Integrated Load-Based Power Saving for BS and MSS in the IEEE 802.16e Network

Chun-Chuan Yang, Yi-Ting Mai, Jeng-Yueng Chen, and Yu-Chen Kuo

***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. LBPS measures traffic load and adaptively generates proper sleep schedule for the current load. Three LBPS schemes has been proposed for MSS (Mobile Subscriber Station) power saving. In this paper, BS power saving is taken into consideration, and our previously proposed LBPS schemes are revised in order to integrate both BS (Base Station) and MSS in sleep scheduling. Two strategies of integrated power saving, MSS-first and BS-first, are proposed in the paper. Simulation study shows that the proposed schemes can effectively achieve high power saving efficiency for both BS and MSS.**

***Index Terms*— Power saving, IEEE 802.16e, LBPS.**

I. Introduction

There are three standard *power saving classes* (*PSC*), *Type I*, *II*, and *III*, in the specification of IEEE 802.16e [1], [2]. In a nutshell, Type I, with its exponentially increased sleep window, is suitable for traffic of *non-real-time variable rate* (NRT-VR) 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* (*RT-VR*) service and *unsolicited grant service* (*UGS*). Many researchers in power saving have been focusing on modeling or performance improvement based on Type I or II [3]-[9].

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 of 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. In order 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 work [10]-[12]. LBPS models and measures traffic proactively, and the sleep schedule is then determined by traffic load obtained. Three LBPS schemes for *Mobile Subscriber Station* (MSS) sleep scheduling were proposed: *LBPS-Aggr* [10], *LBPS-Split* [11], and *LBPS-Merge* [12]. A power saving scheme integrating real-time traffic and non-real-time traffic was also proposed [13]. In this paper, power saving at the *Base Station* (*BS*) is considered, and previously proposed LBPS schemes are revised for accommodating both MSS and BS sleep schedule for more power saving in the IEEE 802.16e network. Results of performance evaluation demonstrate the benefit of integrating BS power saving in LBPS.

The rest of the paper is organized as follows. Our previous work about LBPS is briefly explained in section 2 for better understanding the proposed work in this paper. Schemes of BS-integrated LBPS are presented in section 3. Performance evaluation is presented in section 4. Section 5 concludes this paper.

II. Previous Work

A. Basic idea of LBPS and LBPS-Aggr

The objective of LBPS is to adaptively adjust sleep window size of each MSS to better fit in current traffic load by traffic measurement. 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 *TCP Round-Trip Time* (*RTT*) estimation. For presentation purpose, only downlink traffic is considered in this paper, although uplink traffic can also be integrated into LBPS schemes via some information exchange mechanism between BS and MSS. 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 achieves a proper level of powering saving. 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. In *LBPS-Aggr*, the traffic arrival process is assumed to be Poisson, and data accumulation under load   in a time frame is calculated by the following equation:

Prob [*i* 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:

$P_{Acc}(K, Data\_TH) \equiv Prob$ [# of packet arrivals in K time frames > *Data_TH*]

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

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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 ≡ *LengthAwkSlpCyl* (λ, Data_*TH*) ≡ 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.

B. 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 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 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 least load. In such 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. Since the load of each MSS varies, each group usually has a different value of K^*. In order 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.

Since it's 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.

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

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 as possible, which means the value of $K^\#$ after group merging should be kept as larger as possible. Therefore, the merging process in LBPS-Merge is divided into two phases: (1) *non-degraded merge* and (2) *degraded merge*. Merging of two groups that does not result in a smaller value of $K^\#$ is called a non-degraded merge. A degraded merge is accepted only when a non-degraded merge cannot be found. Simulation study has shown that LBPS-Split and LBPS-Merge outperform LBPS-Aggr and Type I (even Type II) based mechanisms in power saving.

III. Integrated Power Saving for BS and MSS

There are two different strategies for integration of BS power saving in LBPS. The first strategy namely *S1* is to allow BS entering the sleep mode when all MSSs are in the sleep mode. S1 does not require any modification of the LBPS schemes, but the power saving efficiency at BS is limited by the load and sleep schedule of MSS. The other strategy considers about 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 power saving. It's worth mentioning that due to the passive characteristic in power saving, standard PSC Type I or Type II cannot be extended to support BS power saving.

A. Strategy 1 (S1)

Sleep schedule for each MSS is first determined in S1. The time frames in which all MSSs in the sleep mode is scheduled as the sleep time frames for BS. LBPS-Aggr presents the simplest case among LBPS schemes for BS power saving since all MSSs are treated as a single group. 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 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. 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. 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. For the case of *Schedulability* = 1, there is no room for BS power saving.

B. Strategy 2 (S2)

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. Since 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 in order to meet BS's PSE_*TH*. Since 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 (1) final K^* (denoted by K_{final}) > K_{BS} , or (2) $K_{final} \le K_{BS}$, but K_{final} *-1* time frames which are for MSS sleep scheduling are not enough to accommodate all groups. An example for the case of meeting BS's PSE_TH in LBPS-Split under S2 is given in Fig. 1.

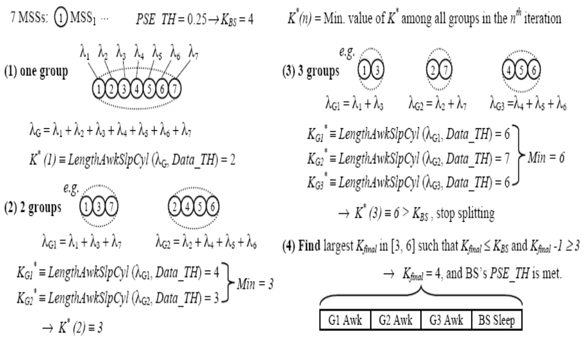

Fig. 1. An example of LBPS-split under S2.

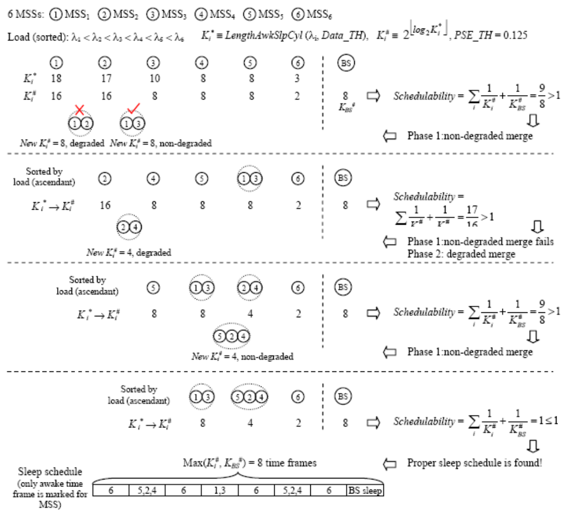

Fig. 2. An example of LBPS-merge under S2.

In LBPS-Merge, each MSS can have its own length ($K^{\#}$) of the *awake-and-sleep cycle* if possible. The idea of different $K^{\#}$ value for different MSS can be further extended to support BS power saving. Given $K_{BS}{}^{\#} = 2^{\lfloor \log_2 K_{BS} \rfloor}$ and $K_{BS} = \lfloor PSE\_TH^{-1} \rfloor$, it implies one out of $K_{BS}{}^{\#}$ time frames should be assigned as BS's sleep time frame in order to meet *PSE_TH*. Therefore, the revised algorithm of LBPS-Merge under S2 treats BS as a special MSS with its own $K_{BS}{}^{\#}$ value in sleep scheduling. 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. Oppositely, the value of $K_{BS}{}^{\#}$ means one *sleep* time frame out of $K_{BS}{}^{\#}$ time frames for BS.
2) Since no MSS should be in the awake mode when BS is in the sleep mode, BS cannot be merged with MSS.

The equation of *Schedulability* is revised to include BS's power saving as follows:

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

An example of LBPS-Merge under S2 is given in Fig. 2.

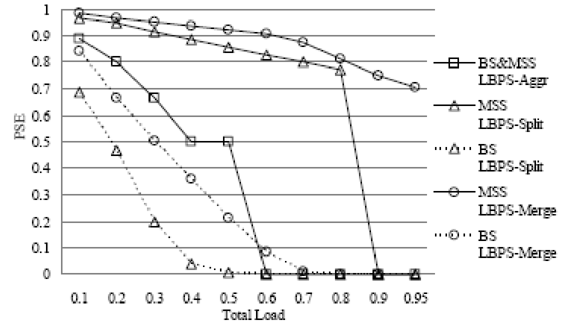

Fig. 3. Power saving efficiency under S1.

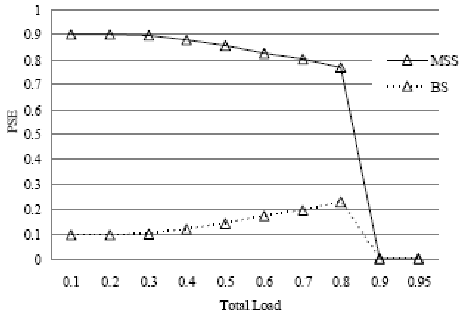

Fig. 4. PSE of LBPS-Split with PSE_TH =0.1

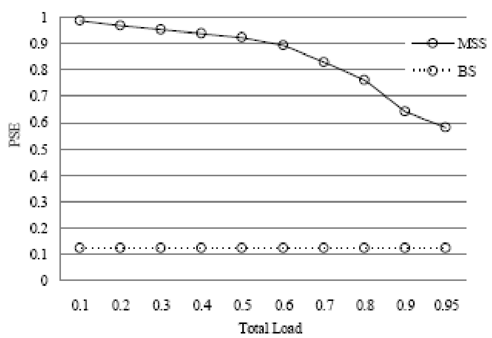

Fig. 5. PSE of LBPS-merge with PSE_TH =0.125

IV. Performance Evaluation

Extensive simulation study has been conducted for performance evaluation of proposed schemes. Due to the limit of paper length, only a few of figures are presented in the paper. Power Saving Efficiency (PSE) for LBPS schemes under S1 is displayed in Fig. 3, which shows (1) if only BS's PSE is considered, LBPS-Aggr is better than the others, and (2) LBPS-Merge outperforms the others if both BS's PSE and MSS's PSE are taken into consideration.

Fig. 4 displays PSE of LBPS-Split with *PSE_TH* = 0.1 (S2). Fig. 5 displays PSE of LBPS-Merge with *PSE_TH* = 0.125 (S2). Fig. 4 and Fig. 5 demonstrate that both revised LBPS-Split and LBPS-Merge can effectively support BS power saving while maintaining high power saving efficiency for MSS. LBPS-Merge outperforms LBPS-Split in both BS and MSS power saving under very heavy load (above 0.9), due to the flexibility of LBPS-Merge allowing different cycle length in sleep scheduling.

V. Conclusion

Most of the research works in power saving of wireless networks focused on the user side. In this paper, power saving at BS is considered along with MSS power saving. In our previous work, the idea of Load-Based Power Saving (LBPS) and three related schemes were proposed for MSS-only power saving in IEEE 802.16e. The previously proposed LBPS schemes are revised in order to integrate both BS and MSS in sleep scheduling. Two strategies of integration of BS and MSS power saving, MSS-first and BS-first, are proposed in the paper. Simulation study shows the benefit of the proposed schemes in power saving for both BS and MSS. Future work of the research is to extend the idea of LBPS in the environment of IEEE 802.16j Multi-hop Relay Network. It's 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 multi-hop wireless networks.

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