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Trade-off guidelines for power management mechanism in the IEEE 802.16e MAC

Min-Gon Kim [a], JungYul Choi [b,*], Minho Kang [a]

[a] The School of Engineering, Information and Communications University, 119 Munjiro, Yuseong-gu, Daejeon, Republic of Korea
[b] Platform Laboratory, KT Corporation, 463-1 Jeongmin-dong, Daejeon, Republic of Korea

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Abstract

Power management is an important part of the emerging standard of IEEE 802.16e (mobile WiMAX). The sleep-mode operation in power management helps to increase the life of a station by saving energy consumed, but at the same time it increases the response delay of awakening medium access control (MAC) service data units (SDUs). Its performance metrics, energy consumption and the average response delay of awakening MAC SDUs, are affected by correlations among the initial sleep window (T_{min}), the final sleep window (T_{max}), and the average interarrival time of awakening MAC SDUs (T_I) during sleep-mode operation. There is a trade-off relationship between the performance metrics, so it is imperative to determine the most effective size for the two windows, T_{min} and T_{max}, in order to reduce energy consumption and still maintain a reasonable response delay time. To reach a fuller understanding of this problem, this paper first models sleep-mode operation in an IEEE 802.16e system and analyzes the effects of the size of the windows on the performance. Based on this analysis, the authors then present a decision making process for leveraging the two performance metrics by manipulating the size of the windows. The decision making process aims to provide some guidelines for determining the most advantageous size of each window to achieve the targeting performance goals.

Keywords: IEEE 802.16e; WiMAX; Power management; Sleep-mode operation; Decision making process

1. Introduction

The explosive growth of the Internet over recent decades has led to increasing demands for high speed and ubiquitous Internet access. To address these requirements, a lot of attention has been given to broadband wireless access (BWA). This technology aims to provide low cost and high performance BWA to residential and small business applications. Worldwide interoperability for microwave access (WiMAX) [2,3] is a standard technology enabling fixed and mobile convergence through BWA technology and flexible network architecture. IEEE 802.16e (mobile WiMAX) [1] is an extension of this technology, targeting for service provisioning to mobile subscriber stations (MSSs). It is optimized to deliver a high data rate to mobile subscribers, and the advanced MAC architecture can simultaneously support real-time applications such as voice over IP (VoIP) in mobile environments. Since an MSS is powered by a limited battery, the energy conservation of an MSS in IEEE 802.16e is a key factor in WiMAX application.

For efficiently managing energy in IEEE 802.16e, an MSS repeatedly goes from wake-mode to sleep-mode whenever it does not communicate with a base station (BS), and vice-versa. Sleep-mode operation is generally controlled by the initial sleep window (T_{min}) and the final sleep window (T_{max}). The main performance metric varies depending on which station (MSS or BS) initiates the MSS to transition into wake-mode. When an MSS wants to initiate self-awakening (*MSS initiating awakening*), energy consumption will be the key performance metric,

* Corresponding author. Tel.: +82 42 870 8247.
E-mail addresses: kmg0803@icu.ac.kr (M.-G. Kim), passjay@gmail.com (J.Y. Choi), mhkang@icu.ac.kr (M. Kang).

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because it can awaken without the response delay of awakening medium access control (MAC) service data units (SDUs). On the other hand, when a BS initiates an MSS to awaken (*BS initiating awakening*), both energy consumption and the response delay of awakening MAC SDUs will be given attention because an MSS should wait to transition in waking mode until the listening state arrives. Since the size of two windows, T_{min} and T_{max}, affects the power management performance, it is necessary to examine their effects and decide the size of the windows based upon performance.

Due to its importance, power management has been paid attention by many researchers. Sleep-mode operation is specified in MAC protocol [1,2]. In [5] and [6], sleep-mode operation and its analytical model are studied in consideration of uplink and downlink traffic. In [7,10], sleep-mode is analytically evaluated in terms of average energy consumption and the average response delay of awakening MAC SDUs. In [8,9], several energy efficient mechanisms are proposed by trading off energy and other costs associated with overhead. Since energy consumption and the response delay have a tradeoff relationship in power management, it is imperative to study and determine the optimal power management condition where the target performance is well satisfied. However, as far as the authors are aware, there has been minimal research regarding this trade-off relationship between energy consumption and the response delay, and how to decide the size of the windows based on reasonable criteria. Therefore, the main purpose of this paper is to explore how to leverage the two windows for satisfying the target performance metrics.

To achieve this end, this paper is organized as follows. Section 2 introduces sleep-mode operation in IEEE 802.16e and the effects of T_{min} and T_{max} on the power management performance. In Section 3, an analytical model for sleep-mode operation and a decision making process for supplying the trade-off guidelines are depicted. Section 4 shows how the two windows affect sleep-mode operation, utilizing both simulation results and numerical analysis. The proposed decision maker also presents suitable operation conditions in power management, depending on its applications. Finally, Section 5 concludes this paper.

2. Overview of power management in IEEE 802.16e

2.1. Sleep-mode operation in IEEE 802.16e

This section explains sleep-mode operation in power management in the IEEE 802.16e MAC and presents a key idea for performance enhancement. In order to reduce energy consumption, an MSS repeatedly goes into wake-mode and sleep-mode during operation by communicating with a BS. Before an MSS goes into sleep-mode, parameters such as T_{min}, T_{max}, and the listening window (L) can be set by an MSS or a BS. With a sleep response message (MOB-SLP-RSP) from the BS, the MSS enters sleep-mode. If the BS wants the MSS to transition into wake-mode, the BS sends an indication message (MOB-TRF-IND) to the MSS during listening state. Then if the MSS needs to be in normal operation the MSS transitions back to wake-mode again after receiving a positive MOB-TRF-IND message, awakening MAC SDU.

Since the management of sleep-mode determines the performance of power management, it is important to observe sleep mode operation in detail, illustrated in Figs. 1 and 2. Fig. 1 shows two initiating sleep-modes, categorized by which station wants to make an MSS transit into sleep-mode. When an MSS itself wants to be in sleep-mode, it sends a BS a sleep request message (MOB-SLP-REQ) which includes information such as T_{min}, T_{max}, L, and so on as shown in Fig. 1(a). After the BS receives the MOB-SLP-REQ message, it sends the MSS a return MOB-SLP-RSP message, which also includes the start time of sleep-mode (T_S), T_{min}, T_{max}, L, and so on. After the MSS receive the MOB-SLP-RSP message, sleep-mode starts. Sleep-mode can also be initiated by a BS as shown in Fig. 1(b). When the BS wants the MSS to initiate sleep-mode, it sends the MSS a MOB-SLP-RSP message. After the MSS receives the MOB-SLP-RSP message, sleep-mode starts. The MOB-SLP-RSP message is sent from the BS to MSSs on broadcast CID or on the MSS's basic CID in response to a MOB-SLP-REQ message, or may be sent unsolicited.

Fig. 2 illustrates initiating wake-mode. After the first sleep window T_1, equal to T_{min}, the MSS transits into a listening state and listens for a MOB-TRF-IND message broadcasted from the BS. The MOB-TRF-IND message indicates whether there was traffic addressed to the MSS during its sleep window. If the MOB-TRF-IND message indication is negative, sleep-mode operation will continues. In this case, the next sleep window doubles the preceding sleep window. This process is repeated until the sleep window reaches T_{max}. After that, the sleep window remains at T_{max} unless there is an awakening MAC SDU that the MSS should wake up.

When the MSS has some protocol data units (PDUs) for the BS, the MSS itself can go into wake-mode. Then the MSS sends a bandwidth request message to the BS. When the MSS initiates awakening, there is no response delay regardless of the sleep window. Therefore, from the power saving viewpoint, a longer sleep window produces better power management performance. On the other hand, wake-mode can also be initiated by a BS when it has some PDUs to transmit to the MSS by sending an awakening MAC SDU to an MSS during its listening state. In this case, the BS should wait to transmit the PDUs until the listening state begins. The BS initiating awakening, thus, has an impact on additional response delay.

Under a certain average interarrival time of awakening MAC SDUs, T_I, the power management performance is affected by the size of T_{min} and T_{max} in sleep-mode. For example, smaller T_{min} and T_{max} could induce less response delay, but consume more energy, because longer listening times can be generated during the sleep-mode. On the other