Power Consumption Study of Listening State in the 802.16e

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Abstract: − In this paper, we analytically study the power consumption of listening state and sleep state operations of IEEE 802.16e. A Mobile Station (MS) goes to sleep state for a pre-defined time, and wake up periodically to listening state to check if the Base Station (BS) has any buffered downlink traffic destined to itself. Although the listening interval is shorter than sleep interval, the power consumption should include both of listening state and sleep state operations. Our proposed model proves 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. But it does not have vehicle mobility function. During the past years, the mobile devices have become more popular, and people desire to have a ubiquitous internet access network. The Worldwide Interoperability for Microwave Access (WiMAX) [1] [2] has been designed for fixed and mobile broadband network through broadband radio access technology. It utilizes 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 in WiMAX, the Mobile Station (MS) 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 becomes the critical 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 (BS) air interface. Under the 802.16e sleep mode operation, an MS starts to sleep for a fixed amount time, called initial-sleep window, and wakes up in order to listen if the BS has any buffered downlink traffic destined to itself. If there 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 for management operation and multicast connections, respectively.

In the literature, Jang [3] presents a model to adapt the length of sleeping period according to the traffic statue. The authors in [4] evaluate the effect of initial sleep window, final sleep window and average interarrival time of MAC frame on the performance of power saving. Both of them do not count the power consumption of listening state.

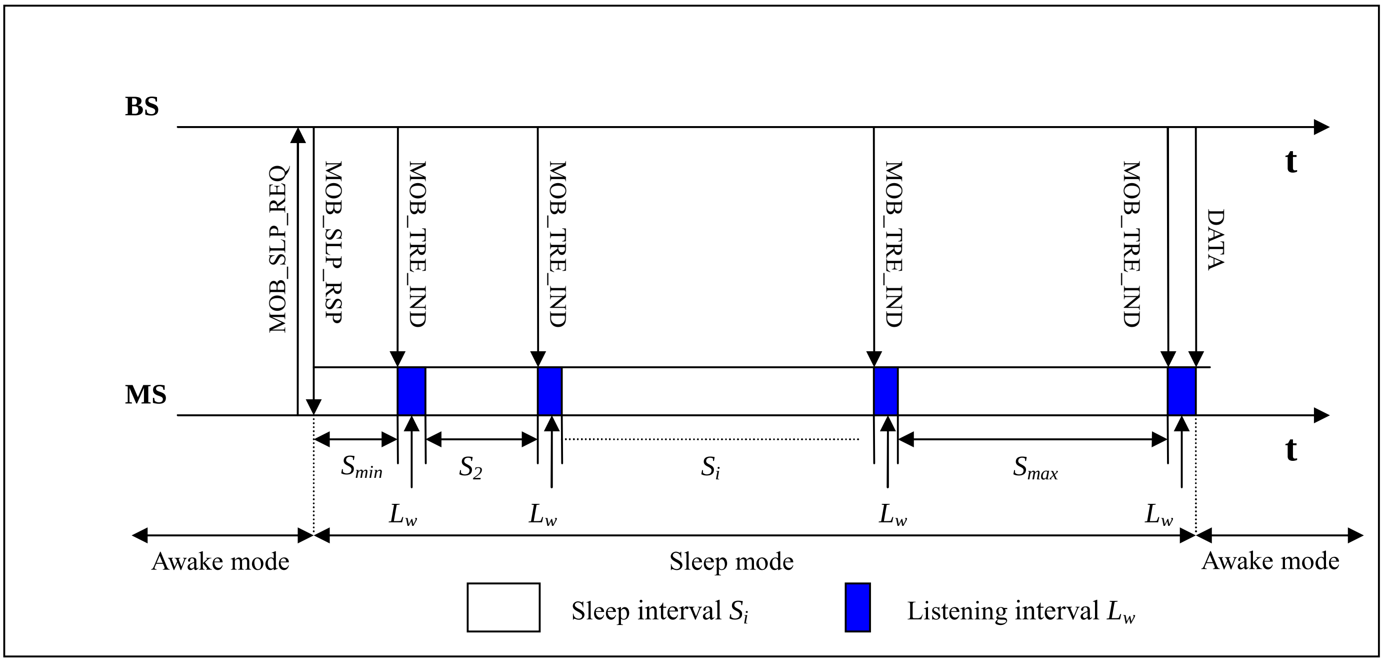

Fig. 1. Illustration of the listening state and sleep state operations in IEEE 802.16e

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. This rest of this paper is organized as follows, Section 2 introduces the overview of listening state and sleep state operations in IEEE 802.16e. We present an analytical model 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

There are three power saving types, we only address Power Saving Class type I. This type is recommended for connections of BE and NRT-VR types. 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. 1. 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 also involves the sleep state and listening state. Before MS entering sleep mode, it shall inform the BS using a sleep request (MOB_SLP-REQ) message and wait for the approval (MOB_SLP-RSP) message from BS. The MS may retransmit MOB_SLP-REQ message if it does not receive the MOB_SLP-RSP message within the defined timer.

After receiving the approving MOB_SLP-RSP message, which carries the initial-sleep window (S_{min}), listening-window, final-sleep window base and final-sleep window exponent, the MS will come into sleep state for an interval defined by S_{min}. When the 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. 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}.

The length of sleep interval in the i^{th} cycle is given by

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

Currently, we do not have any power consumption information of IEEE 802.16e system in listening state and sleep state. We need to borrow the data from 802.11 and find out the power consumption in receiving state is very 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.

3. Analytical model

In this section, we develop the mathematical formula to describe the power consumption of Power Saving Class type I. From the description in section 2, there are some parameters (shown in table 1) related to the power consumption mechanism.

The initial-sleep window (S_{min}) is assigned initial duration for the sleep window (measured in frames). The listening window (L_w) is assigned duration of MS listening window (measured in frames and fixed). The final-sleep window base is assigned final value for the sleep interval (measured in frames). The final-sleep window exponent is assigned 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 $2^{\text{(final-sleep window exponent)}}$

Table 1.
The major parameter formats of MOB_SLP-RSP

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

In this paper, we focus on two power consumption areas, listening state and sleep state. First, we assume the MS shall wake up 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

$$TTL = TPS + TPL \tag{2}$$

$$S_1 = S_{min}$$

$$S_i = 2S_{i-1} \quad , \quad n \geq i > 1$$

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

$$= E_S \; (S_{min} + 2\, S_{min} + \ldots + 2^{n-1} S_{min})$$

$$= E_S \; (2^n - 1)\, S_{min} \tag{3}$$

$$TPL = \sum_{i=1}^{n} E_L L_w = n \; E_L \; L_w \tag{4}$$

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

$$TPL = n \; E_L \; L_w = n\,\alpha E_S \; L_w \tag{5}$$

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

$$TTL = TPS + TPL$$

$$= E_S \; (2^n - 1)\, S_{min} + n\,\alpha E_S \; L_w \tag{6}$$

4. Performance evaluation result

We choose the following parameters:

--- S_{min} (initial-sleep window) = 1,

--- L^w (listening-window) = 1,

--- 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}. 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 [5] is shown in table 2. We use the data for E_S = 50mA and E_L = 350mA, respectively. The α is 7 (350/50).

Table 2.
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)

Figure 2 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 rapidly with the n. But, the curse of *TPL* (the total power consumption in all listening intervals) is slow increased. Figure 3 shows the graph of *TPL* ratio to total power consumption versus the incremental n. In the worst case (n = 1), the ratio 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 ratio 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 4 shows the result for listening window interval 1, 2 and 4, respectively. We find out the interval 2 curve gradually closes to interval 1.

Figure 4 show the effect of S_{min} on energy consumption for the listening state under the MS reaches the final-sleep window (S_{max}) assumption. We find out it is no different for any value of S_{min}.

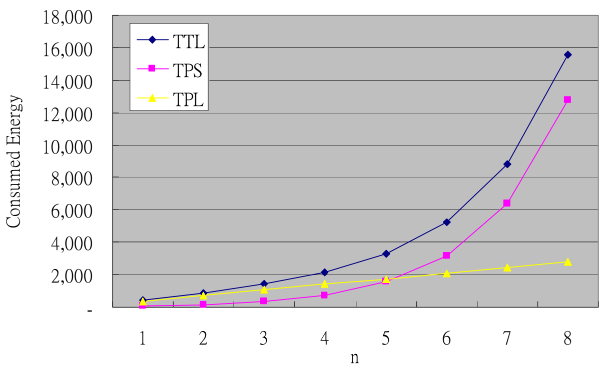

Fig. 2. The effect of *n* on energy consumption

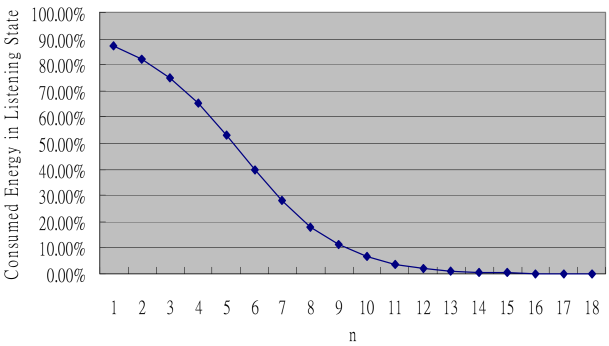

Fig. 3. The effect of n for energy consumption in listening state

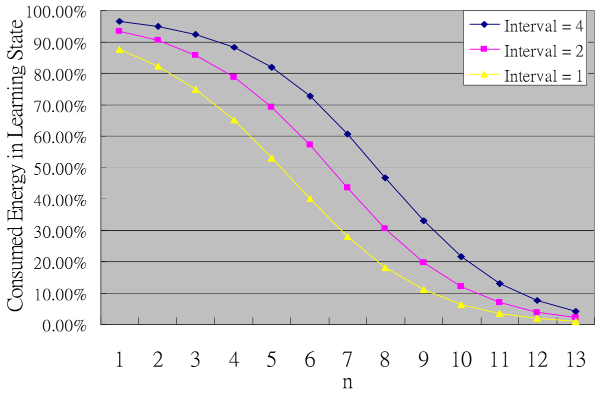

Fig. 4. The effect of n for energy consumption in different listening intervals

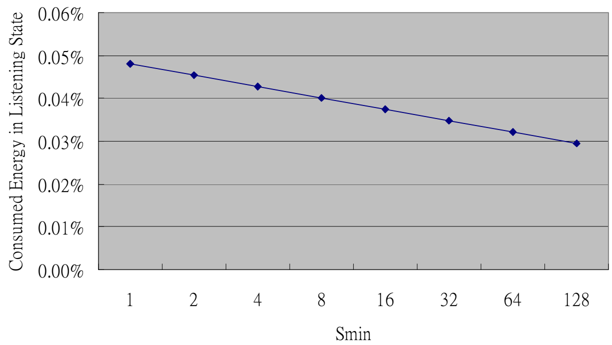

Fig. 5. The effect of S_{min} on energy consumption in listening state

listening-window = 1, final-sleep window = 2^{17}

5. Conclusions

In this paper, we introduce the power saving mechanism of 802.16e standard for Type I, and analyze the listening state and sleep state operations in sleep mode. We also propose an analytical model to evaluate the power consumption in learning state by changing the number of sleep interval to reach awake mode. We show the effect of this parameter and the results indicate that we need to consider downlink traffic frequency. It can influence the power consumption ratio of learning state.

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