Proceedings of the International MultiConference of Engineers and Computer Scientists 2013 Vol II,
IMECS 2013, March 13 - 15, 2013, Hong Kong

Integrated Sleep Scheduling in IEEE 802.16j Multi-Hop Relay Networks

Chun-Chuan Yang, *Yi-Ting Mai, Jeng-Yueng Chen, and Chung-Che Yu

Abstract—**In this paper, our previous work of Load-Based Power Saving (LBPS) for energy saving at the user side is extended to support integrated sleep scheduling for BS, RS, and MSS in the IEEE 802.16j Multi-Hop Relay Network. Topology-dependent time frame structure is adopted in our design to reduce the transmission delay in the relay network, and two LBPS schemes, namely LBPS-Aggr-MR and LBPS-Merge-MR, are proposed. Simulation study shows the proposed LBPS schemes significantly outperform the standard Type I PSC in terms of power saving efficiency.**

Index Terms—**Power Saving, IEEE 802.16j, Relay Network, LBPS**

I. Introduction

Due to the increasing energy prices and for slowing down global warming, energy consumption in development of any information and communications technology is becoming a major concern. Issues about green mobile network [1-2] has obtained more and more attention in the literature. A large part of the related research in energy-efficient design focused on the user side in order to prolong the operational time of the battery-powered devices. Some research papers focused on energy saving at the network side. The idea of power saving access points (PSAP) of IEEE 802.11 was proposed in [3-4] for the application of multi-hop relaying. The authors proposed a new framing structure incorporating sleep subframe that is backward compatible for legacy IEEE 802.11 The proposed PSAP includes network allocation maps in its beacon broadcasts to specify its temporal operation, and thus to coordinate traffic delivery and power saving at both end stations and at the PSAP.

Energy saving in cellular access networks such as UMTS was addressed in [5], 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 the service is available over the whole area. In [6], a generic framework for applying sleep mode to 2G mobile networks such as GSM and HSPA (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.

In our previous work, we focused on IEEE 802.16e and proposed Load-Based Power Saving (LBPS) schemes for MSS (Mobile Subscriber Station) sleep scheduling [7]. LBPS Extension to integrate BS (Base Station) and MSS sleep scheduling was also proposed [8]. In this paper, the idea of LBPS is further extended to cover *IEEE 802.16j Multi-Hop Relay Network* [9-10], in which BS, RS (Relay Station), and MSS are all included in sleep scheduling. Simulation study shows that the proposed schemes can achieve high power saving efficiency for all of BS, RS, and MSS. The remainder of the paper is organized as follows. First of all, our previous work of LBPS is briefly surveyed in section II. Proposed schemes for integrated power saving in IEEE 802.16j Multi-Hop Relay Network are presented in section III. Performance evaluation is presented in section IV. Finally, section V concludes this paper.

II. Previous Work

The objective of LBPS is to adaptively adjust sleep window size of each MSS to better fit in current traffic load via traffic modeling and 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. 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 scheme of LBPS is called *LBPS-Aggr*, in which all the traffic in the network is treated as an aggregate flow in calculating the length of the next awake-and-sleep cycle, denoted by K^* in the paper. The size of the sleep window in a cycle is therefore K^**-1*.

Given the threshold of data accumulation, the best case for an MSS in terms of power saving is to make the MSS a single-member group resulting in the largest value of K^* (the longest possible awake-and-sleep cycle). Therefore, instead of treating all MSSs as one group as in *LBPS-Aggr*, we could firstly make each MSS a single-member group for K^* calculation. Since the load

Manuscript received Dec. 28, 2012; revised Dec. 28, 2012.

This work was supported in part by the National Science Council, Taiwan, under grant no. NSC 101-2221-E-260-025.

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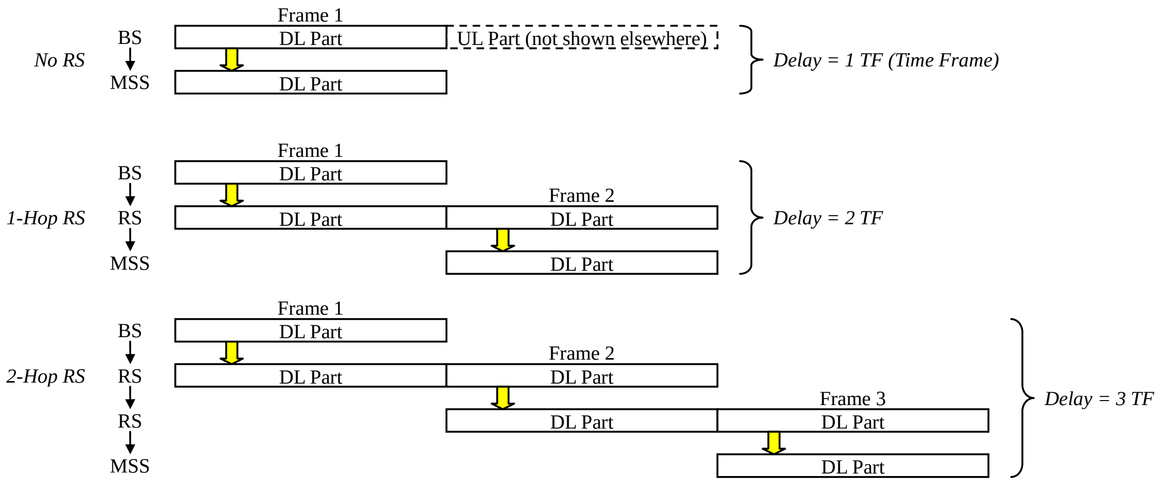


Fig. 1. Impact of frame configuration on transmission delay

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. This 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. The worst case in *LBPS-Merge* is all MSSs be merged as one group (same result as in *LBPS-Aggr*) and $K^\# = 1$ (no sleep window).

III. Integrated Power Saving In IEEE 802.16J Multi-Hop Relay Network

A. Basic idea

Following assumptions are made in our design for integrated sleep scheduling in IEEE 802.16j Multi-Hop Relay Network:

(1) BS is in charge of scheduling for all devices including RS and MSS in the relay network. That is, BS-controlled centralized scheduling is adopted in our proposals.

(2) Non-real-time downlink traffic is the focus of this paper. The case of combined uplink and downlink traffic is left as the future work. Moreover, due to the ease of handling traffic model for multiplexed traffic, the downlink traffic for each MSS is assumed to be *Poisson*.

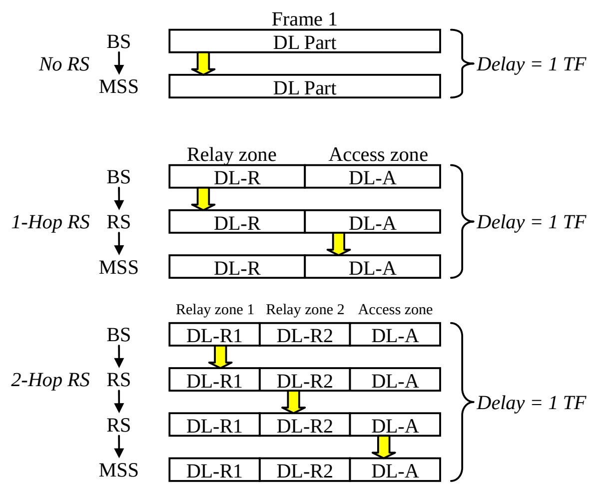


Fig. 2. Topology-dependent frame configuration

(3) TDD (Time Division Duplex) mode is adopted in the framing structure which consists of the Downlink part (DL) and the Uplink (DL) part.

The conventional TDD frame structure, i.e. one DL subframe and one UL subframe, imposes a performance problem when the configuration applied in the relay network. As shown in Fig. 1, the increase of the hop count from BS to MSS makes the transmission delay longer. Therefore, in order to alleviate the impact of multi-hop transmission on delay performance, *topology-dependent frame configuration* is adopted in the proposed schemes. In a relay network, a link connecting network nodes (BS and RS) is called a *relay link*. A link connecting a network node with a user node (MSS) is called an *access link*. As displayed in Fig. 2, two different transmission zones, namely *relay zone* and *access zone*, are used to separate transmissions on the relay link and transmissions on the access link in the topology-dependent frame structure. The relay zone is further divided into a number of sub-zones according to

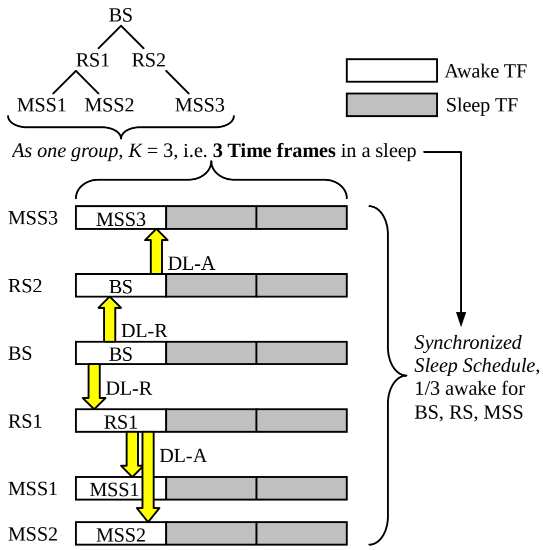


Fig. 3. Example of LBPS-Aggr-MR

the number of RS from BS to MSS. As we can see from Fig. 2, better delay performance can be achieved at the expense of lower multiplexing gain due to shorter zones. In this paper, we assume relay sub-zones and the access zone are equal size.

B. LBPS-Aggr-MR

As in our previous work, the simplest form for integrated sleep scheduling in the relay network is to make BS, all RSs, and all MSSs as one group in the sleep schedule. The scheme is called *LBPS-Aggr-MR* (**LBPS Aggr**egate version for the **M**ulti-Hop **R**elay network) in the paper. The cycle length of the sleep schedule in LBPS-Aggr-MR is determined by the total downlink load for MSS and the accumulation threshold. Given λ_i as the estimated load for MSS_i, the total load $\lambda_s = \Sigma\lambda_i$, and the accumulation threshold *Data_TH* as the size of access zone (i.e. all MSSi share the access zone in the awake time frame), the cycle length (# of time frames) is calculated as follows:

The length of one awake-and-sleep cycle ≡

$$LenAwkSlpCyl\ (\lambda_s, Data\_TH) \equiv K^*$$

$$= Min\{K \mid P_{Acc}(K, Data\_TH) \geq Prob\_TH\},$$

where an *awake-and-sleep cycle* is composed of the current awake time frame and the following sleep time frames, and $P_{Acc}(K, Data\_TH)$ is defined as the probability of data accumulation exceeding *Data_TH* packets over *K* time frames in a row. *Prob_TH* is the pre-defined probability threshold (e.g. 0.8).

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

Prob [# of packet arrivals in *K* time frames > *Data_TH*]

$$= \sum_{n=Data\_TH+1}^{\infty} \frac{e^{-\lambda_s KT}(\lambda_s KT)^n}{n!}, \text{ } T \text{ is the size of a time frame}$$

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

An example of LBPS-Aggr-MR is shown in Fig. 3. Note that the transmission from BS to RS1 and the transmission from BS to RS2 are in the same time frame (in the zone of DL-R) but using different slots. The same situation applies to the case from RS2 to MSS1 and MSS2.

C. LBPS-Merge-MR

The extension of our previous work LBPS-Merge in the relay network is called *LBPS-Merge-MR*, in which each MSS could have its own cycle in sleep scheduling. In the beginning, BS calculates the value of $K^\#$ (in powers of 2) for each MSS according to MSS's load and *DATA_TH* set as the size of the access zone. Schedulability for the current set of $K^\#$ is then checked to see if a feasible schedule can be found by using the same equation in LBPS-Merge. If the schedulability test fails, some MSSs have to be merged as one group. The merging process in LBPS-Merge-MR is somewhat different from that of LBPS-Merge since MSSs could be under different RSs. Following rules are applied in the merging process in LBPS-Merge-MR:

(1) Merging the MSSs under a same RS has priority over merging MSSs under different RSs.

(2) Merging should not reduce as much power saving efficiency as possible, which means the value of $K^\#$ after merging should be kept as large as possible.

Once the sleep schedule for all MSSs is determined, the sleep schedule for a network node (RS or BS) can be determined by combining the schedules of the MSSs under the node. More specifically, the awake time frames for a network node is the union of the awake time frames of the MSSs under the node. An example of LBPS-Merge-MR is given in Fig. 4. Another example illustrating the assignments in the sleep schedule is displayed in Fig. 5.

IV. Performance Evaluation

Simulation study was conducted to evaluate the performance of the proposed schemes. Simulation parameters are listed in TABLE I. Two topologies of the relay network were simulated as shown in Fig. 6.

TABLE I
Simulation Parameters

(# BS, # RS, # MSS)	(1, 6, 12)
Topology Type	*Topo-1*: All 1-hop RS *Topo-2*: All 2-hop RS
# DL Slot in a frame	72 slots
Time Frame Structure (DL part)	*Topo-1*: 36 slots for DL-A & DL-R *Topo-2*: 24 slots for DL-A, DL-R1, DL-R2
Packet size	1 slot
DATA_TH	Size of DL-A
Prob_TH	0.8
Simulation Time	10^5 sec

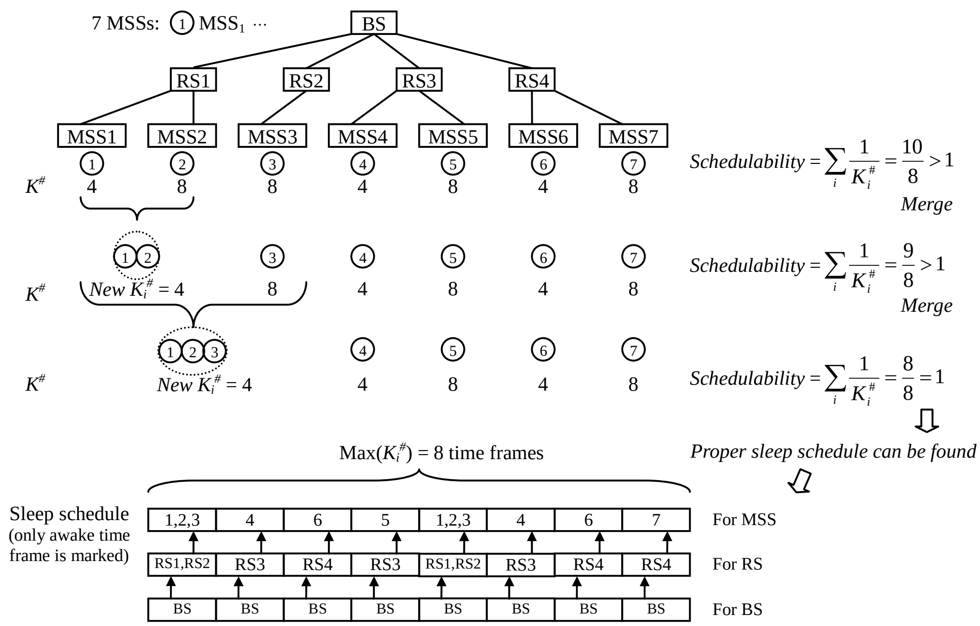


Fig. 4. Example of LBPS-Merge-MR

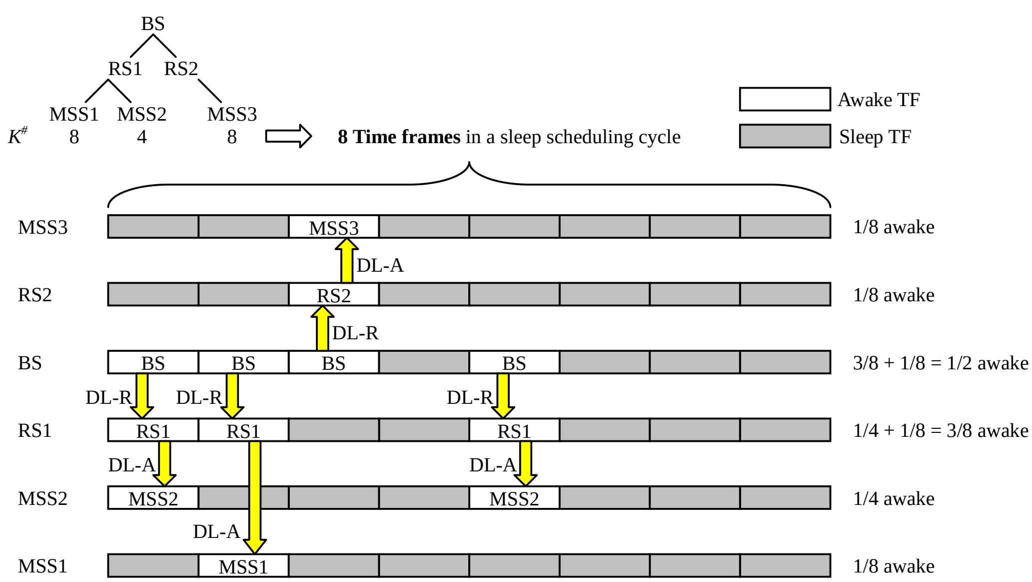


Fig. 5. E.g. LBPS-Merge-MR Sleep Scheduling

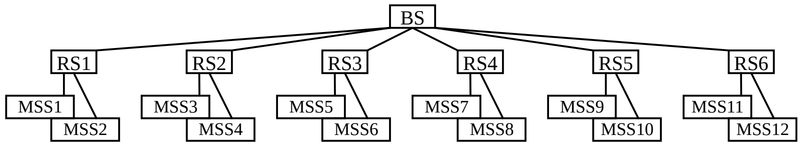
The performance criterion of *Power saving efficiency*, denoted by *PSE*, is defined as the ratio of time entering the sleep mode. For instance, for one awake time frame in a cycle of K time frames for a node (BS, RS, or MSS), the value of the device's *PSE* is calculated as $(K\text{-}1)/K$. The value of *PSE* for a node is computed by averaging all samples in the simulation.

PSE results for Topo-1 and Topo-2 are displayed in Fig. 7 and Fig. 8 respectively, in which in addition to PSE, the curve for the relationship between the internal load and the external load (the y-axis on the left side) is also displayed. Since PSE results for BS, RS, and MSS in LBPS-Aggr-MR are the same, there is only one curve for LBPS-Aggr-MR in each of the figures. PSE results for the network node (BS, RS) and the user device (MSS) in LBPS-Merge-MR are displayed separately by two curves in the figures. Serving as the contrast, PSE results for standard Type I PSC (Power Saving Class) applied in the same relay network are also displayed in the figures. Following observations can be made from the figures:

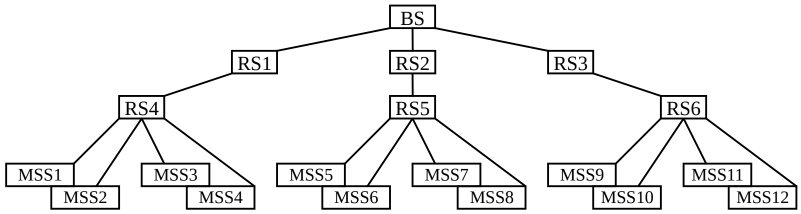
(1) PSE of LBPS-Aggr-MR and LBPS-Merge-MR are significantly better than PSE of Type I, demonstrating the advantage of LBPS schemes. Moreover, PSE of LBPS-Merge-MR is better than PSE of LBPS-Aggr-MR, because of the flexibility of allowing different sleep cycles in LBPS-Merge-MR.

(2) In LBPS-Merge-MR, MSS PSE is better than RS/BS PSE, since the awake time frames of a network node are the union of the awake time

ISBN: 978-988-19252-6-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)



(a) Topo-1



(b) Topo-2

Fig. 6. Two topologies for simulation

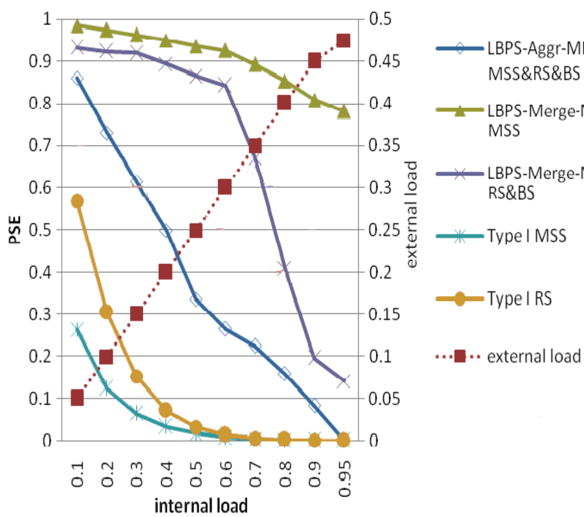


Fig. 7. PSE for Topo-1

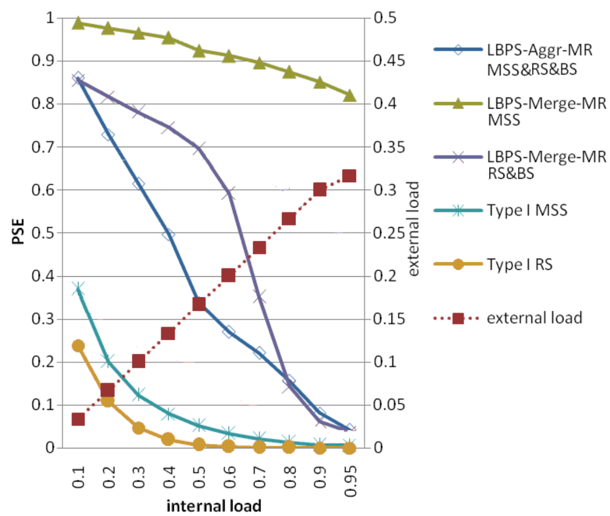


Fig. 8. PSE for Topo-2

frames of all MSSs under the node. It makes the network node have fewer sleep time frames than MSS in a cycle.

(3) Topo-1 and Topo-2 share almost the same PSE result for LBPS-Aggr-MR, due to the synchronized sleep scheduling for BS/RS/MSS. On the other hand, RS/BS PSE of Topo-1 is better than RS/BS PSE of Topo-2 for LBPS-Merge-MR. The reason is an MSS in Topo-2 affects the sleep schedule of its parent RS and grandparent RS (i.e. two RSs), while an MSS in Topo-1 only affects its parent RS.

(4) The curve of the external load in Fig. 8 is with a lower slope than the external load in Fig. 7, showing that Topo-2 generates more internal load than Topo-1 under the same external load. The reason is the longer transmission path from BS to MSS in Topo-2. Therefore, the depth of a relay network in deployment should be limited in order not to sacrifice too much of the achievable throughput.

V. CONCLUSION

Issues about green mobile network have obtained more and more attention in recent years, but a large part of the related work in power saving in the literature focused on the user side. In this paper, our previous work of Load-Based Power Saving (LBPS) is extended to support integrated sleep scheduling for BS, RS, and MSS in the IEEE 802.16j Multi-Hop Relay Network. For reduction of the transmission delay in the relay network, the idea of topology-dependent time frame structure is adopted, in which separated transmission zones are designated for the access link and the relay link. In addition, the relay zone consists of a number of sub-zones according to the hop count of RS on the path from BS to MSS. Two sleep scheduling schemes are proposed: LBPS-Aggr-MR and LBPS-Merge-MR. LBPS-Aggr-MR synchronizes the sleep schedule for BS, RS, and MSS, while different sleep cycles are allowed for different nodes in LBPS-Merge-MR. Simulation study shows that the proposed LBPS schemes outperform the standard Type I PSC in terms of power saving efficiency (PSE) in the relay network, and PSE of LBPS-Merge-MR is even better than LBPS-Aggr-MR.

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ISBN: 978-988-19252-6-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)