate (NRT-VR) type. It is that the response time is not sensitive. We choose the following parameters and evaluate the numerical results for this Power Saving Class of Type I.

--- S_{init} (initial-sleep window) = 1 frame,
--- L_w (listening-window) = 1 frame,
--- final-sleep window base = 255 (2^{10}-1),
--- final-sleep window exponent = 7 (2^3 - 1).

The final-sleep window (S_{max}) ≈ 2^{10} x 2^7 = 2^{17} frames. According to equation (1), we know S_{18} = 2^{17} = S_{max} when n = 18. It means the MS will reach the S_{max} in the 18-th cycle. It is that we do not have any 802.16e power consumption information of E_S and E_L currently. We borrow the power consumption values from the 802.11 WLAN, and the specification of US54G wireless USB card from

MSI is shown in table 3. We use the data for E_S = 50mA and E_L= 350mA, respectively. The α is 7 (350/50).

Table 3:
The major product specifications of US54G

Network Standard	IEEE 802.11/11b/11g
Power Consumption	450mA in continuous transmitting 350mA in continuous receiving 50mA(sleep mode)

In figure 6, we show with the effect of *n* for the *TTL*, *TPS* and *TPL*. The comparison shows that *TPS* (the total power consumption in all sleep intervals) is increased exponentially with the *n*. But, the curse of *TPL* (the total power consumption in all listening intervals) is increased linearly with the *n*.

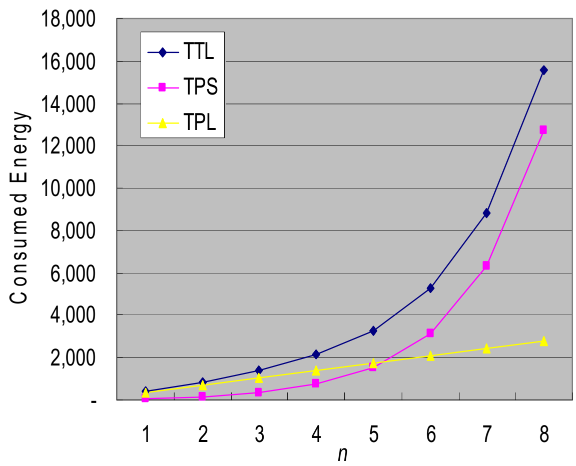

Fig. 6: The effect of *n* on energy consumption

Figure 7 shows the graph of *TPL* rate to total power consumption versus the incremental *n*. In the worst case (*n* = 1), the rate is near 90%. It means an MS starts to sleep for the first time, and wakes up to its first listening state. There is a traffic message waiting for this MS. So, the MS need immediately to enter the awake mode. In the best case (n = 18), the rate is near to 0% (0.05%).

When the MS wake up to listening state, it will normally receive MOB_TRF-IND message from the same BS. So, the listening window size can be 1 frame. It is that the 802.16e has the mobility function, an MS may need to connect to a different BS after the sleep state. It will spend more window size to negotiate with the other BSs. Figure 8 shows the result for listening window interval 1, 2 and 4, respectively. We find out the higher listening interval, the higher listening power consumption rate.

We present a scheme adaptively changes the length of initial-sleep window (S_{init}) in order to maximize power saving effect. Figure 9 shows the result and the rate is too small. So, it is no different for any value of S_{init}.

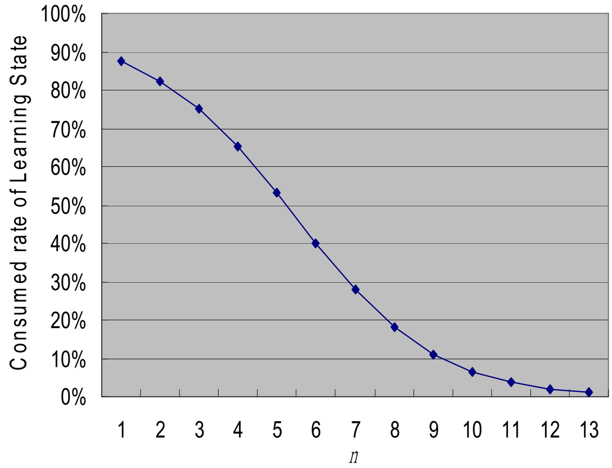

Fig. 7: The effect of *n* for energy consumption in listening state (L_W =1)

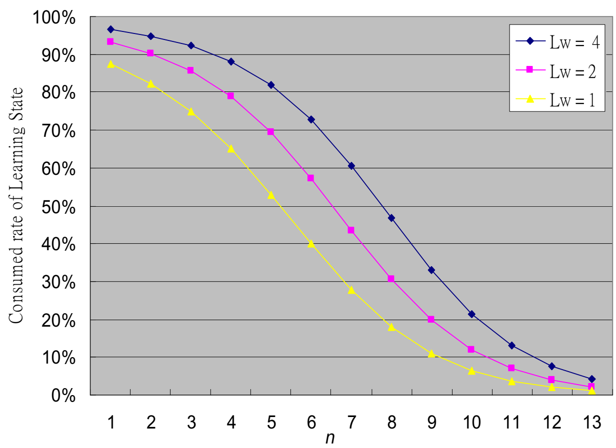

Fig. 8: The effect of n for energy consumption in different listening intervals

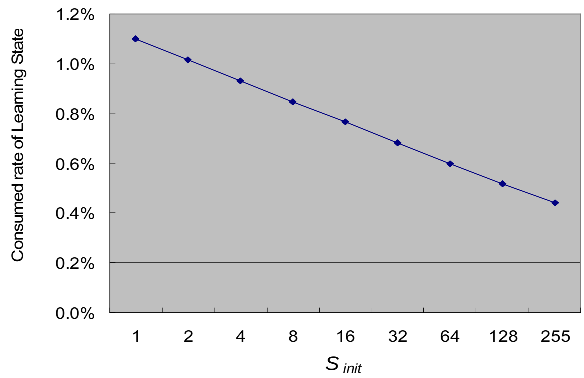

Fig. 9: The effect of S_{init} in listening state (L_W = 1, S_{max} = 2^{17})

4.2 Power Saving Class of Type II

Power Saving Class of this type is recommended for connections of Unsolicited Grant Service (UGS) and Real-time variable rate (RT-VR). The response time is very susceptible and the sleep windows are the same size. We have to do the trade-off between the power saving and response time. We choose the following parameters and evaluate numerical result for this Power Saving Class of Type II.

--- S_{init} (initial-sleep window) = 256 frames,
--- L_w (listening-window) = 1 frame,
--- E_S = 50mA
--- E_L = 350mA
--- α = 7 (350/50).

Figure 10 shows the *TTL*, *TPS* and *TPL* in terms of different *n*. The comparison shows that *TPS* (the total power consumption in all sleep intervals) is increased linearly with the *n*. But, the curse of *TPL* (the total power consumption in all listening intervals) is almost the same value.

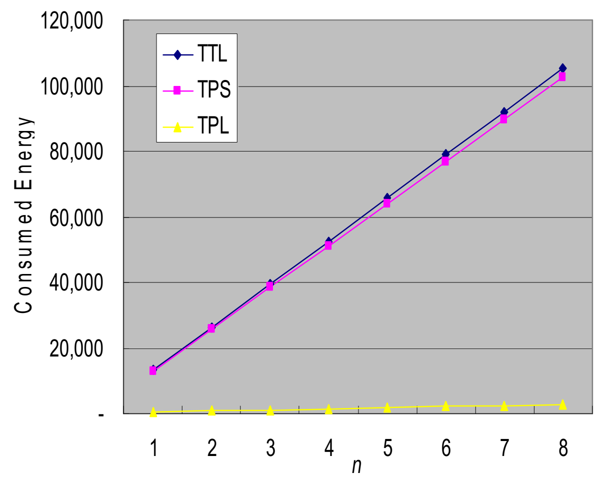

Fig. 10: The effect of n on energy consumption

Figure 11 shows the graph of *TPL* rate to total power consumption versus the incremental *n*. The rate is 2.66% for any *n*. It is that the sleep window and listening window sizes are fixed. The rate will be the same. If we change the listening window sizes to 2 and 3 frame. The rate will be double and triple, respectively (Fig. 12).

802.16e reveals that adjusting the size of initial-sleep window (S_{init}) will enable MS to control the length of sleep windows. But, it does not mention how to determine it. Figure 13 shows the rate of *TPL* to *TTL* and the curve rate is decreased rapidly.

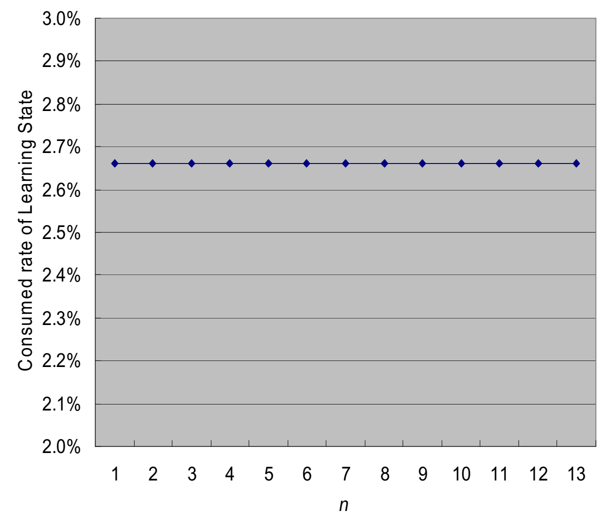

Fig. 11: The effect of n for energy consumption in listening state (L_w = 1)

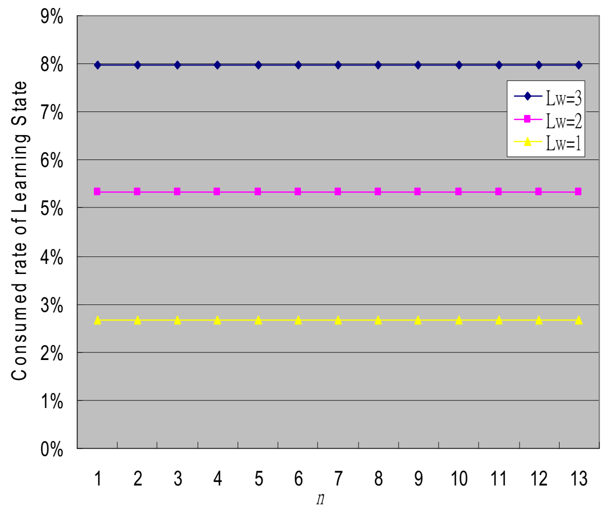

Fig. 12: The effect of n for energy consumption in listening state (L_w = 1, 2 and 3)

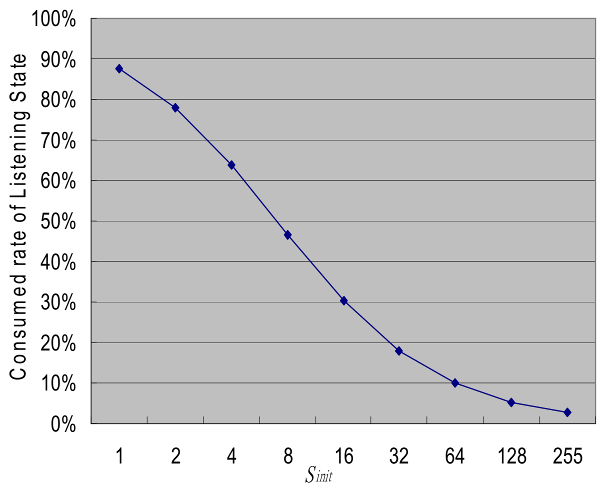

Fig. 13: The effect of S_{init} in listening state (L_W = 1, *n* = 10)

5 Conclusion

In this paper, we introduce the power saving mechanism of 802.16e standard for Type I and Type II , and analyze the listening state and sleep state operations in sleep mode. We also propose an analytical model to evaluate the power consumption in listening state by changing “the number of sleep interval” to reach awake mode. The numerical results show that we need to consider the consumed energy of Listening State with the downlink traffic frequency. It can influence the power consumption rate of listening state.

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