A Clustering Technique of Load-based Power Saving 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 power saving class. The limitation of adopting Type I or Type II was discussed in our previous work, and the idea of applying traffic modeling and measurement called Load-Based Power Saving (LBPS) was 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. Based on the previously proposed protocol LBPS-Aggr, an enhanced protocol called LBPS-Split is proposed in the paper, in which the MSSs are clustered in the schedule for better power saving performance. Simulation results demonstrate that better power saving efficiency can be achieved significantly by LBPS-Split than LBPS-Aggr.**

Keywords-Power Saving, Sleep Schedule, IEEE 802.16e

I. INTRODUCTION

IEEE 802.16 (*WiMax*) [1]-[3] 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. A brief survey of the three standard power saving classes is given in the following.

In IEEE 802.16e, 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 mode of 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 period of time (namely the waiting time threshold), it sends a sleep request message 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 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 to the MSS in the listening window that follows the initial sleep window. Otherwise, the MSS receives a negative traffic indicator 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. 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 the sleep and listening windows and the MSS is allowed to transmit or receive data during listening windows. The MSS switches back to the awake mode if data transmission cannot be completed in the listening 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 the BS. 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 terms of power saving efficiency as well as delay performance for the standards was investigated in [4]-[6]. Jin and Yue [7] proposed a theoretical analysis of Type III power saving class in the case of self-similar multimedia traffic,

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which was characterized by the Pareto distribution with a batch arrival queueing model. Enhanced mechanisms to improve power saving efficiency by properly selecting the size of the sleep window were proposed, including heuristic algorithms based on traffic types [8] or traffic loads [9], and enhancements based on stochastic modeling tools to adaptively adjust the sleep window size [10]-[13].

These protocols mentioned above inherit the characteristic of Type I or Type II, so 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. Therefore, the idea of *Load-based Power Saving* (*LBPS*) was proposed in our previous work [14], which falls in the category of Type III power saving class. A basic version of LBPS called *LBPS-Aggr*, which treats the traffic for all MSSs as aggregate traffic to calculate the sleep window size for MSS, was also proposed.

In this paper, the idea of LBPS is further extended by clustering MSSs in the schedule for better power saving performance. The enhanced version of LBPS is called *LBPS-Split*. Simulation study shows that better efficiency in power saving can be achieved by LBPS-Split over LBPS-Aggr. The rest of the paper is organized as follows. The survey of our previous work is presented in section II. The enhanced protocol LBPS-Split is presented in section III. Simulation study and performance comparison are presented in section IV. Finally, section V concludes this paper.

II. PREVIOUS WORK

A. Load-based Power Saving (LBPS)

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. 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 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 this paper for compactness, although LBPS can also 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

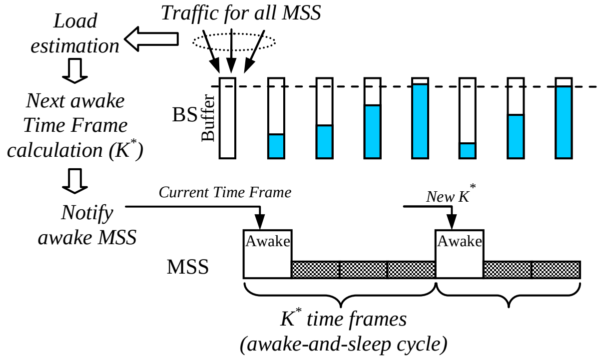

Figure 1. LBPS-Aggr protocol

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 $P_{Acc}(K,$

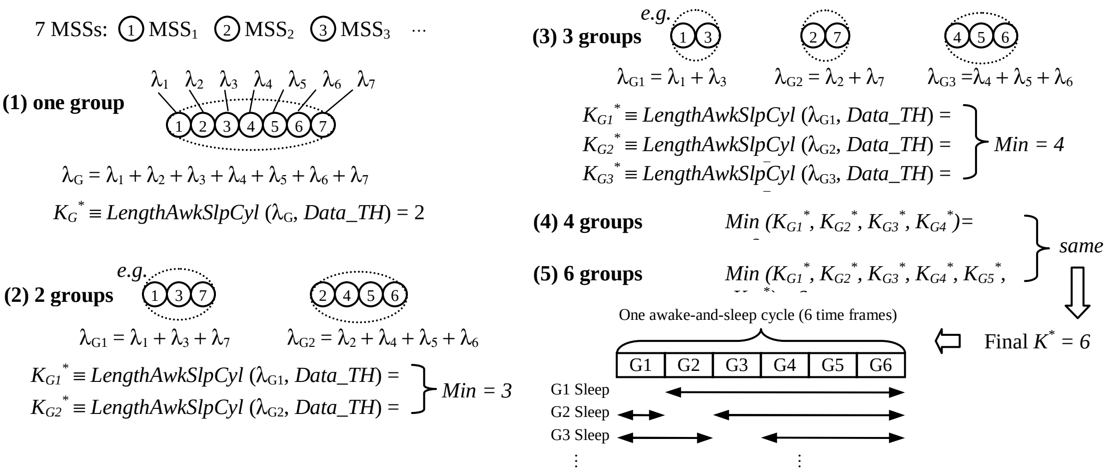

Figure 2. An example of LBPS-Split

Data_TH) is higher than a predefined probability threshold denoted by *Prob_TH*. That is,

The length of one awake-and-sleep cycle

$\equiv LengthAwkSlpCyl(\lambda, Data\_TH) \equiv K^*$

$= Min\{K \mid P_{Acc}(K, Data\_TH) \geq Prob\_TH\}$, 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 1. It's worth mentioning that all of the traffic in the network is treated as an aggregate traffic flow in K^* calculation, but each MSS is independently scheduled for entering the sleep mode in LBPS-Aggr. That is, with the same length of the awake-and-sleep cycle, each MSS may have a different starting time for the cycle.

III. Clustering-based Enhancement LBPS-Split

As will be shown in the section of performance evaluation, power saving efficiency of LBPS-Aggr is significantly better than that of the standard Type I. Experiments also showed the possibility to further improve the performance of LBPS-Aggr in power saving. Considering the case that $K^* = 2$ (the length of the awake-and-sleep cycle is 2 time frames) in LBPS-Aggr, conceptually it implies all MSSs as a whole should be assigned with one awake time frame out of the cycle of two time frames. But in the schedule we could also split the MSSs into two groups and assign a different awake time frame for each group. Given that the load of a split group is always lighter than the load of the original and bigger group, it's very likely that the new K^* value for each of the split groups (with the same value of *Data_TH*) is larger than the original value of 2. The case of the minimal value of the two new K^* values larger than 2 implies the feasibility of further splitting, which leads to an enhanced LBPS protocol namely *LBPS-Split* in the paper.

An example of LBPS-Split with 7 MSSs is illustrated in Figure 2. All of the 7 MSSs is treated as one group (as does in LBPS-Aggr) in the first step. The value of $K_G^* = 2$ in the first step leads to the splitting of the MSSs into 2 groups in the second step. The length of the awake-and-sleep cycle for each group is re-calculated, and the minimal value of K_{G1}^* and K_{G2}^* in the second step leads to 3 split groups in the third step. The splitting process continues until the new minimal value of K^* remains unchanged as in the fourth and the fifth step in the example. The final value of K^* is the length of the awake-and-sleep cycle for all the split groups, and each group is assigned with a different awake time frame by the BS as displayed in the figure.

Power saving performance of LBPS-Split is inevitably affected by the splitting mechanism. In order to maximize power saving efficiency, the minimal value of K^* in each iteration should be maximized. Therefore, the splitting mechanism should try to divide the total load to each split group as equally as possible in order to minimize load difference among the groups.

IV. Performance Evaluation

A. Simulation Environment

Simulation study was conducted to compare the performance of LBPS-Split, LBPS-Aggr, standard Type I in terms of power saving efficiency (denoted by *PSE*) as well as the average access delay (denoted by *AvgDelay*). 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

Table 1. Simulation Parameters

# of MSS	10, 20, 40, 80
Load Distribution	Equal, 8:2, Random
Time Frame Size	160 mini-slots 1 mini-slot = 1 packet
Type I initial sleep window size	2^0 time frame
Type I max sleep window size	2^9 time frames
Listening window size	1 time frame
Data_TH (LBPS-Aggr)	160 packets
Data_TH (LBPS-Split)	0.8*160 packets
Prob_TH (LBPS schemes)	0.8

the time. However, the MSSs in a same group in LBPS-Split are scheduled to be awake in the same time frames, thus the value of *DATA_TH* for the two enhanced schemes is set as 80% of a time frame (i.e. 0.8*160 packets as shown in Table 1) to reduce the probability of data overflow in an awake time frame.

B. LBPS-Split vs. LBPS-Aggr

Simulation results for comparing LBPS-Split, LBPS-Aggr and the standard Type I scheme in terms of power saving efficiency (*PSE*) and the average access delay (*AvgDelay*) in the case of 10 MSSs with *equal load* are displayed in Figure 3 and Figure 4 respectively. As shown in Figure 3, power saving efficiency of LBPS-Aggr is significantly better than standard Type I, and LBPS-Split yields even better power saving performance than LBPS-Aggr, which correspondingly leads to larger *AvgDelay* as display in Figure 4. Moreover, since LBPS-Aggr is a special case of LBPS-Split, *DATA_TH* of LBPS-Split under very heavy load is set as the original 160 packets (one time frame of data) in the protocol and thus the performance results of LBPS-Split and LBPS-Aggr under load 0.9 and load 0.95 converge at same points as displayed in Figure 3 and Figure 4.

C. Impact of the number of MSS and load distribution

Results of power saving efficiency of LBPS-Split under different numbers of MSS are displayed in Figure 5. The figure demonstrates that better *PSE* is achieved for a larger number of MSS, since a larger number of MSS provides more flexibility in splitting MSSs and thus more gain in *PSE* can be obtained. Figure 6 displays the results of *PSE* of LBPS-Split under three different load distributions: *equal load*, *random load*, and *8:2 load*. In the case of “8:2 load”, 80% of the traffic goes to 20% of the MSSs. As demonstrated in the figure, higher variation of load distribution makes lower *PSE* in LBPS-Split.

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 our previous work, the idea of Load-based Power Saving (LBPS) and a basic scheme LBPS-Aggr were proposed, in which all of the traffic in the network is treated as an aggregate flow for estimating the sleep window size. In this paper, an enhanced version of LBPS namely LBPS-Split is proposed. Instead of treating all traffic as a single aggregate flow, LBPS-Split splits MSSs into different groups in sleep scheduling to achieve more power saving efficiency. Simulation study has demonstrated LBPS-Split achieves better power saving efficiency than LBPS-Aggr. Impact of the number of MSS and the variation of load distribution on the performance of power saving are discussed in the paper.

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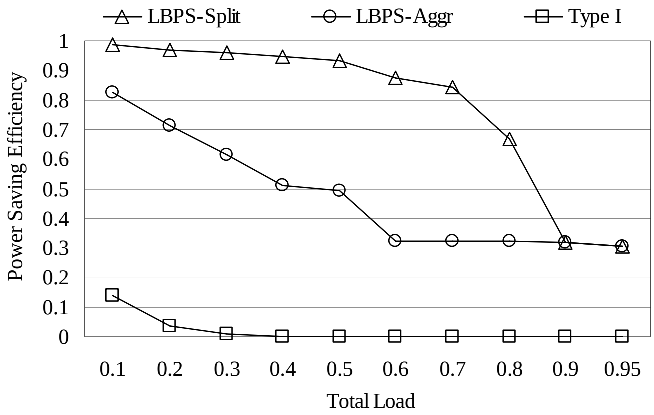

Figure 3. *PSE*: LBPS-Aggr vs. LBPS-Split vs. Type I

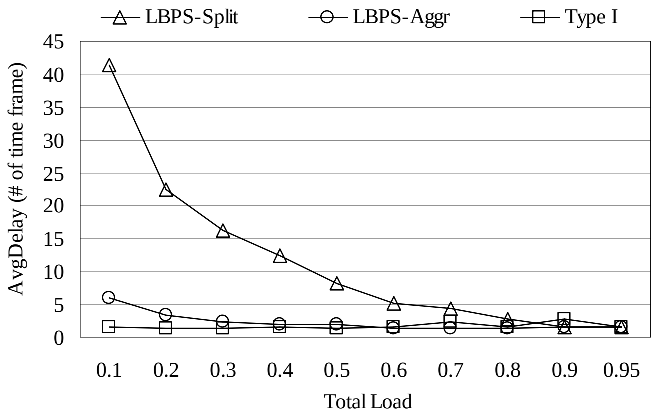

Figure 4. *AvgDelay*: LBPS-Aggr vs. LBPS-Split vs. Type I

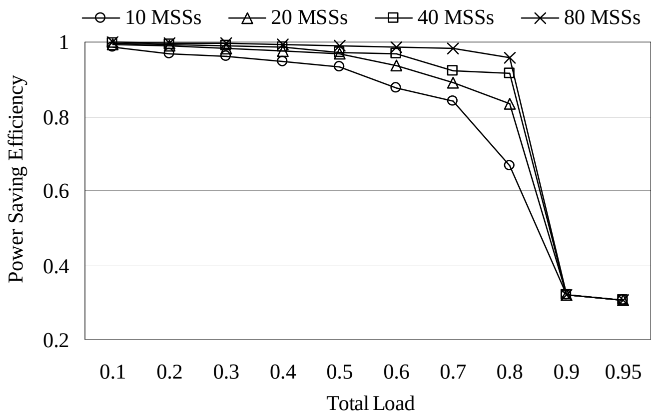

Figure 5. *PSE* of LBPS-Split (Equal load)

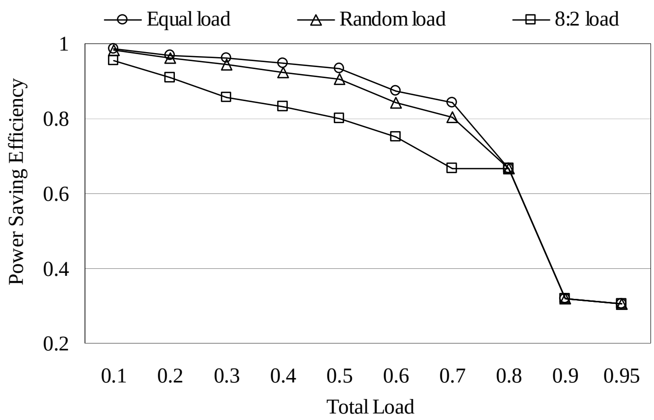

Figure 6. *PSE* of LBPS-Split (10 MSSs)