WIRELESS COMMUNICATIONS AND MOBILE COMPUTING
Wirel. Commun. Mob. Comput. 2015; **15**:601–614
Published online 18 March 2013 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/wcm.2365

RESEARCH ARTICLE

Integrated load-based power saving for BS and MSS in the IEEE 802.16e network

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ABSTRACT

In our previous work, the limitation of standard type I and II power saving in IEEE 802.16e was discussed, and the idea of load-based power saving (LBPS) was proposed for better power-saving efficiency. LBPS measures traffic load and adaptively generates proper sleep schedule for the current load. Three LBPS schemes have been proposed for mobile subscriber station (MSS) power saving. In this paper, base station (BS) power saving is taken into consideration, and our previously proposed LBPS schemes, are extended and revised to integrate both BS and MSS in sleep scheduling. Two strategies of integrated power saving, MSS first and BS first, each with associated LBPS schemes are proposed in the paper. A three-staged concept combining the proposed strategies is also presented to make the best of integrated power saving. A simulation study shows that the proposed schemes can effectively achieve high power-saving efficiency for both BS and MSS. Copyright © 2013 John Wiley & Sons, Ltd.

KEYWORDS
power saving; base station; IEEE 802.16e; LBPS

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1. INTRODUCTION

As the issue of green earth and energy conservation has obtained wide attention in recent years, wireless technologies such as *Worldwide Interoperability for Microwave Access* and *Long Term Evolution Advanced* have been working on power-saving techniques for broadband wireless access networks. There are three standard *power-saving classes* (*PSC*), *types I*, *II*, and *III*, in the specification of mobile Worldwide Interoperability for Microwave Access, IEEE 802.16e [1,2]. The fundamental difference of the three PSCs is the pattern of sleep schedule, which determines the size of sleep windows succeeding the initial sleep window in the case of long idling. Type I, with its exponentially increased sleep window, is suitable for traffic of *non-real-time variable rate* service and *best effort* (*BE*) service. Using an isochronous pattern of sleep and listening windows, type II is recommended to support traffic of *real-time variable rate* service and *unsolicited grant service* (*UGS*).

Most of the researchers in IEEE 802.16e power saving focused on standard type I or II. Related issues in the literature include performance modeling and analysis [3–8], enhancement of standard PSC [9–11], technique dealing with multiple connections and service types [12–15], and novel power-saving schemes [16–19]. In addition to power saving at a *mobile subscriber station* (*MSS*), the idea of a *green base station* (*BS*) [20–24] has also attracted some attention, because the power consumption at BS or access point (AP) is much more than at MSS. However, as will be presented in the next section on related work, most of the work in green BS/AP focused on IEEE 802.11, and integration of sleep schedule for both BS and MSS in IEEE 802.16e has not been addressed.

In our previous work, we have found that neither type I/II nor their extension works can achieve good performance for dynamics of traffic load. The main reason is that most existing mechanisms in a sense adopt a passive way of control in which the sleep schedule is shaped passively by the result of the previous sleep cycle without any information about traffic load or characteristics. To accurately determine the proper sleep schedule, the idea of *load-based power saving* (*LBPS*) in the category of type III has been proposed in our previous works [25–27]. LBPS models and measures traffic proactively, and the sleep schedule is then determined by the estimated traffic load. Three

LBPS schemes for MSS sleep scheduling were proposed: *LBPS-aggr* [25], *LBPS-split* [26], and *LBPS-merge* [27]. A power-saving scheme integrating real-time traffic and non-real-time traffic was also proposed [28]. In this paper, power saving at the BS is considered, and previously proposed LBPS schemes are revised for accommodating both MSS and BS sleep schedules for more power saving in the IEEE 802.16e network. Results of performance evaluation demonstrate the benefit of integrating BS power saving into LBPS schemes.

The rest of the paper is organized as follows. A survey of related works in power saving is presented in Section 2. Our previous work of LBPS is briefly explained in Section 3 for better understanding the proposed work in this paper. Schemes of BS-integrated LBPS are presented in Section 4. Performance evaluation is presented in Section 5. Finally, Section 6 concludes this paper.

2. RELATED WORK

2.1. Performance modeling and analysis

Most of the research work for performance modeling of IEEE 802.16e power saving adopted Markovian analysis and focused on type I or II PSC. In [3], the sleep mode operation in type I was modeled by an M/GI/1/N queueing system with multiple vacations whose periods depend on the previous one. By assuming limited buffer size at the BS and Poisson arrival process, the equations of the dropping probability and mean waiting time of packets in BS's buffer were given in the paper. In [4], the author proposed a probability model for analyzing power consumption and the average delay of type I in the case of both uplink and downlink traffic. In [5], a semi-Markov chain was used to model type I. Average packet delay and average power consumption were analytically derived. Effects of initial sleep window size and final sleep window size were discussed according to numerical results, and the strategy for choosing appropriate operational parameters was given in the paper. In [6], respective analytical models for types I and II were proposed for power efficiency and packet access delay. Power efficiency of the two PSCs was compared, and a power switching scheme between the two PSCs was proposed for optimal power performance. In [7], the authors extended their work in [6] and formalized the problem of optimal sleep mode selection as a probabilistic constrained policy optimization problem to find out the optimal strategies under different traffic conditions that minimize energy consumption and meet the quality-of-service (QoS) requirement. In [8], the authors analyzed the effects of de-jitter buffering on the quality of Voice-Over-Internet Protocol services under type II. A numerical model of the packet drops at the de-jitter buffer, and the end-to-end delay of voice packets including power-saving delay was developed to determine the optimal de-jitter buffer size and maintain the speech quality.

2.2. Enhancement of standard power-saving classes

In [9], the UGS traffic with QoS delay constraint was considered, and an extended work of type II was proposed for multiple MSSs by adopting the idea of reusing the idle fragmentation of the allocated orthogonal frequency-division multiplexing frames to balance power saving and bandwidth utilization. In [10], the idea of Listening Interval Spreading Approach was proposed to combine type I and II schemes, in which the idle time and part of listening intervals in the beginning sleep period are redistributed by using the concept of type II scheme to reduce packet delay, and subsequent periods still use type I scheme to conserve power. In [11], on the basis of type II, the authors proposed an algorithm, namely tank-filling algorithm, that regards the resources of the BS as a sequence of periodical tanks, to assign the sleep cycles of MSSs with the least number of active frames according to delay bounds.

2.3. Power saving for multiple connections and service types

With the consideration of multiple connections between the BS and each MSS, the authors of [12] proposed a sleep-scheduling algorithm for type II to maximize the energy efficiency by appropriate aggregation of the listening intervals of some connections without violating the required QoS constraints. In [13], the authors proposed a Least-Awake-Frame Scheduling algorithm to determine the awake frames for the case of concurrent UGS, real-time polling service, non-real-time polling service, and BE connections at an MSS. The design concept of the Least-Awake-Frame Scheduling is firstly taking all UGS connections into consideration to determine proper awake frames and secondly considering real-time polling service, non-real-time polling service, and BE connections to determine the suitable awake and sleep intervals. In [14], a method of cycle synchronization for types I and II to cover real-time and non-real-time services was proposed. The basic idea is to synchronize the cycles composed of sleep windows and listening windows of all PSCs running on the same MSS to maximize the overlapping of sleep windows while keeping the QoS requirements satisfied. In [15], the Chinese remainder theorem was used in the proposed sleep-scheduling scheme for multiple connections of type II to maximize the unavailability interval (the overlapping of sleep windows).

2.4. Miscellaneous schemes for mobile subscriber station power saving

In [16], several adaptive energy-saving schemes for efficient trade-off between throughput and energy saving for elastic traffic were proposed. The common idea behind the proposed schemes in [16] is that because the amount of available resource for elastic traffic varies, it may be

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DOI: 10.1002/wcm

beneficial for an MSS to sleep at some slots where the MSS cannot receive a sufficiently large number of packets that can compensate for energy consumption. A new sleep mode protocol with the idea of periodic traffic indications was proposed in [17]. The authors claimed that by introduction of periodic traffic indications, the proposed power-saving scheme was better than the IEEE 802.16e standard in terms of simple implementation, reduction of energy consumption, and saving of the resource. In [18], an extensive study of the mutual interaction between power-saving mechanisms and QoS support was carried out for two types of delay-constrained applications, Web and Voice-Over-Internet Protocol, in the context of IEEE 802.16e. The performance was assessed via packet-level simulation to capture the relative contribution of all the factors on the energy-related and QoS-related metrics. In [19], the authors focused on the inefficiency of type I, which is coming from the configuration of its operation and the utilized mechanism of binary-exponential traffic detection. From the concepts of IEEE 802.16m sleep mode operation and by using a discrete-time Markov-modulated Poisson process for representing traffic states, a statistical sleep window control approach was proposed to improve the energy efficiency of an MSS with non-real-time downlink traffic.

2.5. Power saving for base station or access point

Because of the rising awareness of energy conservation, the idea of energy saving at the infrastructure site of wireless networks has attained some attention in the literature. A series of research work in power-saving APs (PSAP) of IEEE 802.11 for the application of multihop relaying has been proposed [20–22]. The authors proposed a new framing structure incorporating sleep subframe that is backward compatible for legacy IEEE 802.11 end stations and existing wired APs. In [21], the authors proposed a media access control protocol for the development of a practical power-saving multihop infrastructure. A PSAP includes network allocation maps in its beacon broadcasts, which specify its temporal operation and thus coordinate traffic delivery and power saving at both end stations and at the PSAP. In [22], the authors extended the concept of network allocation maps and proposed a power-saving QoS-enabled AP for delay-intolerant and loss-intolerant real-time applications. Energy saving in cellular access networks such as Universal Mobile Telecommunications System was addressed in [23], in which analytical models were proposed to characterize the amount of energy that can be saved by reducing the number of active cells during the periods when the traffic is low. When some cells are switched off, radio coverage and service provisioning are taken care of by the cells that remain active, so as to guarantee that the service is available over the whole area. In [24], a generic framework for applying sleep mode to 2G mobile networks such as Global System for Mobile and High-Speed Packet Access systems was proposed. The authors considered a cell with a set of available resources, and two radio allocation schemes were proposed to activate resources only when they are needed to satisfy user demand and QoS requirement so that energy reduction can be achieved.

The issue of integrated sleep scheduling for both the BS and MSSs has received little attention in the literature. In this paper, based on our previous work presented in the next section, integrated power-saving schemes for BS and MSSs are proposed.

3. PREVIOUS WORK

3.1. Basic idea of LBPS and LBPS-aggr

The objective of LBPS is to adaptively adjust the sleep window size of each MSS for a better fit in the current traffic load by traffic measurement. The BS in LBPS needs to estimate the current load for each MSS (denoted by packets per time frame) by collecting and exponentially averaging the samples of load measure as in the *transmission control protocol round-trip time* estimation. For presentation purposes, only downlink traffic is considered in this paper, although uplink traffic can also be integrated into LBPS schemes via some information exchange mechanism between the BS and MSSs. LBPS sets a target threshold of data accumulation in the buffer for an MSS and dynamically calculates its next sleep window size. In this way, LBPS can adapt to different traffic loads and still achieve a proper level of power saving. The basic version of LBPS is *LBPS-aggr*, in which all the traffic in the network is treated as an aggregate flow in calculating the size of the sleep window. In *LBPS-aggr*, the traffic arrival process is assumed to be *Poisson*, and data accumulation under load λ in a time frame is calculated by

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

where T is the length of a time frame.

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

$$\begin{aligned} P_{\text{Acc}}(K, \mathit{Data\_TH}) &\equiv \text{Prob}[\#\text{ of packet arrivals in } K \text{ time frames } > \mathit{Data\_TH}] \\ &= \sum_{i=\mathit{Data\_TH}+1}^{\infty} \frac{e^{-\lambda KT}(\lambda KT)^i}{i!} \\ &= 1 - \sum_{i=0}^{\mathit{Data\_TH}} \frac{e^{-\lambda KT}(\lambda KT)^i}{i!} \end{aligned}$$

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 $P_{\text{Acc}}(K, Data\_TH)$ is higher than a predefined probability threshold denoted by *Prob_TH*. That is,

$$\text{The length of one awake-and-sleep cycle} \equiv LengthAwkSlpCyl(\lambda, Data\_TH) \equiv K^* = \text{Min}\{K \,|\, P_{\text{Acc}}(K, Data\_TH) \geq Prob\_TH\}$$

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.

3.2. LBPS-split and LBPS-merge

LBPS-split was proposed to improve the performance of LBPS-aggr in power saving as explained briefly by the following example. Considering the case that $K^* = 2$ (the length of the awake-and-sleep cycle is two time frames) in LBPS-aggr, conceptually, it implies that 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 the protocol of LBPS-split.

The best case of LBPS-split in power saving is that each of the split groups is composed of a single MSS, and the final value of K^* is therefore determined by the MSS with the least load. In such a case, with the same length (the final K^*) of the awake-and-sleep cycle, each MSS is assigned with one whole awake time frame in a cycle. The idea leads to another perspective of grouping MSSs in sleep scheduling. Instead of treating all MSSs as one group from the start, we could firstly make each MSS a single-member group for K^* calculation. Because the load of each MSS varies, each group usually has a different value of K^*. To achieve a better gain of power saving, the sleep-scheduling algorithm should be able to accommodate different values of K^* as long as a feasible sleep schedule can be found. In the case that a feasible sleep schedule cannot be found for the current state of grouping, merging of some groups is necessary. The idea of treating each MSS as a single-member group from the start and merging groups when necessary leads to another enhanced protocol, namely LBPS-merge.

Because it is difficult to check the schedulability of groups with any possible value of K^*, the value of K^* is converted to the closest and smaller power of 2, denoted by $K^\#$ (i.e., $K^\# = 2^{\lfloor \log_2 K^* \rfloor}$) in LBPS-merge. With the property of powers of 2, a quick check for schedulability can be obtained. Schedulability of a number of groups with different $K^\#$ values is defined by the following equation:

$$Schedulability = \sum_i \frac{1}{K_i^\#}$$

A *schedulability* equal to or smaller than 1 (*schedulability* ≤ 1) indicates that a feasible schedule can be found. *Schedulability* > 1 indicates the necessity of merging some groups. Group merging should not reduce as much power-saving efficiency (PSE) as possible, which means the value of $K^\#$ after group merging should be kept as large as possible. Therefore, the merging process in LBPS-merge is divided into two phases: (1) *nondegraded merging* and (2) *degraded merging*. Merging of two groups that does not result in a smaller value of $K^\#$ is called a nondegraded merging. A degraded merging is accepted only when a nondegraded merging cannot be found. A simulation study showed that LBPS-split and LBPS-merge outperform LBPS-aggr and type I-based (even type II-based) mechanisms in power saving.

4. INTEGRATED POWER SAVING FOR BS AND MSS

Because of the rising energy prices and for slowing down the global warming problem, energy consumption in development of any information and communications technology is becoming a major topic. Issues about green mobile networks have obtained more attention in the literature. As presented in Section 2, a large part of the related research in energy-efficient design focused on the user side to prolong the operational time of battery-powered devices. However, power saving at the network side such as BSs can usually save more energy than at the user side. Therefore, by taking both BS and MSS power saving into consideration, we propose mechanisms of integrated sleep scheduling in this paper.

There are two different strategies proposed for integration of BS power saving in LBPS. The first strategy, namely S1, is to allow BS to enter the sleep mode when all MSSs are in the sleep mode. S1 does not require any modification of the LBPS schemes, but the PSE at BS is limited by the load and sleep schedule of MSS. The other strategy considers the fact that the benefit of power saving at BS is usually larger than power saving at each MSS. Thus, a threshold value for power saving (denoted by *PSE_TH*) at BS is set beforehand in the second strategy, S2, in which the sleep-scheduling algorithm in LBPS schemes must be revised to integrate BS and meet the requirement of *PSE_TH*. In summary, S1 is MSS-first power saving, and S2 is BS-first

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DOI: 10.1002/wcm

power saving. It is worth mentioning that because of the passive characteristic in power saving, standard type I or II PSC cannot be extended to support BS power saving.

4.1. Strategy 1

The sleep schedule for each MSS is first determined in S1. The time frames in which all MSSs in the sleep mode

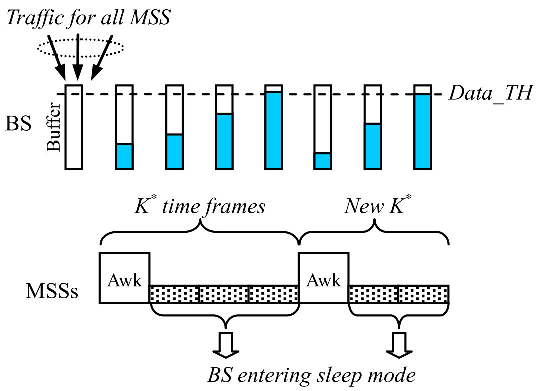

Figure 1. Base station (BS) power saving in load-based power saving-aggr under strategy 1. MSS, mobile subscriber station.

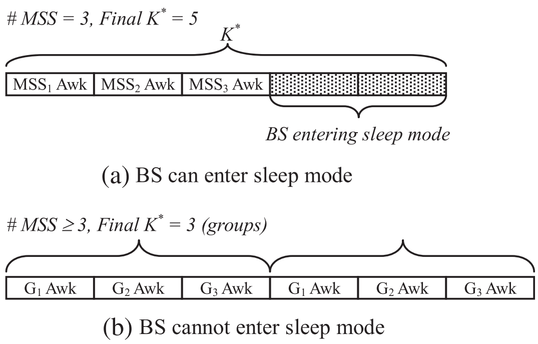

Figure 2. Base station (BS) power saving in load-based power saving-split under strategy 1. MSS, mobile subscriber station.

are scheduled are the sleep time frames for BS. LBPS-aggr presents the simplest case among LBPS schemes for BS power saving because all MSSs are treated as a single group as displayed in Figure 1. Starting from the same method as LBPS-aggr, LBPS-split iteratively splits all MSSs according to the new K^* value. There are two possible cases to end the LBPS-split algorithm. For the case of the final value of K^* larger than the number of MSSs, there is some room for BS power saving as displayed in Figure 2(a). On the other hand, for the case of the final value of K^* no larger than the number of MSSs, there is no room for BS power saving as displayed in Figure 2(b). For LBPS-merge, BS power saving depends on the final value of *schedulability* in the end of the algorithm. For the case of *schedulability* < 1, there is room for BS power saving as displayed in Figure 3(a). For the case of *schedulability* $= 1$, there is no room for BS power saving as displayed in Figure 3(b).

4.2. Strategy 2

In S2, a target of BS power saving (i.e., *PSE_TH*) is set, and the sleep-scheduling algorithm in LBPS schemes should try to meet the goal. Because the sleep time frames are the same for BS and all MSSs in LBPS-aggr, there is no difference between S1 and S2 for LBPS-aggr.

The splitting process of LBPS-split requires some revision to meet BS's *PSE_TH*. Because further splitting makes the *awake-and-sleep cycle* longer (i.e., a larger value of K^*), the basic idea of the revision is to stop the splitting process when the length of the *awake-and-sleep cycle* cannot meet BS's *PSE_TH* for the first time. Given $K_{BS} = \lfloor PSE\_TH^{-1} \rfloor$ and one sleep time frame for BS in a cycle, BS's *PSE_TH* is not met if the following occur: (1) final K^* (denoted by K_{final}) $> K_{BS}$ or (2) $K_{final} \leq K_{BS}$, but $K_{final} - 1$ time frames, which are for MSS sleep scheduling, are not enough to accommodate all groups. The detailed algorithm of the revised LBPS-split for BS power saving is given in Figure 4. An example for the case of meeting BS's *PSE_TH* in LBPS-split under S2 is given in Figure 5.

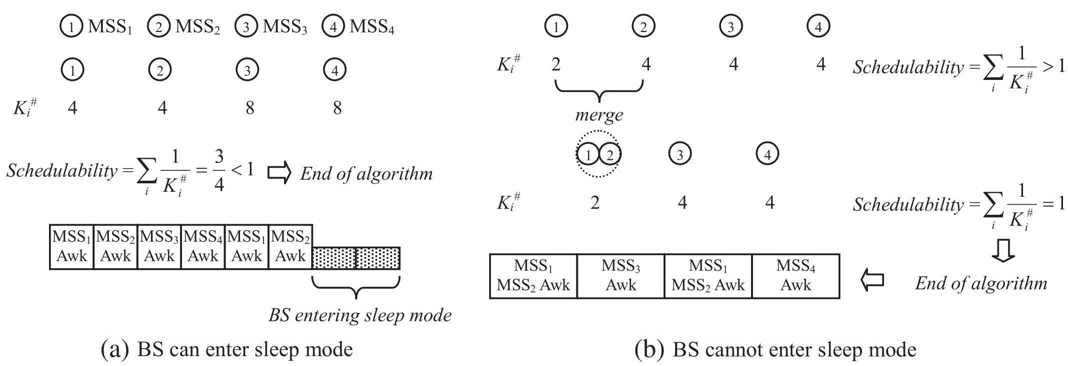

Figure 3. Base station (BS) power saving in load-based power saving-merge under strategy 1. MSS, mobile subscriber station.

Estimate the current load of each $MSS_i = \lambda_i$

Define $K^*(n)$ = the minimal value of K^* among all groups in the n^{th} iteration and $K_{BS} = \lfloor PSE\_TH^{-1} \rfloor$

Initialization: $K^*(0)=1,\ n = 0$

Step 1. Split all MSSs to $K^*(n)$ groups, $G_1 \sim G_{K^*(n)}$ {*splitting should minimize load difference between groups*}

For each group G_i, calculate $K_{Gi} = LengthAwkSlpCyl\ (\lambda_{Gi}, Data\_TH)$, where $\lambda_{Gi} = \sum_{MSS_m \in Gi} \lambda_m$

$K^*(n+1)$ = the smallest one among K_{Gi}

Step 2. If $K^*(n+1) > K_{BS}$, go to Step 3 {*stop, since further splitting cannot meet BS's PSE_TH*}

Else if $K^*(n+1) \neq K^*(n)$, set $n = n + 1$ and go to Step 1. {*further splitting*}

Else go to Step 3

Step 3. Find the largest number K_{final} in $[K^*(n), K^*(n+1)]$ such that $K_{final} \leq K_{BS}$ and $K_{final} - 1 \geq K^*(n)$

If no proper value for K_{final} can be found, return "*BS's PSE_TH cannot be met*".

Step 4. Assign one out of K_{final} time frames as BS's sleep time frame. Split MSSs into K_{final} *-1* groups and each group is assigned with a different awake time frame within the cycle of K_{final} time frames.

Figure 4. Revised algorithm of load-based power saving-split under strategy 2.

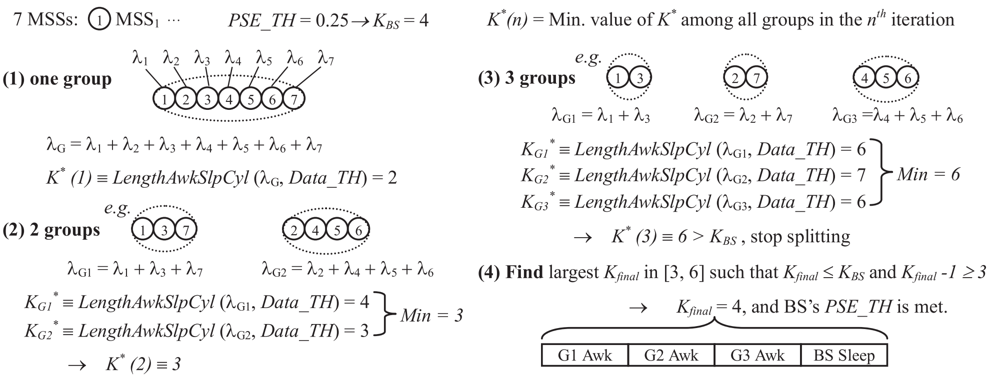

Figure 5. An example of load-based power saving-split under strategy 2. BS, base station; MSS, mobile subscriber station.

In LBPS-merge, each MSS can have its own length ($K^{\#}$) of the *awake-and-sleep cycle* if possible. The idea of different $K^{\#}$ values for different MSSs can be further extended to support BS power saving. Given $K^{\#}_{\mathrm{BS}} = 2^{\lfloor \log_2 K_{\mathrm{BS}} \rfloor}$ and $K_{\mathrm{BS}} = \lfloor PSE\_TH^{-1} \rfloor$, it is implied that one out of $K^{\#}_{\mathrm{BS}}$ time frames should be assigned as BS's sleep time frame to meet *PSE_TH*. Therefore, the revised algorithm of LBPS-merge under S2 treats BS as a special MSS with its own $K^{\#}_{\mathrm{BS}}$ value in sleep scheduling. The following changes are made for LBPS-merge under S2:

(1) For MSS groups, the value of $K^{\#}$ means one *awake* time frame out of $K^{\#}$ time frames. Conversely, the value of $K^{\#}_{\mathrm{BS}}$ means one *sleep* time frame out of $K^{\#}_{\mathrm{BS}}$ time frames for BS.
(2) Because no MSS should be in the awake mode when BS is in the sleep mode, BS cannot be merged with MSS.
(3) The equation of *schedulability* is revised to include BS's power saving as follows:

$$Schedulability = \sum_i \frac{1}{K^{\#}_i} + \frac{1}{K^{\#}_{\mathrm{BS}}}$$

An example of LBPS-merge under S2 is given in Figure 6. The detailed algorithm of LBPS-merge under S2 is presented in Figure 7.

5. PERFORMANCE EVALUATION

A simulation study extended from our previous simulation platform [29,30] on IEEE 802.16e is conducted to evaluate the performance of the proposed schemes. The programming language used in the simulation is Microsoft Visual C++ 6.0 on Windows XP SP3. A point-to-multipoint network consisting of a BS and a certain number of MSSs is simulated. The traffic pattern for each MSS is assumed to be a Poisson process. Simulation parameters are summarized in Table I. The simulation program focuses on the media access control layer of IEEE 802.16e with the

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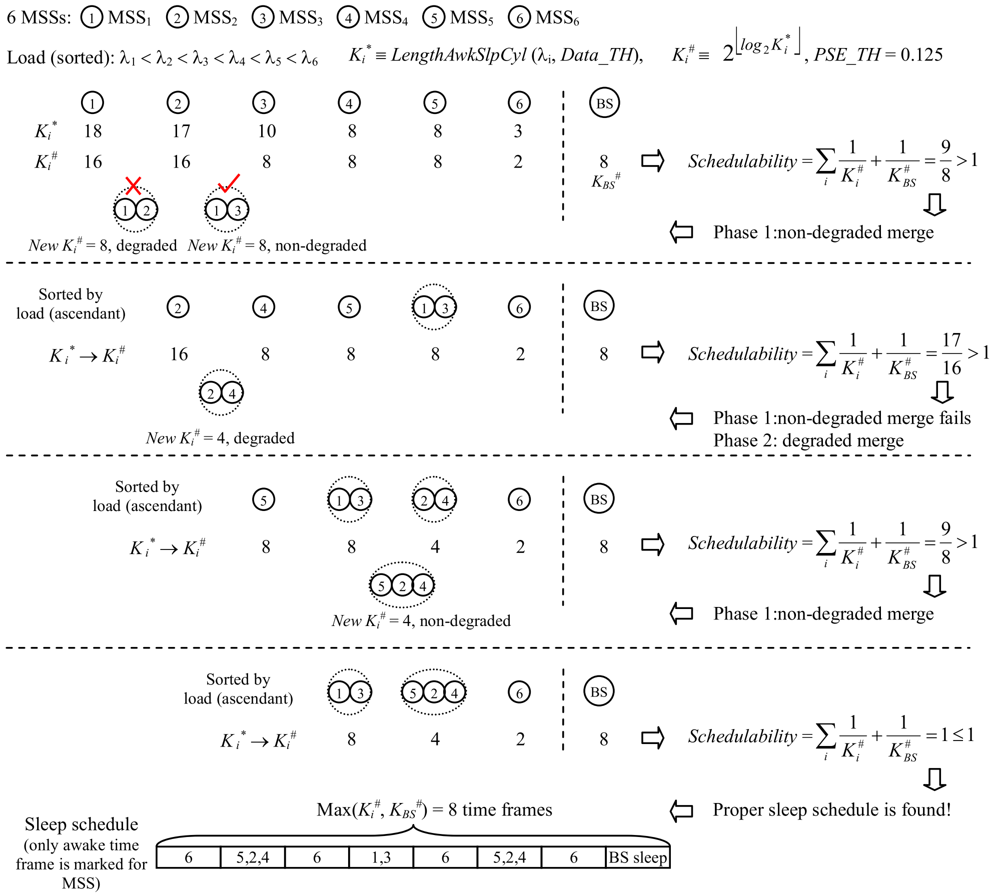

Figure 6. An example of load-based power saving-merge under strategy 2. BS, base station; MSS, mobile subscriber station.

$K_{BS} = \lfloor PSE\_TH^{-1} \rfloor$, $K_{BS}^{\#} = 2^{\lfloor \log_2 K_{BS} \rfloor}$

Estimate the current load of each $MSS_i = \lambda_i$, each MSS_i initially forms a group, λ_G = the total load in a group.

1. Sort the MSS groups in the ascendant order of load.

   For each group, calculate $K_G^{*} = LengthAwkSlpCyl\ (\lambda_G, Data\_TH)$, and convert K_G^{*} to the closest and smaller power of $2 = K_G^{\#} = 2^{\lfloor \log_2 K_G^{*} \rfloor}$.

2. If ($Schedulability = \sum \frac{1}{K_G^{\#}} + \frac{1}{K_{BS}^{\#}} \le 1$) or (the number of MSS groups = 1) go to step 3.

   Else {

   Phase 1: *Non-degraded merge* (only for MSS)

   Try to merge the smallest load group to another group until a non-degraded merge is found.

   If a non-degraded merge is found, repeat step 1 & 2 , else perform Phase 2.

   Phase 2: *Degraded merge* (only for MSS)

   Merge the two groups with the smallest loads and repeat step 1 & 2.

   }

3. If *Schedulability* ≤ 1, assign one out of $K_{BS}^{\#}$ time frames as BS's sleep time frame, and schedule the MSS groups according to the final set of $K_G^{\#}$.

   Else return "*BS's PSE_TH cannot be met*"

Figure 7. Revised algorithm of load-based power saving-merge under strategy 2. BS, base station; MSS, mobile subscriber station.

Table I. Simulation parameters.

Parameter	Value
# of MSS	10, 40
# of mini-slots in a time frame	100
Size of packet	1 mini-slot
Data_TH	80 packets
Prob_TH	0.8
Traffic pattern	Poisson
Simulation time	10^5 s

MSS, mobile subscriber station.

assumption of constant physical channel state and using the lowest level (quadrature phase-shift keying) of the modulation and coding scheme.

It is worth mentioning that to achieve the best possible performance, power saving in any communication systems should consider and integrate all related dimensions, such as scheduling, resource allocation, error control, dynamic channel quality, modulation and coding scheme, upper-layer protocols, and so on, which usually involves a cross-layer design and still remains as a challenging research topic. In this paper, we merely focus on integrated sleep scheduling for BS and MSS. Effects from other dimensions, for example, adaptive modulation and coding (AMC) [31–33], on the proposed schemes are beyond the scope of this paper.

Three performance criteria are defined in the simulation as presented in the following:

(1) *PSE* is defined as the ratio of time entering the sleep mode. For instance, for one awake time frame in a cycle of K time frames for a device (BS or MSS), the value of the device's *PSE* is calculated as $(K-1)/K$. The value of *PSE* for BS or for the group of MSSs is computed by averaging all samples in the simulation.
(2) The *average access delay*, denoted by *AvgDelay*, is defined as the average time for a downlink packet from the BS to reach the destination MSS.
(3) *Total power consumption*, in watts (W), is measured by adding up the power consumption of BS and all MSSs.

5.1. Performance results in S1

The *PSE* of LBPS schemes under S1 is displayed in Figure 8, noting that *PSE*s for BS and for MSSs in the LBPS-aggr have the same curve because they are treated as a single group in the scheme. If only BS's *PSE* is considered, Figure 8 shows that LBPS-aggr is better than the others with the following reason. Because the goal of LBPS-split and LBPS-merge in S1 is to maximize the MSS's *PSE* by grouping MSSs and assigning different sleep frames to each group, the BS's *PSE*, which is affected by the degree of overlapping of the sleep frames, is compromised in both schemes. Figure 8 also shows that LBPS-merge outperforms the others if both BS's and MSS's *PSE*s are taken into consideration.

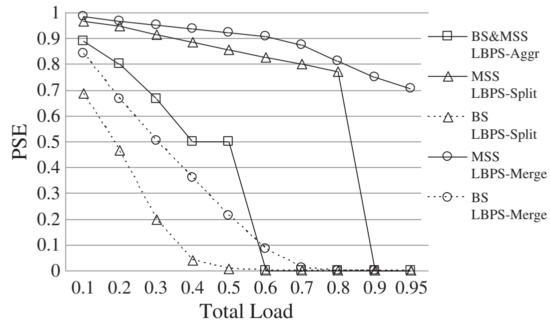

Figure 8. Base station (BS)/mobile subscriber station (MSS) power-saving efficiency (*PSE*) of load-based power saving (LBPS) schemes in strategy 1.

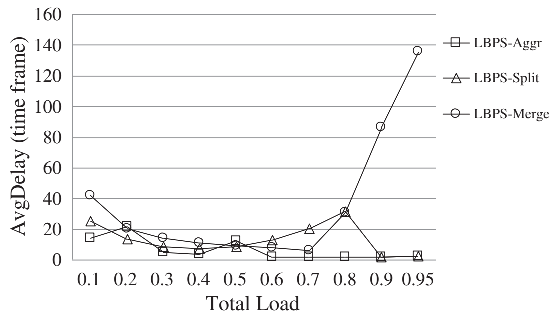

Figure 9. Mobile subscriber station access delay in strategy 1. AvgDelay, average access delay; LBPS, load-based power saving.

The *AvgDelay* of MSS in S1 is displayed in Figure 9, which presents a complicated relationship among LBPS schemes as the total load goes up. The behavior of the access delay in a power-saving scheme is affected by multiple factors as explained in the following. Firstly, the access delay goes up as the input load goes up according to the principle of the queuing theory. Secondly, the length of the *awake-and-sleep* cycle of an MSS makes the upper bound of the waiting time in the buffer, meaning that the more power saving at an MSS, the longer waiting time the MSS would observe. Thirdly, BS power saving would also affect the access delay, as the more power saving at the BS, the less available bandwidth (capacity) MSSs can use, leading to the longer access delay. Interaction of the aforementioned factors makes it difficult to draw a simple rule to explain the behavior of the access delay.

The impact of the number of MSSs on *PSE* was also investigated in the simulation study. Figures 10 and 11 display *PSE* of BS and MSS under different numbers of MSSs for LBPS-split and LBPS-merge, respectively. Both figures show that a larger number of MSS benefits *PSE* of both BS and MSS under the same load because a larger number of MSSs provides more flexibility in group splitting or merging, and thus, more gain in *PSE* can be obtained.

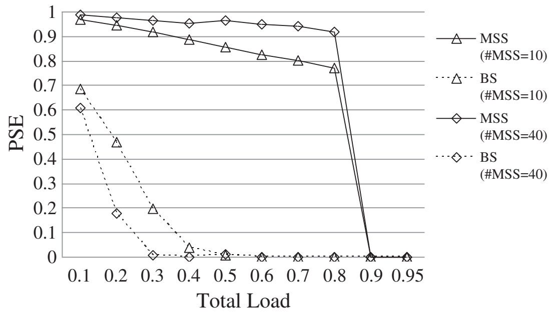

Figure 10. Impact of the number of mobile subscriber stations (MSSs) for load-based power saving-split in strategy 1. BS, base station; PSE, power-saving efficiency.

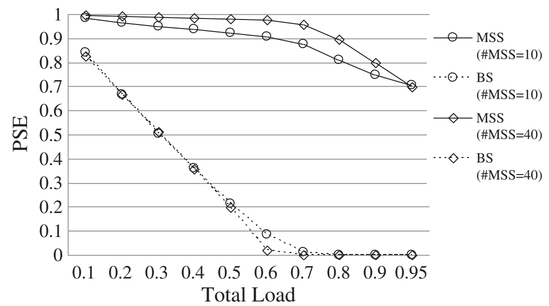

Figure 11. Impact of the number of mobile subscriber stations (MSSs) for load-based power saving-merge in strategy 1. BS, base station; PSE, power-saving efficiency.

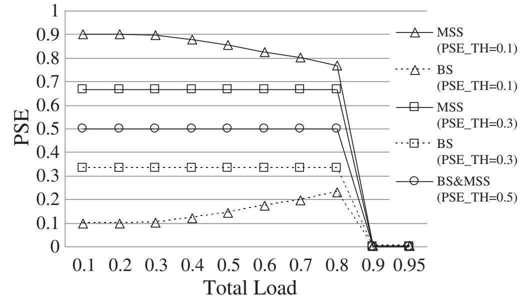

Figure 12. Base station (BS)/mobile subscriber station (MSS) power-saving efficiency (*PSE*) of load-based power saving-split in strategy 2.

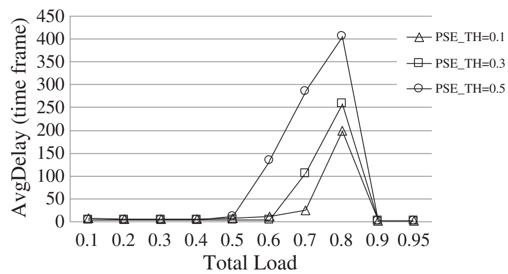

Figure 13. Mobile subscriber station access delay of load-based power saving-split in strategy 2. AvgDelay, average access delay; PSE, power-saving efficiency.

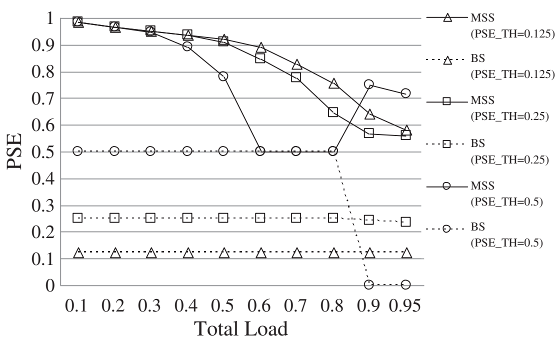

Figure 14. Base station (BS)/mobile subscriber station (MSS) power-saving efficiency (*PSE*) of load-based power saving-merge in strategy 2.

5.2. Performance results in S2

The power-saving performance of LBPS-split in S2 is displayed in Figure 12 with the following observations:

(1) The target *PSE_TH* for BS is met, and meanwhile, a certain level of power saving for MSS is still achieved when the total load is under 0.8. Compared with that in Figure 8, *PSE* of MSS for LBPS-split in S2 is compromised because of the preset level of BS's *PSE_TH* in S2.
(2) BS's *PSE* for the case of $PSE\_TH = 0.1$ exceeds 0.1 and keeps increasing when the load is higher than 0.3. It is because BS's *PSE* is in the form of $(1/K_{\text{final}})$ in LBPS-split, in which K_{final} as an integer is the final length of the *awake-and-sleep* cycle. As the load goes up, the value of K_{final} goes down and results in the tendency of having a higher *PSE* than *PSH_TH*.
(3) BS's and MSS's *PSE*s are the same for the case of $PSE\_TH = 0.5$. This is because $K_{\text{final}} = 2$ for load in 0.1–0.8, which leads to the result of $PSE = 0.5$ for both BS and MSS.

The *AvgDelay* for LBPS-split in S2 is displayed in Figure 13, indicating that a larger *PSE_TH* would result in a higher access delay when the load is between 0.5 and 0.8. Results of *PSE* and *AvgDelay* of LBPS-merge in S2 are displayed in Figures 14 and 15, in which *PSE_TH* is in the form of $(1/2^K)$ because the length of the *awake-and-sleep* cycle in LBPS-merge is in the form of 2^K. Similar observations as aforementioned in LBPS-split can be found in LBPS-merge. Figures 12 and 14 demonstrate that both LBPS-split and LBPS-merge in S2 can effectively support BS power saving while maintaining high power-saving efficiency for MSS. Furthermore, LBPS-merge outperforms LBPS-split in both BS and MSS power saving under very heavy load (above 0.9) because of the flexibility of LBPS-merge that allows different cycle lengths in sleep scheduling.

A comparison of BS's PSE in S1 with that in S2 for LBPS-split is illustrated in Figure 16 and for LBPS-merge in Figure 17. Both figures demonstrate that S1 is better than S2 in terms of BS's PSE only when the total load is pretty light (under 0.2). Therefore, S2 with an adaptive value of *PSE_TH* for different loads should be a better way for BS power saving.

From the viewpoint of energy conservation, it is also important to investigate the total power consumption in addition to the value of *PSE* at BS and MSS because BS and MSS present different levels of the power consumption. As a matter of fact, the power consumption at BS in the awake mode is normally up to hundred times the power consumption at an MSS. Parameters of estimating power consumption in watts (W) are listed in Table 2. The total power consumption including BS and MSS is calculated as

$$\begin{aligned} &\textit{Total power consumption} \\ &\quad = PSE_{\mathrm{BS}} \times C_{\mathrm{BS}}^{\mathrm{Sleep}} + (1 - PSE_{\mathrm{BS}}) \\ &\quad\quad \times C_{\mathrm{BS}}^{\mathrm{Awake}} + N_{\mathrm{MSS}} \times \Big[PSE_{\mathrm{MSS}} \times C_{\mathrm{MSS}}^{\mathrm{Sleep}} \\ &\quad\quad\quad + (1 - PSE_{\mathrm{MSS}}) \times C_{\mathrm{MSS}}^{\mathrm{Awake}} \Big] \end{aligned}$$

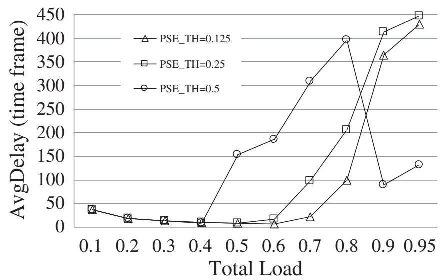

Figure 15. Mobile subscriber station access delay of load-based power saving-merge in strategy 2. AvgDelay, average access delay; PSE, power-saving efficiency.

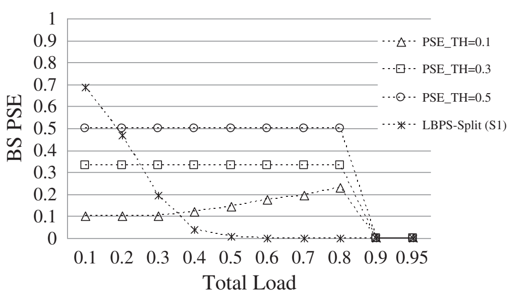

Figure 16. Base station (BS) power-saving efficiency (*PSE*) of load-based power saving (LBPS)-split: strategy 1 versus strategy 2.

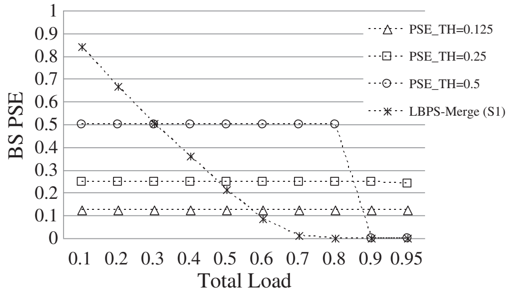

Figure 17. Base station (BS) power-saving efficiency (*PSE*) of load-based power saving (LBPS)-merge: strategy 1 versus strategy 2.

Table 2. Parameters for estimating power consumption.

Notation	Value	Description
$C_{\mathrm{BS}}^{\mathrm{Awake}}$	100 W	BS power consumption in the awake mode
$C_{\mathrm{BS}}^{\mathrm{Sleep}}$	18 W	BS power consumption in the sleep mode
$C_{\mathrm{MSS}}^{\mathrm{Awake}}$	0.75 W	MSS power consumption in the awake mode
$C_{\mathrm{MSS}}^{\mathrm{Sleep}}$	0.05 W	MSS power consumption in the sleep mode

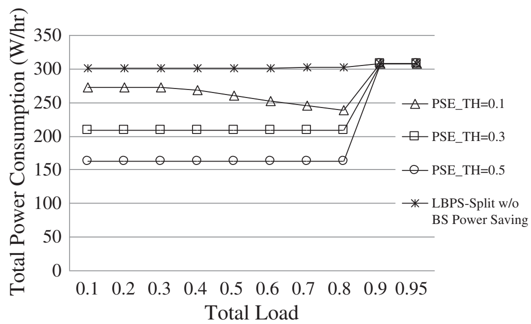

Figure 18. Total power consumption of load-based power saving (LBPS)-split in strategy 2. BS, base station; PSE, power-saving efficiency.

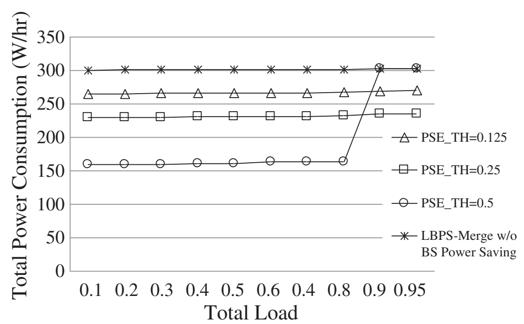

Figure 19. Total power consumption of load-based power saving (LBPS)-merge in strategy 2. BS, base station; PSE, power-saving efficiency.

Wirel. Commun. Mob. Comput. 2015; **15**:601–614 © 2013 John Wiley & Sons, Ltd.
DOI: 10.1002/wcm

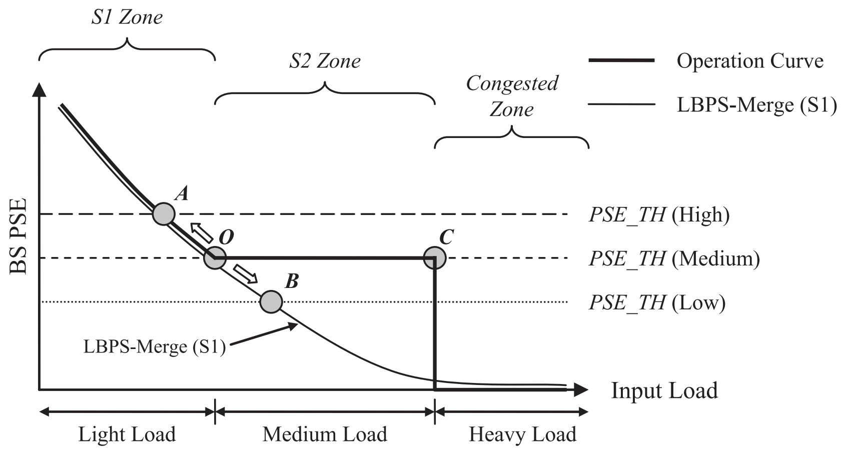

Figure 20. Optimal operation for integrated sleep scheduling. BS, base station; LBPS, load-based power saving; PSE, power-saving efficiency.

where PSE_{BS} and PSE_{MSS} are the average *PSE*s for BS and MSS, respectively, and N_{MSS} is the number of MSSs.

Figures 18 and 19 display the total power consumption of LBPS-split and LBPS-merge, respectively, in S2 with and without BS power saving. Note that only MSS power saving is considered in the case of "without (w/o) BS power saving" in the figures. Both figures demonstrate the merit of BS power saving in terms of reducing total power consumption.

5.3. Optimal operation for integrated sleep scheduling

The benefit of BS power saving with the proposed schemes has been demonstrated by the performance results in previous sections, but the phenomenon where BS's and MSS's PSEs are affected by each other is also observed. The proposed schemes under S1 and S2 are based on different philosophies, which makes it difficult, if not impossible, to determine which strategy is the best one in all times. S1 is MSS first meaning that lengthening the battery life at MSS (the user side) is the main focus, whereas S2 by setting the power-saving goal (*PSE_TH*) of BS is aiming for cost reduction of energy consumption at the operator side. In a nutshell, MSS's PSE is optimized in S1, but S2 tries to achieve a certain level of BS power saving, which is usually not based on technical concern. Moreover, it is inappropriate to combine BS's PSE and MSS's PSE into a single index for optimization. On the other hand, we also observe from Figures 16 and 17 that each of S1 and S2 presents better BS PSE over different load conditions. Therefore, instead of looking for optimized operation of integrated sleep scheduling, we propose the idea of three-staged integrated power saving by taking advantage of different strategies over different loads.

As illustrated in Figure 20, there are three zones for integrated power saving: *S1 zone*, *S2 zone*, and *congested zone*. The S1 zone is used for the condition of light load, in which the MSS-first strategy does not sacrifice much of BS's PSE. As the input load increases and moves to the part of medium load, the S2 zone takes over. The switching point from S1 to S2 (e.g., point ***O*** in Figure 20) is determined by setting the value of *PSE_TH* for BS. That is, S1 is in operation starting from the light load. When the goal of BS's PSE cannot be met by the MSS-first strategy of S1, S2 replaces S1. Raising (e.g., point ***A*** in Figure 20) or lowering (e.g., point ***B*** in Figure 20) the value of *PSE_TH* affects the activation time of S1 and S2. As mentioned earlier, the value of *PSE_TH* is usually determined by nontechnical factors such as operation budgeting.

The third zone, congested zone, is activated when *PSE_TH* for BS cannot be met because of the heavy load. In the congested zone, there is no room, making it inappropriate for BS power saving and for not making the MSS's performance (PSE and access delay) worse. The congested zone also indicates the need for distributing some load to other BSs if possible, which has the benefit of creating some room for BS power saving.

Last but not least, among the proposed schemes for integrated sleep scheduling, LBPS-merge is preferred for better BS's and MSS's PSEs, although LBPS-split presents more flexibility in selecting the value of *PSE_TH*.

6. CONCLUSION

Most of the research works in power saving of wireless networks focused on the user side. In this paper, power saving at the BS is considered along with power saving at the MSS. In our previous work, the idea of LBPS and three related schemes, LBPS-aggr, LBPS-split, and LBPS-merge, were proposed for MSS-only power saving in IEEE 802.16e. The previously proposed LBPS schemes are revised to integrate both BS and MSS in sleep scheduling.

Two strategies of the integrated power saving, MSS first (S1) and BS first (S2), each with associated LBPS schemes, have been presented in the paper. A simulation study has shown that S1-based schemes favor MSS power saving and S2-based schemes favor BS power saving. Power saving at MSS lengthens its operational time powered by battery, but power saving at BS can greatly reduce power consumption. Therefore, S2-based schemes are preferred from the aspect of green mobile networks. Moreover, a discussion about optimization of integrated sleep scheduling is presented in the paper, and a three-staged operation adopting S1 and S2 in different load conditions is proposed.

A future work of research is to extend the idea of LBPS in the environment of IEEE 802.16j multihop relay network. It is expected that high power-saving efficiency would inevitably result in high access delay. Therefore, finding a good balance between power-saving efficiency and access delay will be a key issue for power saving in multihop wireless networks. Furthermore, Poisson modeling for data arrival process brings the benefit of easy handling of traffic multiplexing in the proposed LBPS schemes, but it presents the concern of unrealistic assumption. Investigation of more sophisticated stochastic models such as Pareto distribution applied in LBPS is left as the future work of the research.

ACKNOWLEDGEMENTS

Part of the research work in this paper has been published in the Proceedings of the 2012 International Conference on Advancements in Information Technology, June 2012, Hongkong.

This work was supported in part by the National Science Council, Taiwan, ROC, under grant no. NSC 100-2221-E-260-027.

REFERENCES

1. IEEE Std. 802.16e-2006. IEEE standard for local and metropolitan area networks part 16: air interface for fixed and mobile broadband wireless access systems—amendment for physical and medium access control layers for combined fixed and mobile operation in licensed bands, Feb. 2006.
2. IEEE Std. 802.16-2009. IEEE standard for local and metropolitan area networks part 16: air interface for broadband wireless access systems, May 2009.
3. Seo JB, Lee SQ, Park NH, Lee HW, Cho CH. Performance analysis of sleep mode operation in IEEE 802.16e. In *Proceedings of the IEEE 60th Vehicular Technology Conference (VTC 2004-Fall)*, Vol. 2, Los Angeles, CA, Sept. 2004; 1169–1173.
4. Xiao Y. Performance analysis of an energy saving mechanism in the IEEE 802.16e wireless MAN. In *Proceedings of the IEEE 3rd Consumer Communications and Networking Conference (CCNC 2006)*, Vol. 1, Las Vegas, Nevada, Jan. 2006; 406–410.
5. Han K, Choi S. Performance analysis of sleep mode operation in IEEE 802.16e mobile broadband wireless access system. In *Proceedings of the IEEE 63rd Vehicular Technology Conference (VTC 2006-Spring)*, Vol. 3, Melbourne, Australia, Jan. 2006; 1141–1145.
6. Kong L, Tsang DHK. Performance study of power saving classes of type I and II in IEEE 802.16e. In *Proceedings of the 31st IEEE Conference on Local Computer Networks (LCN 2006)*, Tampa, Florida, Nov. 2006; 20–27.
7. Kong L, Tsang DHK. Optimal selection of power saving classes in IEEE 802.16e. In *Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC 2007)*, Hong Kong, March 2007; 1836–1841.
8. Kim H, Kim T. Analysis of optimal jitter buffer size for VoIP QoS under WiMAX power-saving mode. *IEICE Transactions on Communications* 2010; **E93.B**(6): 1395–1402.
9. Huang SC, Jan RH, Chen C. Energy efficient scheduling with QoS guarantee for IEEE 802.16e broadband wireless access networks. In *Proceedings of the 2007 International Conference on Wireless Communications and Mobile Computing (IWCMC 2007)*, Honolulu, Hawaii, Aug. 2007; 547–552.
10. Sheu ST, Cheng YC, Chen LW, Wu JS, Chang J. Listening Interval Spreading Approach (LISA) for handling burst traffic in IEEE 802.16e wireless metropolitan area networks. In *Proceedings of the IEEE 64th Vehicular Technology Conference (VTC 2008-Fall)*, Calgary, Alberta, Sept. 2008; 1–5.
11. Chen JJ, Liang JM, Tseng YC. An energy efficient sleep scheduling considering QoS diversity for IEEE 802.16e wireless networks. In *Proceedings of the 2010 IEEE International Conference on Communications (ICC2010)*, Cape Town, South Africa, July 2010; 1–5.
12. Tseng HL, Hsu YP, Hsu CH, Tseng PH, Feng KT. A maximal power-conserving scheduling algorithm for broadband wireless networks. In *Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC 2008)*, Las Vegas, Nevada, April 2008; 1877–1882.
13. Lin CY, Chao HL. Energy-saving scheduling in IEEE 802.16e networks. In *Proceedings the 33rd IEEE on Local Computer Networks (LCN 2008)*, Quebec, Canada, Oct. 2008; 130–135.
14. Wu Y, Le Y, Zhang D. An enhancement of sleep mode operation in IEEE 802.16e systems. In *Proceedings of the IEEE 69th Vehicular Technology Conference (VTC 2009-Spring)*, Barcelona, Spain, April 2009; 1–6.

15. Chen TC, Chen JC. Maximizing unavailability interval for energy saving in IEEE 802.16e wireless MANs. *IEEE Transactions on Mobile Computing* 2009; **8**(4): 475–487.
16. Lee J, Bahk S. Adaptive energy saving scheme for downlink elastic traffic in wireless networks. In *Proceedings of the 2009 IEEE Conference on Wireless Communications and Networking Conference (WCNC 2009)*, Budapest, Hungary, April 2009; 1882–1886.
17. Hwang E, Kim KJ, Son JJ, Choi BD. The power-saving mechanism with periodic traffic indications in the IEEE 802.16e/m. *IEEE Transactions on Vehicular Technology* 2010; **59**(1): 319–334.
18. Cicconetti C, Lenzini L, Mingozzi E, Vallati C. Reducing power consumption with QoS constraints in IEEE 802.16e wireless networks. *IEEE Transactions on Mobile Computing* 2010; **9**(7): 1008–1021.
19. Hsu CH, Feng KT, Chang CJ. Statistical control approach for sleep mode operations in IEEE 802.16m systems. *IEEE Transactions on Vehicular Technology* 2010; **59**(9): 4453–4466.
20. Zhang F, Todd TD, Zhao D, Kezys V. Power saving access points for IEEE 802.11 wireless network infrastructure. In *Proceedings of the 2004 IEEE Wireless Communications and Networking Conference (WCNC 2004)*, Vol. 1, Atlanta, GA, 2004; 195–200.
21. Li Y, Todd TD, Zhao D. Access point power saving in solar/battery powered IEEE 802.11 ESS mesh networks. In *Proceedings of the 2nd International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks (Qshine 2005)*, Orlando, Florida, USA, 2005; 45–49.
22. Kholaif AM, Todd TD, Koutsakis P, Smadi MN. QoS-enabled power saving access points for IEEE 802.11e networks. In *Proceedings of the 2008 IEEE Wireless Communications and Networking Conference (WCNC 2008)*, Las Vegas, Nevada, April 2008; 2331–2336.
23. Marsan MA, Chiaraviglio L, Ciullo D, Meo M. Optimal energy savings in cellular access networks. In *Proceedings of the 2009 IEEE International Conference on Communications (ICC 2009)*, Dresden, Germany, Aug. 2009; 1–5.
24. Saker L, Elayoubi SE, Chahed T. Minimizing energy consumption via sleep mode in green base station. In *Proceedings of the 2010 IEEE Wireless Communications and Networking Conference (WCNC 2010)*, Sydney, Australia, July 2010; 1–6.
25. Yang CC, Fang CH, Lin JR. Adaptive power saving strategy based on traffic load in the IEEE 802.16e network. In *Proceedings of the International Conference on Information and Communication Technologies (ICICT 2010)*, Tokyo, Japan, May 26–28, 2010.
26. Yang CC, Mai YT, Chen JY, Shen YS. A clustering technique of load-based power saving in the IEEE 802.16e network. In *Proceedings of the Annual International Conference on Mobile Communications, Networking and Applications (MobiCONA 2011)*, Singapore, June 2011; M5–M9.
27. Yang CC, Mai YT, Chen JY, Shen YS, Kuo YC. LBPS: load-based power saving in the IEEE 802.16e network. *Computers and Electrical Engineering* 2012; **38**(4): 891–905.
28. Mai YT, Yang CC, Chen JY, Lin MH. An integrated load-based power saving scheme in IEEE 802.16e. In *Proceedings of the 2012 FTRA International Conference on Advanced IT , Engineering and Management (FTRA AIM 2012)*, Seoul, Korea, Feb 6–8, 2012; 71–72.
29. Mai YT, Yang CC, Lin YH. Design of the cross-layer QoS framework for the IEEE 802.16 PMP networks. *IEICE Transactions on Communications* 2008; **E91-B**(5): 1360–1369.
30. Yang CC, Mai YT, Tsai LC. Design of the QoS framework for the IEEE 802.16 mesh networks. *International Journal of Communication Systems* 2009; **22**(12): 1543–1562.
31. Iseda K, Tsuruoka T, Kato T. Power consumption control technology in WiMAX MAC layer. *Fujitsu Scientific & Technical Journal* 2008; **44**(3): 256–263.
32. Ketonen J, Juntti M, Cavallaro JR. Receiver implementation for MIMO-OFDM with AMC and precoding. In *Proceedings of the 2009 Conference Record of the Forty-Third Asilomar Conference on Signals, Systems and Computers*, California, USA, Nov. 2009; 1268–1272.
33. Shabrawy TOE, Wahed SHA. Adaptive power saving receiver for DVB-H exploiting adaptive modulation and coding. *International Journal of Communications, Network and System Sciences* 2010; **3**(2): 152–166.

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