Adaptive Power Saving Strategy Based on Traffic Load in the IEEE 802.16e Network

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Abstract- Previous works in IEEE 802.16e power saving mainly focused on standard Type I or Type II. The limitation of adopting Type I or Type II is discussed in the paper, and the idea of applying traffic modeling and measurement mechanisms called Load-Based Power Saving (LBPS) is proposed. The base station in LBPS measures the traffic load and estimates the sleep window size for mobile subscriber stations by setting a threshold for data accumulation. A basic version of LBPS, LBPS-Aggr, is presented in the paper. Simulation results demonstrate that better power saving efficiency can be achieved by LBPS-Aggr than Type I and Type II.

Keywords: IEEE 802.16e, Power Saving, Sleep Schedule

I. INTRODUCTION

IEEE 802.16 (*WiMax*) [1-2] is an emerging and promising broadband wireless access (BWA) technology that provides high-speed and high-bandwidth wireless access. In 2005, IEEE released the version of IEEE 802.16e [2] (*Mobile BWA*), which enhances the IEEE 802.16 standard to support *mobile subscriber stations* (*MSS*). That is, MSS can roam around anywhere within the range of the network and not to be bound to a single location. As in other wireless networking devices, IEEE 802.16e MSS relies on batteries for power supply, and without proper power management, the energy requires to keep MSS connected to the network over extended periods of time quickly dissipates. Therefore, *power saving* in IEEE 802.16e has been an important issue in recent years.

The most waste of power has been identified as a wireless device such as MSS listening on the radio channel while there is nothing there to receive, thus existing power saving techniques at the MAC layer consist primarily of sleep scheduling protocols, in which the scheduler cycles the radio between *on* and *off* power states to reduce power consumption. Three power saving classes are defined in the standard of IEEE 802.16e, namely *Type I*, *Type II*, and *Type III*, to make sleep scheduling more flexible and accommodate different traffic characteristics of various applications and services. As presented in the next section, a fundamental difference of the three standard classes is the pattern of sleep, which determines the size of sleep windows succeeding the initial sleep window in the case of long idling. Type I, with an exponential increase of the sleep window size, is recommended for non-real-time variable bit rate or best-effort connections. Type II, with a constant sleep window size, is recommended for time-sensitive (real-time) connections. Type III, with the sleep window size controlled by the base station (BS), is recommended for multicast and management connections, although it is not addressed too much in the standard.

Most of the researches in the literature focused on Type I and Type II. The performance of existing Type I and Type II power saving protocols is mainly affected by two important operational parameters, *the waiting time threshold* and *the sleep window size*. The w*aiting time threshold* is the time interval of idling that the MSS waits before entering into the sleep mode, and *the sleep window size* is the duration of sleep. Power saving efficiency can be improved by selecting proper values for the two operational parameters. However, since these protocols inherit the characteristic of Type I or Type II, the sleep pattern in the protocols is limited to either exponential pattern (Type I) or constant pattern (Type II), which implies the limitation of the protocols in dealing with variable bit rate (VBR) connections.

In our opinion, neither exponential nor constant sleep patterns can provide enough capability to effectively deal with power saving for VBR traffic. A straightforward and better method is to proactively model and measure the traffic in the network, and the sleep window size is determined according to traffic parameters obtained from traffic measurement. This paper presents our first step of applying traffic modeling and measurement in power saving. We assume the arrival process of each connection is *Poisson process*, thus the proposed power saving strategy in the paper is called *Load-based Power Saving* (*LBPS*). Since the BS is at the best position for traffic measurement, the BS is responsible for notifying each MSS of the sleep window size, which means LBPS belongs to Type III power saving class. A basic version of LBPS called *LBPS-Aggr*, which treats the traffic for all MSSs as one aggregate traffic to calculate the sleep window size for MSS, is proposed in the paper. Simulation study shows that significantly better efficiency in power saving can be achieved by LBPS-Aggr over Type I, and LBPS-Aggr also outperforms in power saving efficiency than Type II at the cost of slightly more delay.

The rest of the paper is organized as follows. Standard power saving classes in IEEE 802.16e and some related research works are surveyed in section II. The basic idea of LBPS and the protocol of LBPS-Aggr are presented in section III. Simulation study and performance comparison are presented in section IV. Finally, section V concludes this paper.

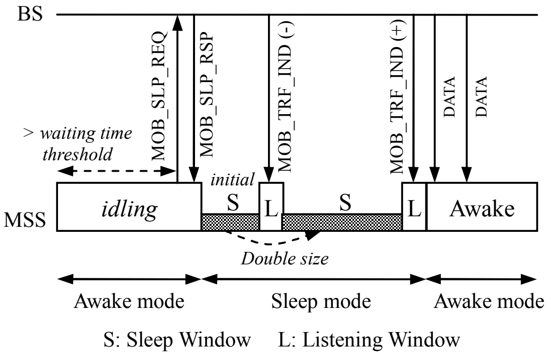

Figure 1. IEEE 802.16e Type I power saving class

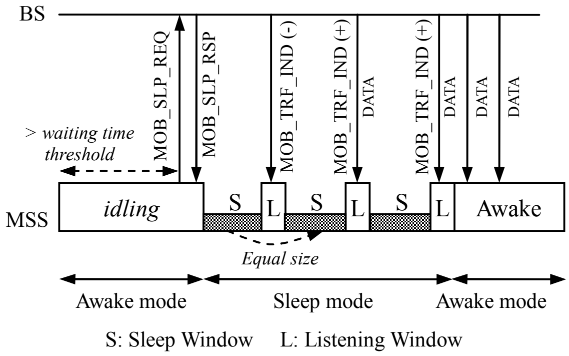

Figure 2. IEEE 802.16e Type II power saving class

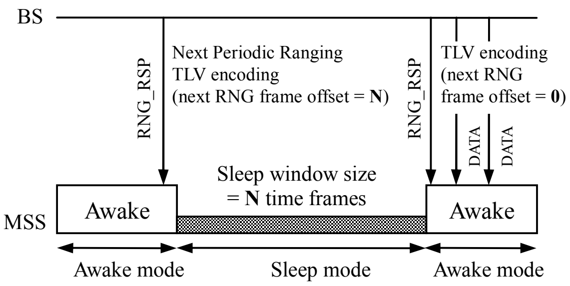

Figure 3. IEEE 802.16e Type III power saving class

II. Related Work

In IEEE 802.16e [2], an MSS has two operation modes, *awake* mode and *sleep* mode, in the three standard power saving classes, Type I, II, and III. The awake mode is the normal operation. Two operating windows, *the sleep window* and *the listening window*, are further defined in the sleep mode of Type I and Type II. When a Type I or Type II MSS has no data to transmit or receive for a fixed time (called the waiting time threshold), it sends a sleep request message *MOB_SLP-REQ* to the BS. The message carries the information about the class of power saving, the size of the initial sleep window, the size of the final sleep window, and the size the listening window. Upon receiving the response message *MOB_SLP-REP* from the BS, the MSS turns off its radio transceiver and enters into the initial sleep window in the sleep mode. If some data destined to the MSS arrives during its sleep window, the BS buffers the data and sends positive traffic indicator *MOB_TRF-IND* to the MSS in the listening window that follows the initial sleep window. Otherwise, the MSS receives a negative *MOB_TRF-IND* and enters into the next sleep window.

In Type I, the sleep window is increased exponentially until reaching the maximum size or some data has arrived for the MSS to transmit or receive (i.e. positive *MOB_TRF-IND* from the BS) as illustrated in Figure 1. The specification of IEEE 802.16e recommends Type I is suitable for traffic of *non-real-time variable rate* (*NRT-VR*) service and *best effort* (*BE*) service, such as web browsing. Type II power saving uses an isochronous pattern of sleep and listening windows, and the MSS is allowed to transmit or receive data during listening windows as shown in Figure 2. The MSS switches back to the awake mode if data transmission cannot be completed in the listening window. Thanks to the constant size of the sleep window, Type II is recommended to support traffic of *real-time variable rate* (*RT-VR*) service and *unsolicited grant service* (*UGS*), such as voice over Internet Protocol (VOIP) and video streaming. As a less addressed power saving class, Type III has no listening windows. An MSS of Type III is activated or deactivated by *TLV* (*Type-Length-Value*) encoding in *RNG_RSP* message sent by the BS as illustrated in Figure 3. The size of the next sleep window is determined by the offset value in TLV encoding. The MSS switches back to the awake mode if the offset value is zero. Type III is recommended for multicast connections and management operations.

Most of the research works for IEEE 802.16e power saving in the literature focused on Type I and II. Performance analysis in power saving efficiency as well as delay performance were investigated in [3-5]. In [6], a semi-Markov decision process was used to select the optimal sleep mode between Type I and Type II. Some heuristic mechanisms were proposed for improvement of power saving efficiency, including setting a proper initial sleep window size [7], sleep scheduling for multiple connections at an MSS [8], sleep scheduling based on delay threshold [9], optimized waiting time threshold to enter into the sleep mode [10], and redistribution of the idle periods and a number of interim listening periods in order to reduce the response time of interactive traffic [11], etc. As mentioned in section I, the idea of applying traffic modeling and measurement in determination of Type III sleep window size has not been addressed in the literature, which is the main goal of this paper.

III. Load-Based Power Saving

A. Basic idea

The objective of LBPS is to adaptively adjust sleep window size of each MSS to better fit in current traffic condition (load) by traffic measurement. LBPS achieves this goal by setting a target threshold of data accumulation in the buffer for an MSS and dynamically calculating next sleep window size. In this way, LBPS can adapt to different traffic load and still achieves a proper level of powering saving. As illustrated in Figure 4-(a), the benefit of powering saving based on data accumulation is that LBPS does not awake the MSS

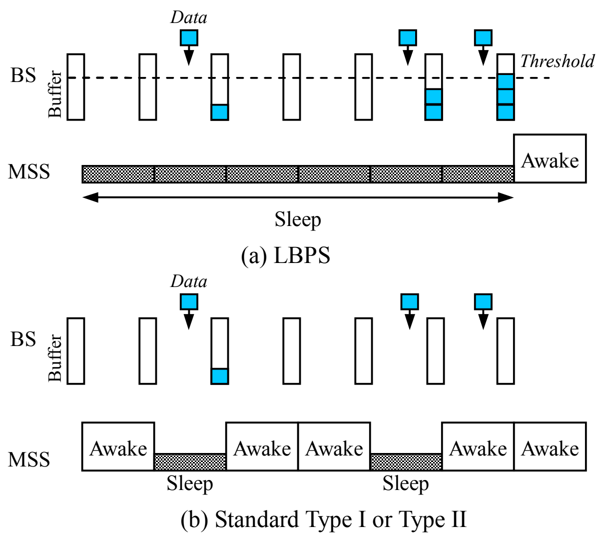

Figure 4. Power saving in light load: LBPS vs. Type I/II

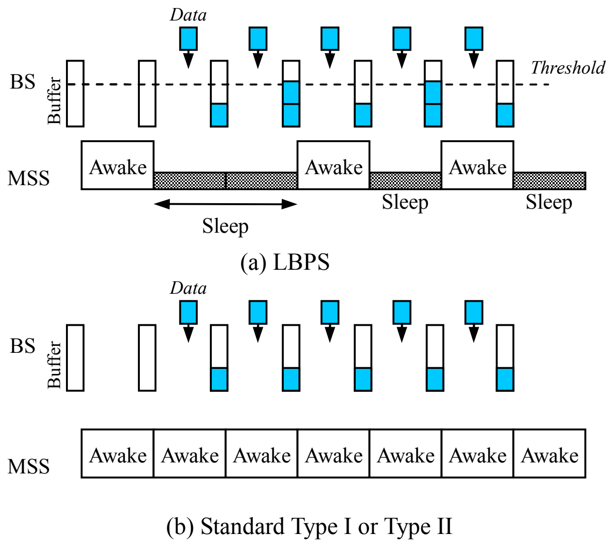

Figure 5. Power saving in heavy load: LBPS vs. Type I/II

when only a small amount of data arrives, while standard Type I or Type II does not have much chance entering the sleep mode under the same traffic condition as shown in Figure 4-(b). Under heavier load, LBPS still expects to achieve a reasonable level of powering saving while Type I or Type II has no gain at all in power saving as displayed in Figure 5.

There are a couple of things that need to be done in order to realize the goal of LBPS. Firstly, we need a stochastic model to characterize the traffic in the network. In this paper, as the first step of LBPS, *Poisson process* is adopted as the modeling tool and *exponential averaging* is used for estimation of the traffic load (rate). Moreover, only downlink traffic (from the BS to MSSs) is considered in the paper for compactness, although LBPS can also easily deal with uplink traffic. Secondly, considering a larger value of the threshold for data accumulation achieves more power saving gain but also results in larger delays, *one time frame* of data should be a suitable upper bound for the threshold. Finally, the sleep window size is calculated as the number of time frames required to reach the threshold of data accumulation. The basic version of LBPS, *LBPS-Aggr*, in which all the traffic in the network is treated as an aggregate flow in calculating the size of the sleep window, is presented in the following.

B. LBPS-Aggr protocol

In LBPS-Aggr, the BS needs to estimate the current load in the network (denoted by λ packets per time frame) by collecting and exponentially averaging the samples of load as in *TCP Round-Trip Time* (*RTT*) estimation. Since the traffic arrival process is assumed to be Poisson, data accumulation under load λ in a time frame is calculated by the following equation.

$$Prob\ [i \text{ packet arrivals in a time frame}] = \frac{e^{-\lambda T}(\lambda T)^i}{i!},$$

where T is the length of a time frame.

The threshold of data accumulation is denoted by *Data_TH* (packets). The probability of data accumulation exceeding *Data_TH* packets over K time frames in a row can be calculated as follows:

$$P_{Acc}(K, Data\_TH) \equiv$$

$$Prob\ [\#\text{ of packet arrivals in } K \text{ time frames} > Data\_TH]$$

$$= \sum_{i=Data\_TH+1}^{\infty} \frac{e^{-\lambda KT}(\lambda KT)^i}{i!}$$

$$= 1 - \sum_{i=0}^{Data\_TH} \frac{e^{-\lambda KT}(\lambda KT)^i}{i!}$$

The number of time frames (including the current awake time frame) before the next awake time frame for an MSS is calculated as the smallest value of K such that $P_{Acc}(K, Data\_TH)$ is higher than a predefined probability threshold denoted by *Prob_TH*. That is,

The length of one awake-and-sleep cycle $\equiv K^*$

$= Min\{K \mid P_{Acc}(K, Data\_TH) \geq Prob\_TH\}$, where an *awake-and-sleep cycle* is composed of the current awake time frame and the following sleep window.

The size of the sleep window in a cycle is therefore K^* *- 1*, which is sent by the BS to the currently awake MSSs to prepare for entering the sleep mode. Since the load in the network may change dynamically, the BS calculates the new value of K^* in each awake time frame of MSS. The protocol of LBPS-Aggr is illustrated in Figure 6.

C. Performance analysis

In the normal operation of LBPS-Aggr, in which transmission of the data accumulated in K^* time frames can be finished in one awake time frame, the power saving efficiency is $\frac{K^*-1}{K^*}$. If the amount of the accumulated data cannot be finished transmission in a

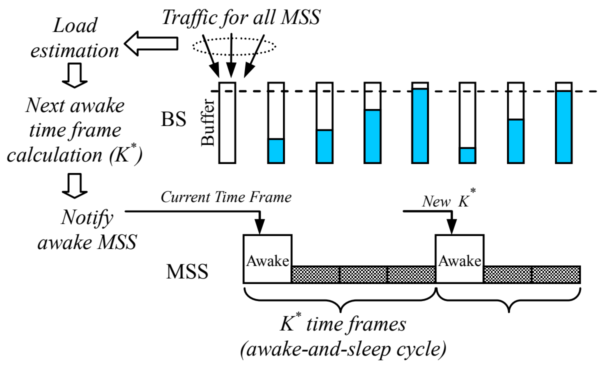

Figure 6. LBPS-Aggr protocol

time frame, the MSS must be stay awake until all of its data is cleared. In the case, the power saving efficiency becomes $\dfrac{K^*-1}{K^*+N_{ext}}$, where N_{ext} is the number of extra awake time frame to clear out the accumulated data. Therefore, the average power saving efficiency (denoted by *PSE*) for an MSS is calculated as the following equation.

$$PSE = \sum_{i=0}^{\infty}\left(\frac{K^*-1}{K^*+i}\times Prob[N_{ext}=i]\right) \qquad (1)$$

We assume the packet arrival time at the BS is uniformly distributed among the time frames in one awake-and-sleep cycle, the average access delay for a packet is the half of the cycle length. Therefore, the average access delay for a packet (denoted by *AvgDelay*) considering different cycle length is calculated as the following equation.

$$AvgDelay = \sum_{i=0}^{\infty}\left(\frac{K^*+i}{2}\times Prob[N_{ext}=i]\right) \qquad (2)$$

IV. Performance Evaluation

Simulation study was conducted to compare the performance of LBPS-Aggr, standard Type I, and standard Type II, in terms of power saving efficiency as well as the average access delay. Parameters used in the simulation are listed in Table 1. Note that the threshold of data accumulation *Data_TH* in LBPS-Aggr is set as a full time frame, but since each MSS operates its awake-and-sleep cycles independently of others, the accumulated data for concurrently awake MSSs can be cleared out in one time frame in most of the time, i.e. $Prob[N_{ext}=0] \approx 1$.

Power saving efficiency (*PSE*) of LBPS-Aggr and Type I under different input loads is displayed in Figure 7, which also includes the numerical result from Equation-(1). The figure demonstrates a significantly better power saving performance of LBPS-Aggr over Type I.

In order to investigate the performance of LBPS-Aggr for traffic with delay constraint (*RT-VR*), LBPS-Aggr can be easily extended to support the requirement of bounded delay, denoted by $D_{RT\text{-}VR}$. LBPS-Aggr calculates the value of K^* as presented in section III, but the final value of the awake-and-sleep cycle is set as the smaller one of K^* and $D_{RT\text{-}VR}$. Figure 8 displays the power saving efficiency of LBPS-Aggr and Type II for RT-VR traffic, in which $D_{RT\text{-}VR}$ = 3 time frames. Delay performance (*AvgDelay*) for the case of Figure 8 is shown in Figure 9. The two figures demonstrate that a better power saving efficiency can be achieved by LBPS-Aggr over Type II at the cost of slightly more access delay.

Table 1. Simulation Parameters

# of MSS	16 (equal load)
Time Frame Size	160 mini-slots 1 mini-slot = 1 packet
Data_TH (LBPS-Aggr)	160 packets
Prob_TH (LBPS-Aggr)	0.8
Type I initial sleep window size	2^0 time frame
Type I max sleep window size	2^9 time frames
Type II sleep window size	2 time frames
Listening window size (Type I, II)	1 time frame

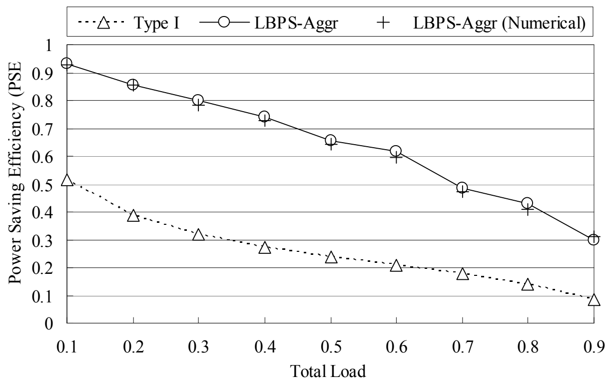

Figure 7. Power saving efficiency: LBPS vs. Type I

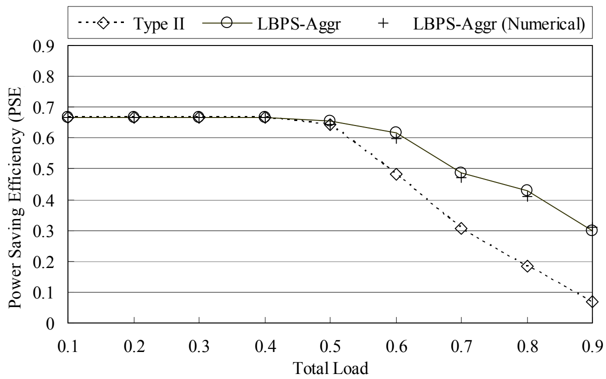

Figure 8. Power saving efficiency: LBPS vs. Type II

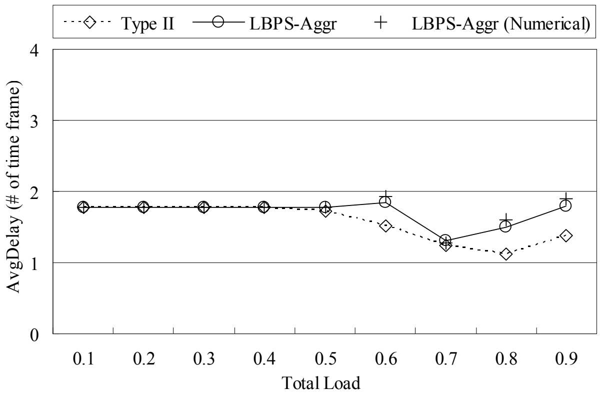

Figure 9. Average access delay: LBPS vs. Type II

V. CONCLUSION

As the mobility-supporting version of IEEE 802.16 (WiMax), IEEE 802.16e was released in 2006. The subscriber station in IEEE 802.16e is no longer stationary but mobile and should be powered by battery, so power saving has become an important and practical issue in IEEE 802.16e. There are three types of power saving in the specification of IEEE 802.16e, Type I, II, and III. Most of the research works focused on Type I or Type II, which means these previous works inherited the limitation of Type I or Type II in selection of the sleeping pattern: either adopting the exponential pattern of Type I or the constant pattern of Type II for the sleep window size. In this paper, we propose the idea of applying traffic modeling and measurement mechanisms for adaptively determining the sleep window size that can fit for different traffic loads. The proposed strategy is called Load-Based Power Saving (LBPS) that belongs to IEEE 801.16e Type III power saving. LBPS models and measures the traffic, and estimates the sleep window size by setting a proper threshold for data accumulation. A basic version of LBPS, LBPS-Aggr, is presented in the paper. Simulation study has demonstrated that LBPS-Aggr significantly outperforms Type I in power saving, and by considering delay bound in determining the sleep window size, LBPS-Aggr outperforms Type II in power saving efficiency at the cost of slightly more delay.

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