Enhanced Power Saving Mechanism to Maximize Unavailability Interval in the IEEE 802.16 Mobile WiMAX

JIA-SHENG R. CHEN
Graduate Institute of Applied Science and Engineering
Fu Jen Catholic University, New Taipei City
Department of Electrical Engineering
Lee-Ming Institute of Technology, New Taipei City
TAIWAN
494598065@mail.fju.edu.tw
YUAN-CHANG CHANG*
Department of Electronic Engineering
Hwa Hsia University of Technology, New Taipei City
TAIWAN
ycchang@cc.hwh.edu.tw
HSING MEI
Department of Computer Science and Information Engineering
Fu Jen Catholic University, New Taipei City
TAIWAN
mei@csie.fju.edu.tw

Abstract: - In this paper, an energy conservation mechanism to maximize the unavailability interval and to improve the energy efficiency for the Power Saving Class in WiMAX are proposed. The proposed method can be implemented in commercial fields and is fully compatible with the 802.16 standard. It provides a systematic way to adjust the start frame number of the first sleep window, one of the relevant parameters defined in power saving performance. The sleep cycle concept from IEEE 802.16m is applied to increase the unavailability interval. In summation to the computational complexity, simulations are studied to the procedure of the proposed algorithms. Our proposed model proves the unavailability interval ratio may increase up to 49.8% in some instance.

Key-Words: - Power saving, Start frame number, Unavailability interval, WiMAX

1 Introduction

With the maturity of IEEE 802.11 wireless local area network (WLAN), we hold the ability to access high-speed internet connection in whatever place. However, vehicle mobility functions are not specified in WLAN standards. During the last decade, the mobile devices have become more popular, and people want to access to the ubiquitous internet access system. The Worldwide Interoperability for Microwave Access (WiMAX) [1-2] is designed for fixed and mobile broadband network through broadband radio access technology.

The main power source of the mobile device is the battery. Mobile users enjoy numerous application services and an increase of calling time and traffic volume affect the battery power consumption of the mobile device. The major factors of energy loss in wireless networks are sleep/idle mode, packet collision and retransmission of packets [3]. If the mobile device is at an insufficient battery level, it will dilute the ability to synthesize compounds due to errors and mutations [4] and cause the mobile device system failure. It is the primary motivation for this report.

The Mobile Station (MS) in the Mobile WiMAX needs to utilize the battery as its principal energy source, and the 802.16 defines the sleep mode and idle mode to increase the MS battery service time.

Sleep mode is a state that an MS release the RF for a pre-negotiated period of the serving Base Station (BS) air interface. It is defined by the inaccessibility of the MS as observed from the serving BS traffic. Implementation of sleep mode is optional for the MS and mandatory for the BS [2].

The processing time between the MS and BS is always carved up into cycles. Each cycle includes an awake mode and sleep mode. When the MS has data to send or receive, it is in the awake mode. Otherwise, it will come to the sleep mode. The sleep mode is illustrated in Fig. 1. Under the 802.16 sleep mode operation, an MS starts to sleep for a fixed initial-sleep window time. It wakes up in the listening window interval to listen if the BS has any buffered downlink traffic appointed to the MS. If there is no such signal, MS obtains the next sleep window size and starts to the sleep state again. Otherwise, it gets into the awake mode.

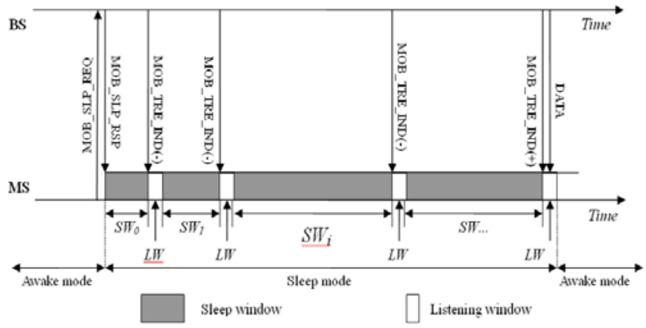

Fig. 1 Illustrations of the listening and sleep state operations

1.1 Overview of Power Saving Mechanism in 802.16

There are three types of Power Saving Class (PSC) [2], which differ from their parameter sets, operations, procedures of activation/deactivation, and policies of MS availability of data transmission. PSC of type I is recommended for Best Effort (BE) and Non-Real-Time Variable Rate (NRT-VR) type. For the type I, the MS sleeps for a sleep window range and then wakes up to listen if there is any incoming packet during the listening window. If there is still no packet to send or receive, the MS exponentially doubles the previous sleep window interval.

PSC of type II is suited to Unsolicited Grant Service (UGS) and Real-Time Variable Rate (RT-VR) type. For type II, the MS sleeps for a specified interval and then wakes up to check packet arrivals. The MS starts the same fixed sleep interval if there is no packet to send/ receive.

PSC of type III works for multicast connections as well as for management services. For type III, it is active for only one sleep window, then deactivated and goes backward to normal operation.

1.2 Problem Statement

In 802.16, the unavailability interval [2] is named as the time interval in which all active power saving classes does not overlap with any listening window. During the unavailability interval in Downlink or Uplink, the BS shall not transmit any traffic to the MS. Therefore, the MS may shut down physical connection components or perform other activities that do not need to link with the BS. If only one PSC is used, an MS can turn off the power during the sleep window and holds the battery energy. Nevertheless, if an MS uses more than one PSC no matter that these PSCs are the same type or different types. It can turn off the power only within the unavailability interval. It is evident that if more PSCs are used, the MS will turn off the power for a shorter period than only one PSC is used.

An MS PSCs example is presented in Fig. 2 with two connections. Connector 1 and 2 are Type I, and Type II, respectively. Each PSC operates according to the mechanisms described earlier with different parameters. The unavailability intervals are those frames when the two connections are in sleep windows, which is shown at the bottom of Fig. 2. Although the connection 1 and 2 has 31 and 24 frames of sleep windows in the first 36 frames, respectively, the MS can totally only power down to 21 frames in the first 36 frames. From the above results, we obtain the sleep window frame ratio for connection 1 and 2 has 86.11% (31/36) and 66.67% (24/36), respectively. However, the unavailability interval ratio for these two connections is down to 58.33% (21/36). The divergence of the ratio is close to 28%.

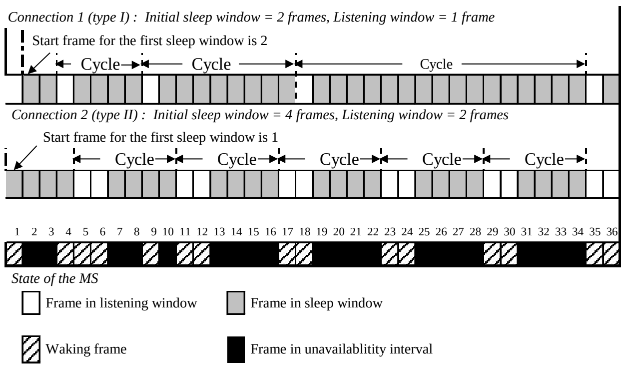

Fig. 2 Example of sleep mode operation

1.3 Related Works

In the literature, Jang [5] proposes a model to adapt the length of the sleeping period, according to the traffic status. The authors in [6] value the effect of the initial sleep window, final sleep window and average interarrival time of Media Access Control (MAC) frame for the performance of energy saving.

In [7-8], the authors present an analytical example of Type I and examine the power consumption of 802.16, including the incoming and outgoing frames. Han [9] has determined the sleep mode operation in terms of average energy consumption and frame response delay. Reference [10] has studied the performance of sleep mode that is designated in the MAC protocol. It is estimated the energy use in the listening state by modifying the sleep interval in [11]. The authors place a Chinese Remainder Theorem that is to get the maximum Unavailability Interval, which the transceiver can be powered down in [12-13]. Huang [14] offers a Bucket Checker power saving schedule to a single mobile station with multi-UGS connections. However, all of them concentrate on the performance analysis of only one type of PSC. They all do not take into account for service connections of the types I and type II power saving classes simultaneously.

The authors [15] derive a new packet dependent power distribution pattern based on the issue of weight capacity and packet prioritization. It employs the new power allocation model to allocate power. In the Kwon's proposed mechanism [16-17], the MS changes the sleep window of PSC I when the MS is using PSC I and PSC II. In case that the MS is using PSC II and PSC III, the MS adjusts the sleep window of PSC III. Chen [18] brings up an algorithm that can incorporate Type I and Type II PSCs while still maximizing the unavailability intervals of an MS. Kwon and Chou present a Harmonized Power Saving Mechanism. An MS adjusts the duration of the sleep window of PSC I to match the starting point of the listening windows of PSC I with the nearest listening window of PSC II [19]. Although they all consider the mixing of type I and II PSCs, their proposals need to consume the extra energy to operate their proposed mechanisms.

1.4 Motivation and Objectives

It is quite common that one MS may have multiple living connections and different power saving classes simultaneously. If multiple power saving classes exist in the same MS, the sleep mode operation requires to be further examined. As specified in the 802.16 standard, there are three parameters for Power Saving Class of Type I and II: (1) sleep window, (2) listening window, and (3) start frame number [2]. It is that the lengths of listening window and sleep window are independent among different power saving classes. The actual length of MS's unavailability intervals depends on the overlapping of all the sleep windows. The start frame number also determines the duration of the unavailability intervals.

Our goal is to make the maximum unavailability intervals for the power saving class of type I and type II. The design concept is to redesign the sleep cycle and change the start frame number so that the MS has more unavailability sleep frames.

Since type III is none related to this inquiry because of the role of design, it will not be discussed in this report.

1.5 Organization

The remainder of this paper is organized as follows. Section II describes our proposed method including the adjustment of the starting frame number and the regularization of initial sleep window size. In Section III, we present our analytical model and verify the performance result of simulation programming in C. In the end, conclusions are made in Section IV.

2 Proposed Power Saving Mechanism

We adopt 802.16m [20] Sleep Cycle (SC) concept as the means of the sleep window interval and listening window interval. The sleep cycle is shown in Fig. 3, except for the first initial-sleep cycle (SC_0). It shall start with a listening window. Then, a sleep window shall come after the listening window and goes to the end of the current sleep cycle. Here, we just change the definitions for the power saving classes of type I and describe below.

If the MS has traffic to transmit or receive, it is in the awake mode. Otherwise, it will get into a sleep mode. The sleep mode also affects the listening window and sleep window. 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 the MOB_SLP-REQ message if it does not receive the MOB_SLP-RSP message within a specified time [2].

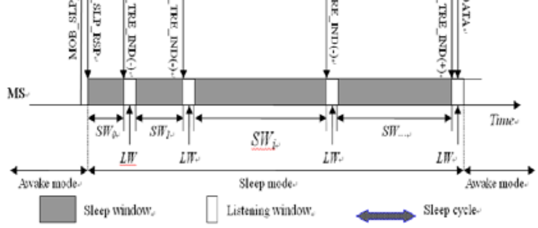

Fig. 3 Illustrations of the sleep cycle in IEEE 802.16

According to the standards [2], the MOB_SLP-RSP shall include the following parameters (Table 1) which related to the power saving class mechanism.

Table 1 The parameters of MOB_SLP-RSP

Symbols	Descriptions
SW_0	Initial-sleep window
LW	Listening window
F_{first}	Start frame number for first sleep window
FSW_{base}	Final-sleep window base
$FSWexp$	Final-sleep window exponent

$$sleepWin = min(2 \cdot prevSleepWin, FSW_{base} \cdot 2^{FSWexp})$$

Where

sleepWin is the sleep window

prevSleepWin is the previous sleep window

We add new variables to this report, which are Initial-sleep cycle (SC_0), i^{th}-sleep cycle (SC_i) and Final-sleep cycle (SC_{final}). SC_0, SC_i and SC_{final} are formulated as follows:

$$SC_0 = SW_0$$
$$SC_i = LW + i^{th}\text{-sleep window}, \quad i > 0$$
$$SC_{final} = LW + FSW_{base} \cdot 2^{FSWexp}$$

2.1 Proposed Power Saving Classes

When the MS receives the approving MOB_SLP-RSP message, it will come into initial-sleep cycle set by SC_0 and wakes up to the listening state. During the listening window, the MS listens to a traffic sign (MOB_TRE-IND) to determine the next state. When the MS senses a positive message sign, it will change to the awake mode. Otherwise, the MS will return to the sleep state and increase the preceding *sleep window* in the original 802.16 standards. However, we redefine this procedure to repeat the preceding *sleep cycle*. This process is iterated as long as the length of sleep cycle does not get on to the final-sleep cycle (SC_{final}). If the MS has reached SC_{final}, it shall hold the sleep cycle as fixed SC_{final}.

The length of the i^{th} sleep cycle (SC_i)is defined as

$$SC_i = \min(2 \cdot SC_{i-1}, SC_{final}), \quad i > 0$$

The criteria for type II remain the same definitions in this report. When the MS receives a negative signal (MOB_TRF-IND (-)) message indicating in the listening window, it shall start the same fixed sleep window in the power saving classes of type II.

2.2 Regularization and Adjustment Method

A method of increasing unavailability intervals for sleep mode operation of WiMAX is presented, which can cover both the type I and Type II services in the sleep mode operation. The primary idea is to regularize the length of the initial-sleep cycle (SC_0) and specify the start frame number of the first sleep window (F_{first}) of all power saving classes running on the same MS. The length of the unavailability intervals of the MS can be maximized, and the energy consumption is diminished.

It is that the irregular duration of sleep cycles will drop the unavailability rate (Fig. 2). We define a basic-sleep cycle (SC_{basic}) parameter to solve this problem. The initial-sleep cycle (SC_0) for any PSC is set:

$$SC_0 = 2^i \cdot SC_{basic}, \quad i >= 0$$

The example shown in FIG. 4 indicates the duration length of the basic-sleep cycle (SC_{basic}) is four frames. The initial-sleep cycle (SC_0) for connection 1, 2 and 3 has four, four and eight frames, respectively.

If we adjust the start frame number of any PSC, it will not change the demeanor of that PSC. As shown in Fig. 4 (b), each class still sleeps and listens for the same period in their sleep cycle after the amendment of the starting frame number. However, if the start frame number of a PSC is initiated at another different frame number, the unavailability intervals of the MS will be not the same quantity.

In the standards, the start frame number can be changed. We aim to determine the start frame number of each power saving class (except the first one) so that the unavailability intervals can be maximized. The primary concept is the offset among the starting frame number of all PSCs should be the exponentiation of 2 for the basic-sleep cycle (SC_{basic}). We denote the start frame number of the first PSC as $F_{1\text{-}first}$. The start frame number (F_{first}) for each of the other PSCs should be assigned to:

$$F_{first} = \begin{cases} F_{1\text{-}first} & , if\ F_{first} <= F_{1\text{-}first} \\ F_{1\text{-}first} + 2^i \cdot SC_{basic} & , if\ F_{first} >= F_{1\text{-}first} \end{cases}$$

Where i >= 0

The new start frame number of connection 2 and 3 in Fig. 4 (b) is 5 and 5, respectively. The total unavailability interface is 22 frames after the adjustment, which is more than that in Fig. 4 (a) at the same period. It is worth to stand a few additional delays. In the worst case, only less than one basic-sleep cycle (SC_{basic}) time of delay would occur.

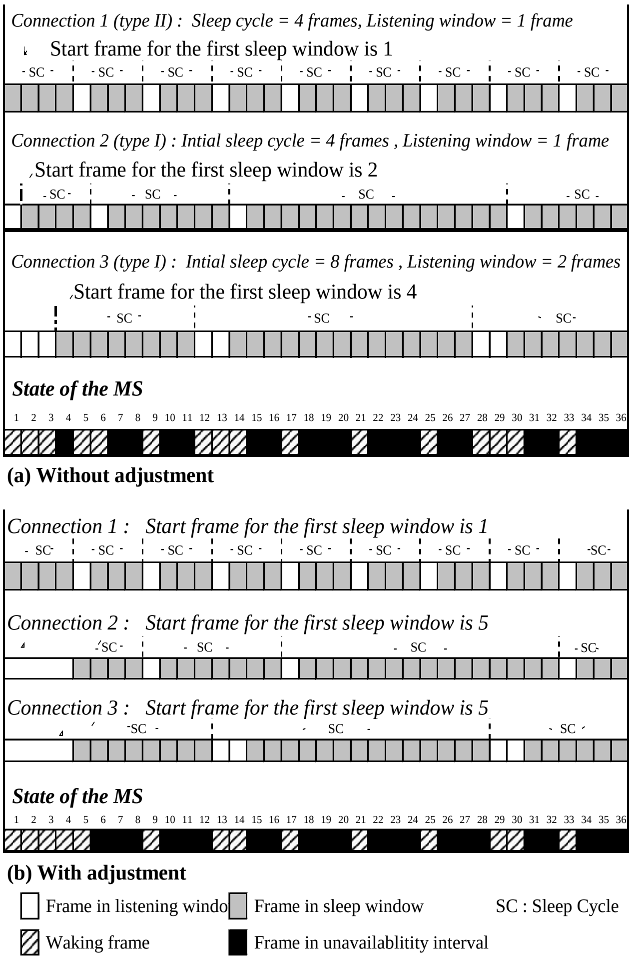

Fig. 4 Example of proposed power saving classes

3 Performance Evaluation Result

In this section, we inspect the performance of our proposed mechanisms using simulation written in C language and show three cases for a different combination of power saving class types. Parameters used in our mathematical calculation are listed in Table 2. All the simulations are run for the duration of five-second period. We investigate the results of the unavailability interval ratio without and with adjustment.

The mobile users spend 128 minutes per day in mobile applications [21]. The top 5 services are Browsing the Internet, Checking Social Networks, Listening to Music, Playing Games and Making Calls. The first case of simulation is all types I connections. For example, the mobile user can access Line, WeChat and WhatsApp at the same time. All of the above services are Best Effort (BE) or Non-Real-Time Variable Rate (NRT-VR) type. The parameters used in this simulation case are listed in Table 3. Fig. 5 describes the effect of the unavailability interval ratio within five seconds range. The engagement between them is from 20% to 1.6% as time increasing.

Table 2 Numerical and Simulation Parameters

Parameters	**Value**
Simulation interval	5,000 ms
Frame length	5 ms
Basic-sleep cycle (SC_{basic})	4 frames

Table 3 Parameters in case I (Type I)

Parameters	Value
Connection 1 – Start frame number for first sleep window	3
Connection 2 – Start frame number for first sleep window	1
Connection 3 – Start frame number for first sleep window	2
Sleep cycle	4 frames
Listening window size	1 frame

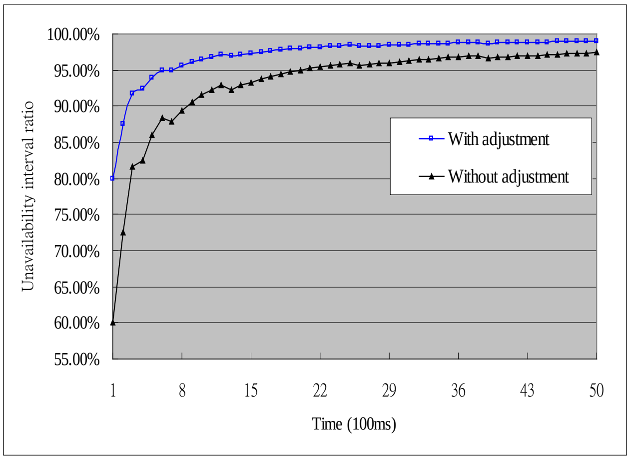

Fig. 5 Result of case I (Type I)

The mobile user also can utilize the VoIP and Video Streaming in the mean time. These applications are Unsolicited Grant Service (UGS) and Real-Time Variable Rate (RT-VR) type. The simulation parameters utilized in this second case with three type II connections are listed in Table 4. Fig. 6 shows the numerical evaluation of the unavailability interval ratio within five seconds range. The difference between them is from 40% to 49.8% as time increasing.

Table 4 Parameters in case II (Type II)

Parameters	Value
Connection 1 – Start frame number for first sleep window	3
Connection 2 – Start frame number for first sleep window	1
Connection 3 – Start frame number for first sleep window	2
Sleep cycle	4 frames
Listening window size	1 frame

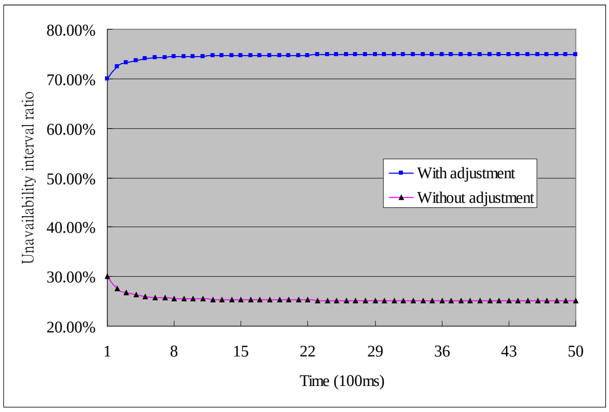

Fig. 6 Result of case II (Type II)

The mobile users may utilize smartphone for browsing the Internet, making calls, watching films and checking emails concurring. So, it is reasonable to presume that two PSC type I's and one PSC type II are used simultaneously. Table 5 gives the values of the parameters used in case III. Fig. 7 reveals the unavailability interval ratio within five-second range. The gap between them is from 20% to 1.6% as time increasing.

Table 5 Parameters in case III (Type I and II)

Parameters	Value
Connection 1 – Start frame number for Type I first sleep window	3
Connection 2 – Start frame number for Type II first sleep window	1
Connection 3 – Start frame number for Type I first sleep window	2
Sleep cycle	4 frames
Listening window size	1 frame
Final-sleep cycle size	256 frames

4 Conclusions

3G and 4G get more popular in recent years. How to keep power on mobile devices is a critical problem for mobile users of wireless networks. In this report, we propose a novel modification management strategy to increase the unavailability interval. In parliamentary law to verify the performance improvement, the simulation experiment is performed. The results confirm the efficiency of our proposed mechanism. Moreover, this increase is involved with the sleep cycle and the adjustment of the starting frame number of the first sleep window. In the best case, the unavailability interval ratio can be improved up to 49.8% of all type II connections. In the mixture connections of type I and II, it still can save 6.25% in the first 800ms interval.

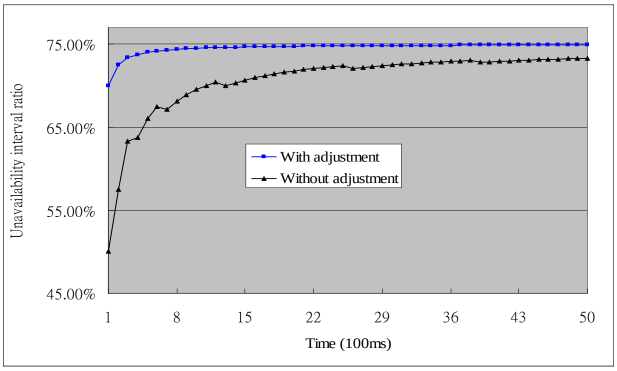

Fig. 7 Result of case III (Type I and II)

References:

[1] IEEE Computer Society, and IEEE Microwave Theory and Techniques Society, IEEE Standard for Local and metropolitan area networks -- Part 16: Air Interface for Fixed Broadband Wireless Access Systems, *IEEE Std. 802.16-2004*, October 2004.

[2] IEEE Computer Society, and IEEE Microwave Theory and Techniques Society, IEEE Standard for Air Interface for Broadband Wireless Access Systems, *IEEE Std. 802.16-2012*, August 2012.

[3] Sandra Sendra, Jaime Lloret, Miguel Garcia and José F. Toledo, Power saving and energy optimization techniques for wireless sensor networks, *Journal of Communications*, Vol. 6, No. 6, pp 439 – 459, September 2011.

[4] Yilun Shang, Vulnerability of networks: Fractional Percolation on random graphs, *Physical Review E*, Vol. 89, No. 1, January 2014.

[5] Jaehyuk Jang, Kwanghun Han and Sunghyun Choi, Adaptive Power Saving Strategies for IEEE 802.16e Mobile Broadband Wireless Access, *2006 Asia-Pacific Conference on Communications*, pp 1 – 5, August 2006.

[6] Min-Gon Kim, Minho Kang, and Jung Yul Choi, Performance Evaluation of the Sleep Mode Operation in the IEEE 802.16e MAC, *The 9th International Conference on Advanced*

Communication Technology, Vol. 1, pp 602 – 605, February 2007.
[7] Yang Xiao, Energy Saving Mechanism in the IEEE 802.16e Wireless MAN, *IEEE Communication Letters*, Vol. 9, No. 7, pp. 595-597, July 2005.
[8] Yang Xiao, Performance Analysis of an Energy Saving Mechanism in the IEEE 802.16e Wireless MAN, *2006 3rd Consumer Communications and Networking Conference*, Vol. 1, pp. 406-410, January 2006.
[9] Kwanghun Han, and Sunghyun Choi, Performance Analysis of Sleep Mode Operation in IEEE 802.16e Mobile Broadband Wireless Access System, *2006 IEEE 64th Vehicular Technology Conference*, Vol. 3, pp. 1141-1145, Spring 2006.
[10] Yan Zhang, and Masayuki Fujise, Energy Management in the IEEE 802.16e MAC, *IEEE Communications Letters*, Vol. 10, No. 4, pp 311-313, April 2006.
[11] Jia-Sheng R. Chen, Hsing Mei, and Yuan-Chang Chang, On the Power Consumption of 802.16e Listening State, *WSEAS Transaction on Communications*, Issue 9, Vol. 7, September 2008.
[12] Tuan-Che Chen, Ying-Yu Chen, and Jyh-Cheng Chen, An Efficient Energy Saving Mechanism for IEEE 802.16e Wireless MANs, *IEEE Transactions on Wireless Communications*, Vol. 7, Issue 10, pp. 3708-3712, October 2008.
[13] Tuan-Che Chen, Jyh-Cheng Chen, and Ying-Yu 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, April 2009.
[14] Wen-Chuan Huang, A Feasible Power Saving Scheduling Approach in WiMAX 802.16e Networks, *WSEAS Transaction on Communications*, Vol. 13, pp. 378-385, 2014
[15] Hua Hou, and Gen-Xuan Li, Cross-layer Packet Dependent OFDM scheduling based on proportional fairness, *WSEAS Transaction on Communications*, Issue 1, Vol. 11, January 2012.
[16] Sang-Wook Kwon, and Dong-Ho Cho, Dynamic Power Saving Mechanism for Mobile Station in the IEEE 802.16e Systems, *2009 IEEE 69th Vehicular Technology Conference*, pp. 1-5, Spring 2009.
[17] Sang-Wook Kwon, and Dong-Ho Cho, Enhanced Power Saving Through Increasing Unavailability Interval in the IEEE 802.16e Systems, *IEEE Communications Letters*, Vol. 14, Issue 1, pp. 24-26, January 2010.
[18] Tuan-Che Chen, and Jyh-Cheng Chen, Extended Maximizing Unavailability Interval (emu) Maximizing Energy Saving in IEEE 802.16e for Mixing Type I and Type II PSCs, *IEEE Communications Letters*, Vol. 13, No. 2, pp. 151-153, February 2009.
[19] Sang-Wook Kwon and Dong-Ho Cho, A Harmonization Among Power Saving Class in the IEEE 802.16e Systems, *2010 7th IEEE Consumer Communications and Networking Conference*, pp. 1-2, January 2010.
[20] IEEE Computer Society, and IEEE Microwave Theory and Techniques Society, IEEE Standard for Local and metropolitan area networks -- Part 16: Air Interface for Fixed Broadband Wireless Access Systems, Amendment 3: Advanced Air Interface, *IEEE Std. 802.16m-2011*, May 2011.
[21] GSMA and ATKearney, *The Mobile Economy 2013*, Groupe Speciale Mobile Association, 2013.