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Load-Based Power Saving in IEEE 802.16j Multi-Hop Relay Networks

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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, in which the number of relay zone (for transmission over the relay link) depends on the hop count of RS in the network. Focused on non-real-time traffic, 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.

Keywords Power Saving · IEEE 802.16j · Relay Network · LBPS

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1 Introduction and Related Work

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 High Speed Packet Access (HSPA) 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 Mobile Subscriber Station (MSS) sleep scheduling [7]. LBPS Extension to integrate Base Station (BS) 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, Relay Station (RS), and MSS are all included in sleep scheduling. In the following, we make a survey of the research work for IEEE 802.16j as well as power saving for the mesh networks.

Most of the related work for IEEE 802.16j Multi-Hop Relay Network focused on throughput improvement. To enhance the capacity of access links in centralized wireless relay networks, Lu and Liao [11] proposed an algorithm to organize multiple relay stations to form a virtual antenna array which cooperatively serving a mobile station. In [12], the authors considered fixed relay in two-hop WiMAX networks and proposed a cooperative relay selection algorithm based on signal intensity parameters of Carrier to Interference and Noise Ratio (CINR) on relay links and SINR on access links. By taking into account both instantaneous channel conditions and queuing status to define cross-layer relay selection metrics, Ding et al [13] proposed joint scheduling and relay selection algorithms for both one-way and two-way networks. Authors of [14] proposed a scheduling algorithm to upgrade the PMP-relay in IEEE 802.16j to logical mesh topology using adaptive RS grouping, in which new signaling to support horizontal-RS neighbor scanning, bandwidth request, PDU forwarding and connection management, were also proposed. In [15], the authors focused on the problem of fixed length frame resources between the access zone and the relay zone, and proposed two novel frame structures to offer better performance than the IEEE 802.16j frame structure in terms of throughput and latency.

Related work about power saving for relay networks mainly focused on wireless mesh networks. In [16], the authors proposed the idea of cooperative transmission by Subscriber Station (SS) pairing in WiMax mesh mode to reduce the average transmitting power, since after pairing only a half of SSs in a mesh network need to transmit data packets to the BS. The proposed SS pairing was based on the calculation of the energy cost between each possible pair of SSs, and the minimum weight matching algorithm was then performed to choose the optimal set of SS pairs. Authors of [17] and [18] proposed power saving cooperative routing by taking power consumption into consideration in finding transmission path in wireless sensor mesh networks. Their idea was to translate the transmission power advantage into distance, and the number of hops of a path can be reduced by increasing the transmission distance, which also reduces the power consumption for transmission from the source to the destination. Chen et al [19] proposed an energy-aware cross-layer solution for multimedia delivery over wireless mesh networks, which includes an MAC layer scheme for mesh device (routers) sleep period management and an extension of the Optimized Link State Routing algorithm (OLSR). In [20], the authors proposed a cross-layer energy-adaptive scheduling and queue management framework for minimizing energy consumption in IEEE 802.11s mesh networks. The proposed scheduler aimed at choosing the most energy efficient modulation and coding scheme under the constraint of packet delay. Proposed queue management adopted the idea of randomized early packet dropping for saving energy and avoiding congestion. Authors of [21] addressed the problem of resource provisioning in solar-powered wireless mesh networks and proposed a genetic algorithm for assigning battery and solar panel sizes for each network node so that outage-free operation is obtained.

It's found that the focus of this paper, power saving for IEEE 802.16j Multi-Hop Relay Network, has not been addressed in the literature. Based on our previous work, two integrated sleep scheduling schemes covering not only the user nodes (MSSs) but also the network nodes (BS and RS) are proposed in this paper. Simulation study shows that the proposed schemes can achieve high power saving efficiency for all of BS, RS, and MSS.

It's worth mentioning that the newest version in the IEEE 802.16 family [22], IEEE 802.16m [23] also known as *Mobile WiMAX Release 2*, was proposed to support advanced air interface with data rates of 100 Mbps mobile and 1 Gbps fixed, and has become one of the 4G candidate systems [24]. Standardization of power saving is not revised in IEEE 802.16m comparing with the previous version of IEEE 802.16d which is earlier than IEEE 802.16j, therefore the proposed power saving schemes in this paper can be applied in the environment of IEEE 802.16m. Another 4G candidate system, *Long Term Evolution (LTE, Release 10 and beyond*) [25] adopts the idea of *Discontinuous Reception mode* (DRX) [26] to conserve the power of the mobile terminal namely the *User Equipment* (*UE*). The UE powers down most of its circuitry in DRX when there are no packets to be transmitted or received, which is similar to the basic concept of power saving in IEEE 802.16. However, due to the difference of LTE from IEEE 802.16, including the frame structure for resource allocation and scheduling, downlink and uplink channel structure, *CQI*-based (*Channel Quality Indicator*) signaling for the selection of the modulation and coding scheme, etc., revision of the power saving mechanism designed for IEEE 802.16 is required in order to properly fit in LTE, which is left as the future work of the paper.

The remainder of the paper is organized as follows. First of all, our previous work of LBPS is briefly surveyed in Sect. 2. Proposed schemes for integrated power saving in IEEE 802.16j Multi-Hop Relay Network are presented in Sect. 3. Performance evaluation is presented in Sect. 4. Finally, Sect. 5 concludes this paper.

2 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

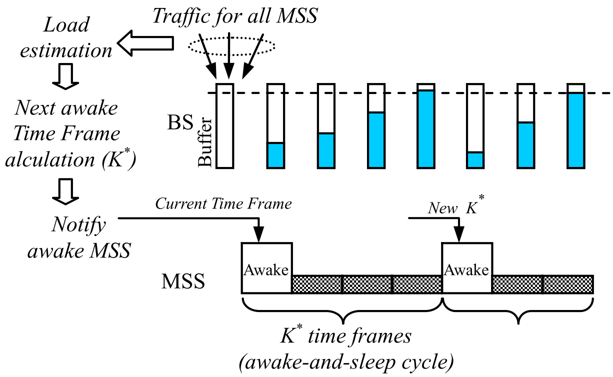

Fig. 1 LBPS-Aggr protocol

current load (denoted by packets per time frame) for each MSS 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 $K^* - 1$. An illustration of *LBPS-Aggr* is displayed in Fig. 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 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 an 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). An example of the *LBPS-Merge* protocol for illustration purpose is displayed in Fig. 2.

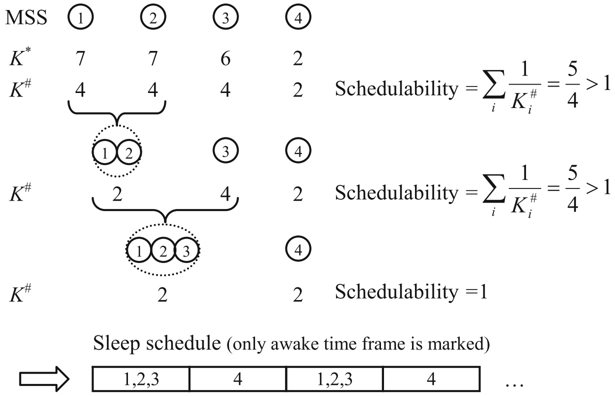

Fig. 2 Example of LBPS-Merge

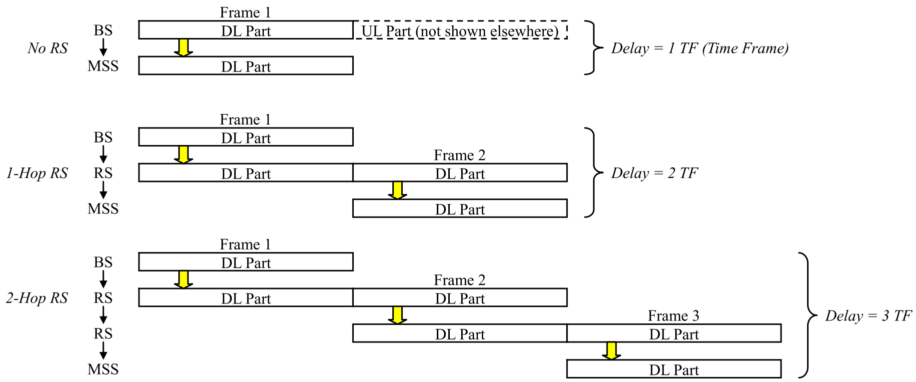

Fig. 3 Impact of frame configuration on transmission delay

3 Integrated Power Saving In IEEE 802.16j Multi-Hop Relay Network

3.1 Basic Idea

Following assumptions are made in our design for integrated sleep scheduling in the 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*.
(3) Time Division Duplex (TDD) 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 in a time frame, imposes a performance problem when the configuration applied in the relay network. As shown in Fig. 3, 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

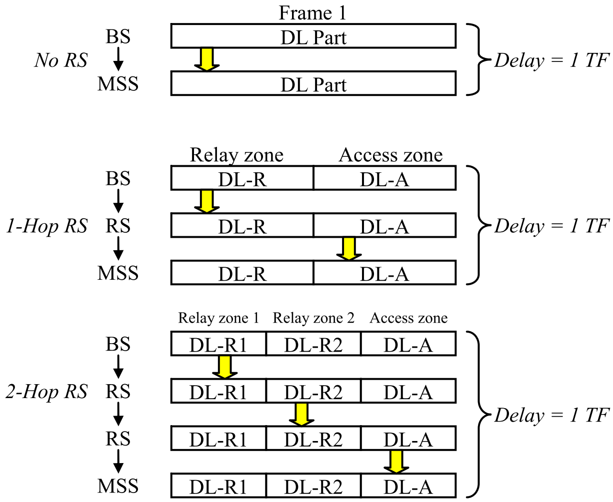

Fig. 4 Topology-dependent frame configuration

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. 4, 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 the number of RS from BS to MSS. As we can see from Fig. 4, 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. For a relay network with the same hop count of RS for all MSSs, the number of relay zone in our proposed *topology-dependent frame configuration* is same as the number of hop count of RS in the network as shown in Fig. 4. For a relay network with different hop counts of RS, the number of relay zone depends on the protocol design as well as the number of hop count of RS, which will be explained in the our proposed protocols in the following sections.

3.2 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 $Data\_TH$ set as the size of access zone (i.e. all MSS_i share the access zone in the awake time frame), the cycle length (# of time frames) is calculated as follows:

$$\begin{aligned}\text{The length of one awake-and-sleep cycle} &\equiv LenAwkSlpCyl(\lambda_s, Data\_TH) \equiv K^*\\ &= Min\{K|P_{Acc}(K, Data\_TH) \geq Prob\_TH\},\end{aligned}$$

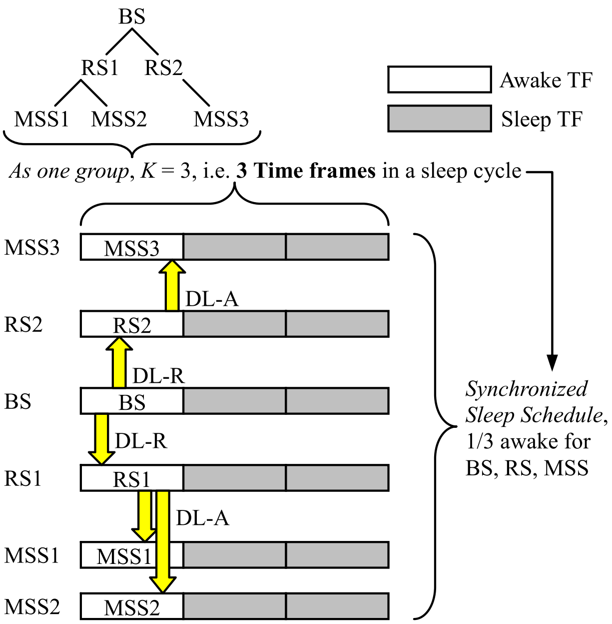

Fig. 5 Example of LBPS-Aggr-MR

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. *Data_TH* is the size of the access zone. *Prob_TH* is the pre-defined probability threshold (e.g. 0.8).

$$
\begin{aligned}
&P_{Acc}(K, Data\_TH) \equiv Prob[\text{\#of packet arrivals in} K \text{time frames} > Data\_TH] \\
&= \sum_{n=Data\_TH+1}^{\infty} \frac{e^{-\lambda_s KT}(\lambda_s KT)^n}{n!}, T \text{ is the size of a time frame} \\
&= 1 - \sum_{n=0}^{Data\_TH} \frac{e^{-\lambda_s KT}(\lambda_s KT)^n}{n!}
\end{aligned}
$$

An example of LBPS-Aggr-MR is shown in Fig. 5. The estimated value of K in the figure is assumed to be 3, which means all nodes in the network as a whole awake one time frame out of a cycle of three time frames. The BS has to manage the transmission scheduling in the awake time frame for each MSS by the combination of transmission in the relay zone as well as the access zone. An example of the packet scheduling for the awake frame in Fig. 5 is displayed in Fig. 6, in which the downlink packets buffered at the BS for each MSS are displayed in different filling patterns.

Since all MSSs (and RS/BS) are grouped together in sleep scheduling in LBPS-Aggr-MR, the number of relay zone in LBPS-Aggr-MR frame configuration for a relay network with different hop count of RS could be any of the numbers of RS hop count in the network. However, as will be presented in the section of performance evaluation, it is suggested to select the largest number of RS hop count to achieve better power saving as well as delay performance for LBPS-Aggr-MR.

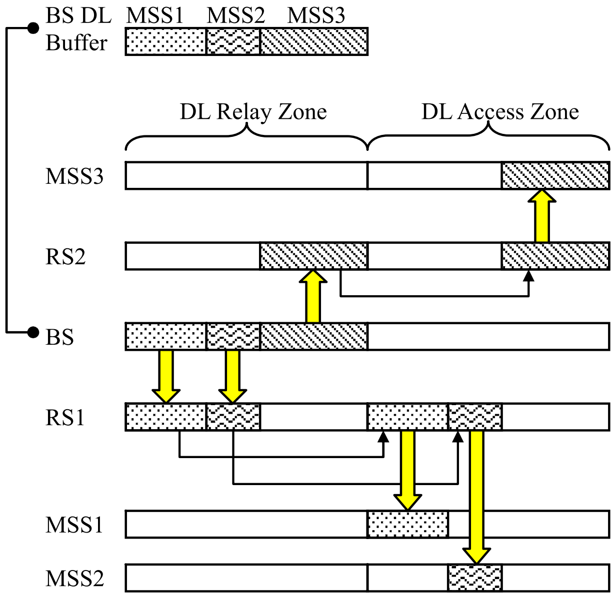

Fig. 6 Transmission scheduling for the awake time frame in Fig. 5

3.3 LBPS-Merge-MR

The extension of our previous work LBPS-Merge in the relay network is called *LBPS-Merge-MR*, in which instead of having all nodes in a group, 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 in sleep scheduling. The merging process in LBPS-Merge-MR is somewhat different from that of LBPS-Merge since MSSs could be under different RSs with different hop counts, and merging MSSs could result in grouping RSs in sleep scheduling. 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. The objective of this rule is to separate RSs in sleep scheduling as much as possible in order to make the best of the power saving efficiency for RSs.
(2) Merging of MSSs 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.
(3) Merging of MSSs under the same hop count of RS (i.e. Merging MSSs with the same path length) has priority over merging MSSs under different hop count of RS (i.e. Merging MSSs with different path lengths). This rule gives the benefit of allowing different number of relay zone in the time frame for each of MSS groups until two or more MSS groups with different hop counts of RS are merged. The selection of the number of relay zone for the merged MSS groups with different hop counts of RS is suggested to be the largest hop count of RS as in the case of LBPS-Aggr-MR.

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.

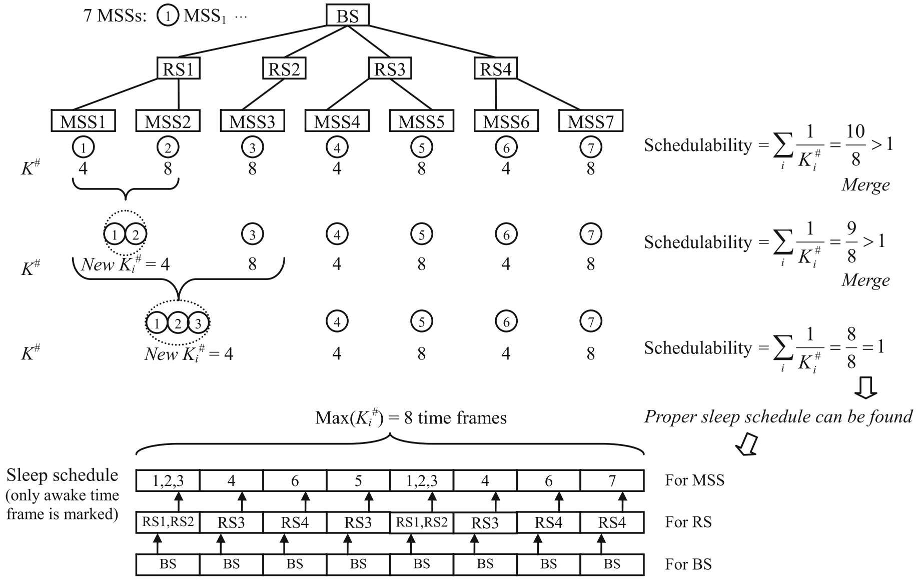

Fig. 7 Example of LBPS-Merge-MR

More specifically, the awake time frames for a network node are the union of the awake time frames of the MSSs under the node. An example of LBPS-Merge-MR is given in Fig. 7, in which there are 7 MSSs in the relay network with the topology of 1-hop RS. As shown in the figure, the test of *Schedulability* is applied after each merging operation until a proper sleep scheduling can be found ($Schedulability \leq 1$). The reciprocal of the final value of $K^{\#}$ for an MSS is actually the ratio of the sleep frame for the MSS. Adding up the reciprocal of $K^{\#}$ of all MSSs under an RS gives the ratio of the sleep frame for the RS. Therefore, the case of "$Schedulability = 1$" by the end of the LBPS-Merge-MR protocol implies no room for BS power saving as the case of Fig. 7 . Once the final value of $K^{\#}$ for each MSS is determined, the sleep scheduling as well as packet transmission scheduling in the awake time frame can be determined accordingly by the BS. Another example illustrating the assignments in the sleep schedule and packet transmissions in the awake time frame is displayed in Fig. 8.

4 Performance Evaluation

4.1 Simulation Environment

Simulation study was conducted to evaluate the performance of the proposed schemes. Simulation parameters are listed in Table 1. Three topologies of the relay network were simulated as shown in Fig. 9, in which the transmission path from the BS to the MSS is via 1-hop of RS in *Topo-1*, and 2-hop of RS in *Topo-2*. *Topo-3* is a hybrid of 1-hop RS and 2-hop RS. The total number of MSSs in each of the topologies is the same of 12 MSSs, each with the same load. As shown in Fig. 9, the same number of MSSs is assigned to each leaf node of RS in *Topo-1* and *Topo-2*. For *Topo-3*, five cases, Cases A $\sim$ E in Fig. 9c, each with different number of MSSs under 1-hop RS and 2-hop RS are simulated for deeper investigation of the performance.

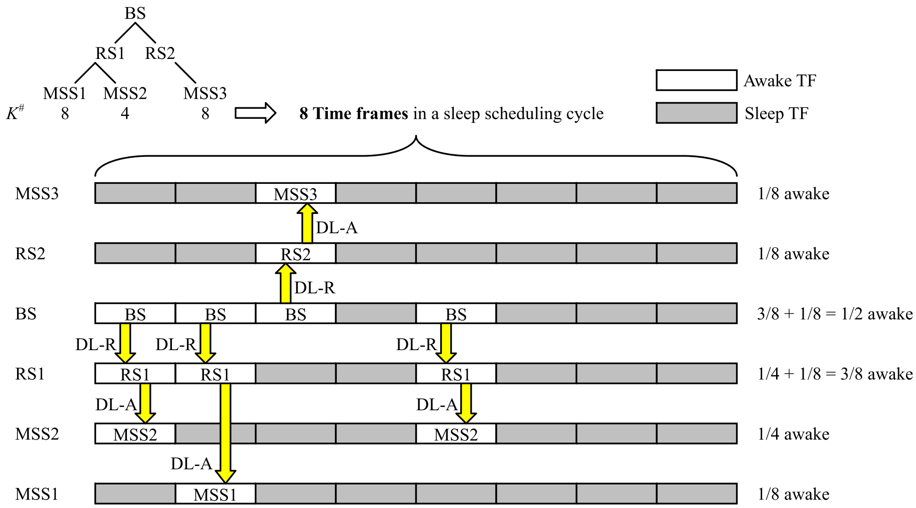

Fig. 8 E.g. LBPS-Merge-MR sleep scheduling

Table 1 Simulation parameters

(# BS, # RS, # MSS)	(1, 6, 12)
Topology type	*Topo-1*: 1-hop RS
	Topo-2: 2-hop RS
	Topo-3: 1-hop RS + 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
	Topo-3: 36 slots for 1 relay zone (1RZ)
	24 slots for 2 relay zones (2RZ)
Packet size	1 slot
DATA_TH	Size of DL-A
Prob_TH	0.8
Simulation Time	10^5 s

The total number of DL slots in a time frame is 72 slots. Since the relay zone is in equal size with the access zone, the number of DL slots for the relay zone and the access zone depends on the hop count of RS in the network. There is only one relay zone in *Topo-1*, so the relay zone and the access zone are each assigned with 36 slots. In *Topo-2*, the configuration of two relay zones results in 24 slots for the relay zone and the access zone respectively. In *Topo-3*, there are two options for the number of relay zone in the protocol of LBPS-Aggr-MR: 1 relay zone (*1RZ*) or 2 relay zones (*2RZ*).

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 $(K-1)/K$. The value of *PSE* for a node is computed by averaging all samples in the simulation.

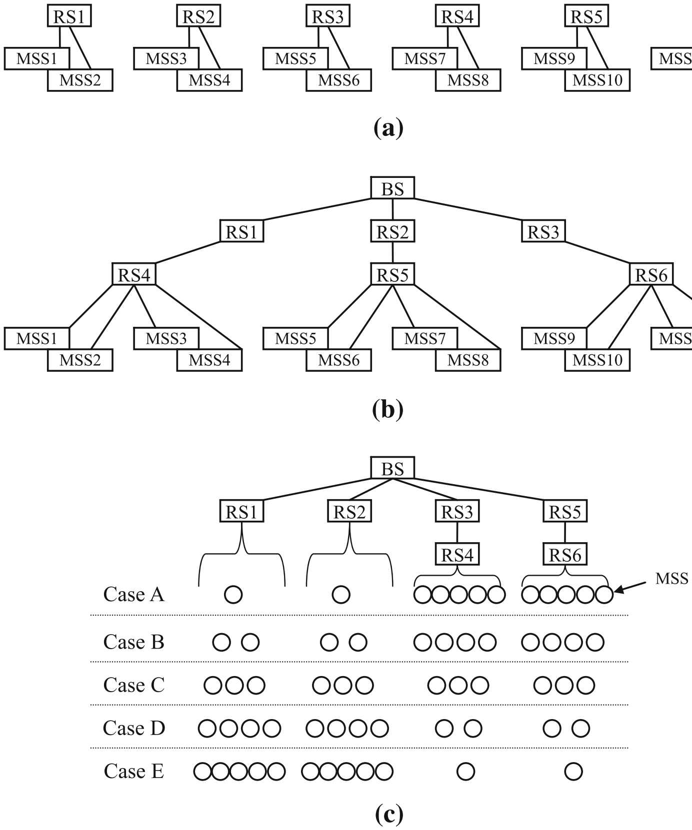

Fig. 9 Topologies for simulation. **a** *Topo-1* (1-hop RS) **b** *Topo-2* (2-hop RS) **c** *Topo-3* (Hybrid of 1-hop RS & 2-hop RS)

4.2 Results for Topo-1 and Topo-2

PSE results for *Topo-1* and *Topo-2* are displayed in Figs. 10 and 11 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. The external load is defined as the traffic load from Internet to the relay network, while the internal load is defined as the traffic load within the relay network. Due to the fact of multiple transmissions for a packet to arrive at the MSS, the internal load within a multi-hop relay network is usually larger than the external load.

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 Figs. 10 and 11. *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 Power Saving Class (PSC) applied in the same relay network are also displayed in the figures. Following observations can be made from Figs. 10 and 11:

(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

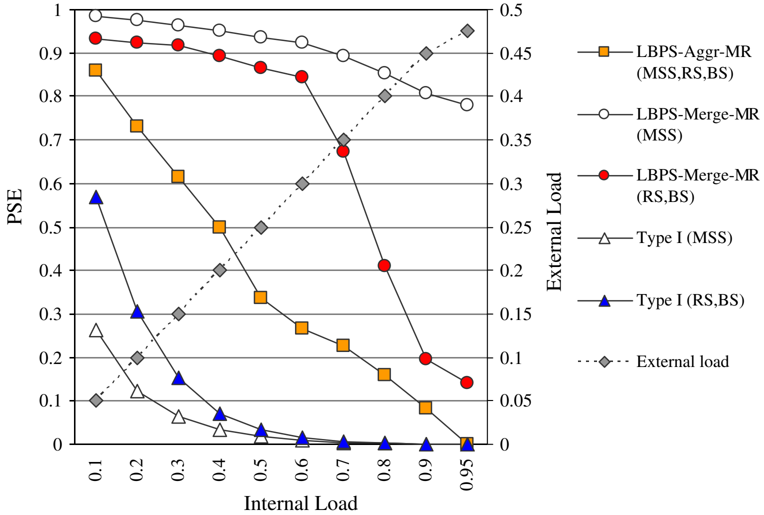

Fig. 10 *PSE* for *Topo-1*

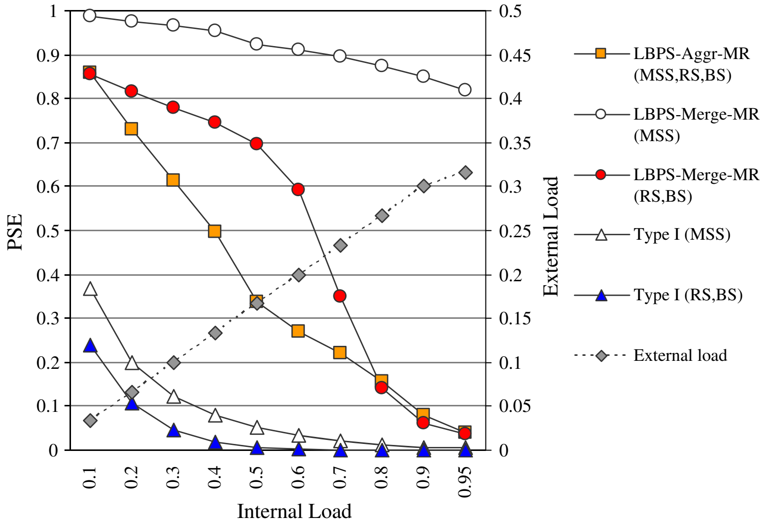

Fig. 11 *PSE* for *Topo-2*

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 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

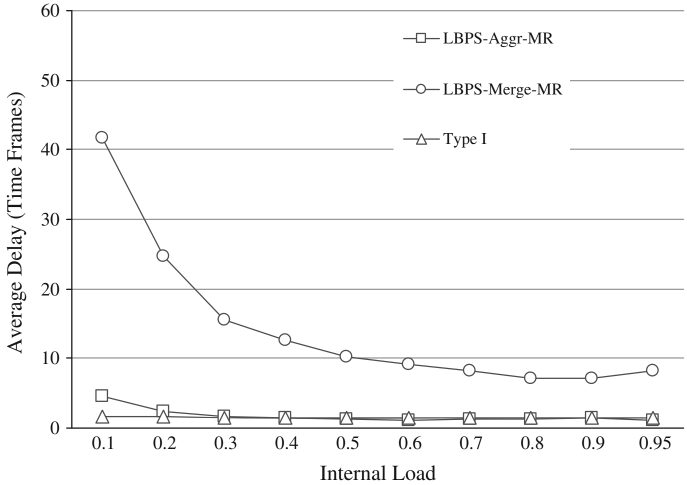

Fig. 12 *Average Delay* for *Topo-1*

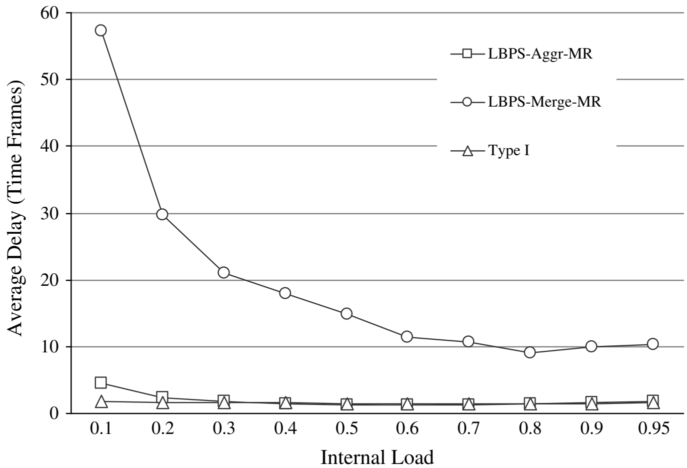

Fig. 13 *Average Delay* for *Topo-2*

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. 11 is with a lower slope than the external load in Fig. 10, 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.

The average delay for packet transmission from the BS to the MSS in *Topo-1* and *Topo-2* is displayed in Figs. 12 and 13 respectively. *PSE* of the MSS affects the delay performance. A larger PSE (of MSS) results in a higher delay, therefore the average delay by LBPS-Merge-MR is always higher than the delay by LBPS-Aggr-MR and Type I PSC in both figures. Moreover, the average delay by LBPS-Merge-MR decreases as the internal load increases.

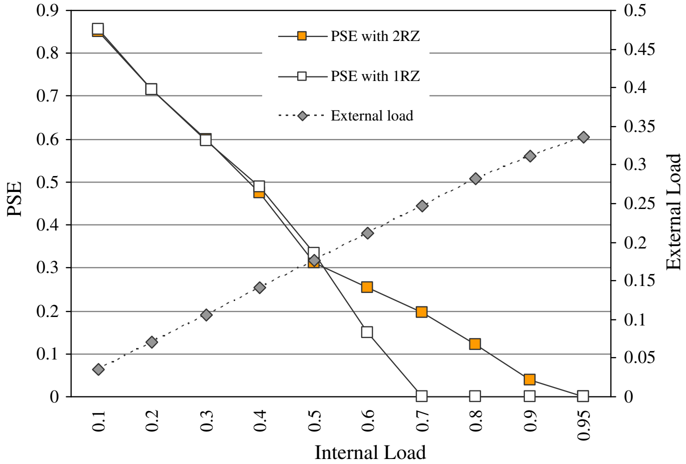

Fig. 14 LBPS-Aggr-MR *PSE* for *Topo-3-Case A*

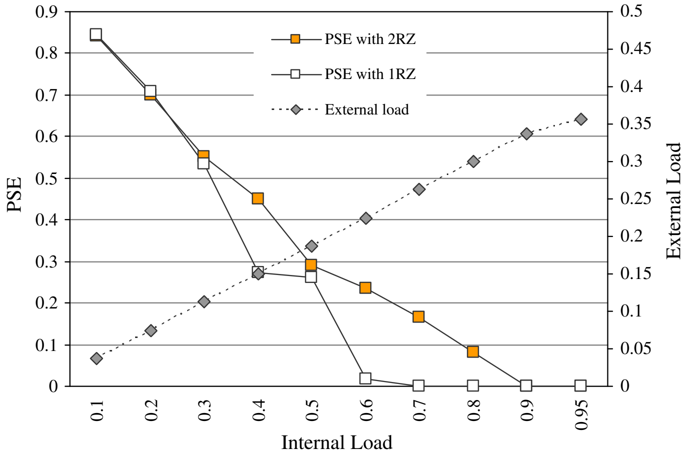

Fig. 15 LBPS-Aggr-MR *PSE* for *Topo-3-Case B*

The reason is due to the reduction of the sleep cycle length when the load is increased, which overtrumps the delay-increasing effect by increasing the load.

4.3 Results for Topo-3

PSE results of LBPS-Aggr-MR for each of the fives cases (*Case A* $\sim$ *Case E*) of *Topo-3* are displayed in Figs. 14, 15, 16, 17 and 18 , in which two options for frame configuration, *1RZ and 2RZ*, are included. Note that given the same total number of MSS in the network, the difference among the five cases is the ratio of the number of MSS under 1-hop RS and 2-hop RS. Following observations can be made from Figs. 14, 15, 16, 17 and 18:

(1) Comparing the curve of the external load of the five cases, it is shown that as the number of MSS under 1-hop RS increases, the maximum external load is also increased. The reason is because an MSS under 1-hop RS only requires one transmission for a packet

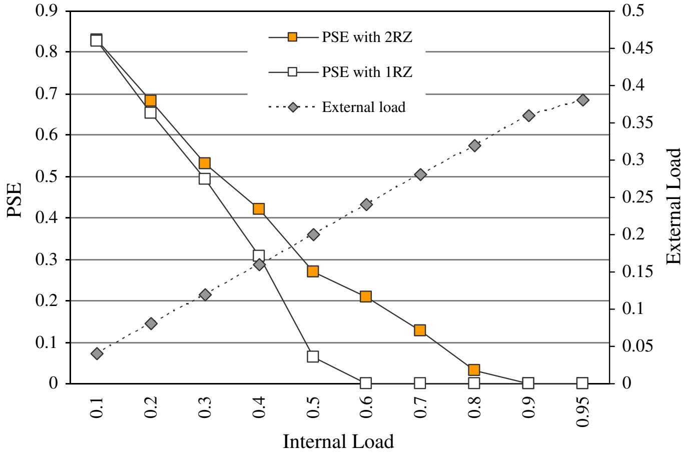

Fig. 16 LBPS-Aggr-MR *PSE* for *Topo-3-Case C*

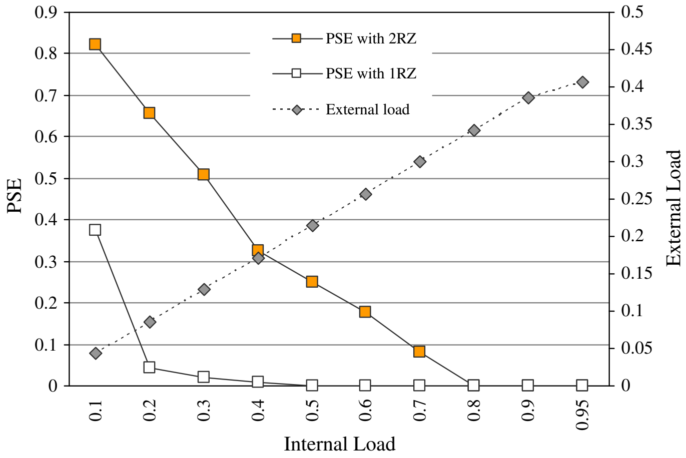

Fig. 17 LBPS-Aggr-MR *PSE* for *Topo-3-Case D*

over the relay link, while an MSS under 2-hop RS requires two transmissions over the relay link. Therefore, fewer MSSs under 2-hop RS (e.g. Case E) can achieve a higher external load.

(2) LBPS-Aggr-MR *PSE* in both of *1RZ* and *2RZ* is decreased as the number of MSS under 1-hop RS increases. The reason is explained as follows. When the number of MSS under 1-hop RS increases (Case A →B ...→ E), the same internal load is mapping to a higher external load. For instance, the internal load of 0.5 maps to the external load of 0.18 in *Case A*, 0.19 in *Case B*, 0.2 in *Case C*, 0.21 in *Case D*, and 0.23 in *Case E*. A higher external load leads to a lower *PSE* value.

(3) Although the *PSE* value of both *1RZ* and *2RZ* decreases from *Case A* to *Case E*, the reduction of *PSE* in the case of *1RZ* is more significant than that of *2RZ*. The reason is because when an MSS under 2-hop RS exists in the network, all of the nodes in the protocol of LBPS-Aggr-MR with *1RZ* configuration would have to awake two consecu-

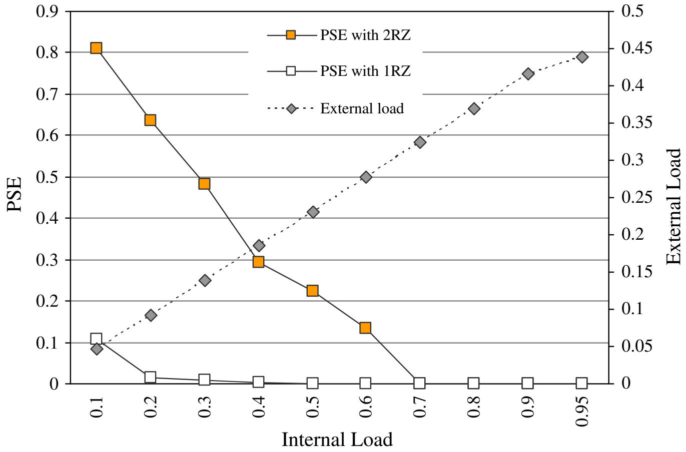

Fig. 18 LBPS-Aggr-MR *PSE* for *Topo-3-Case E*

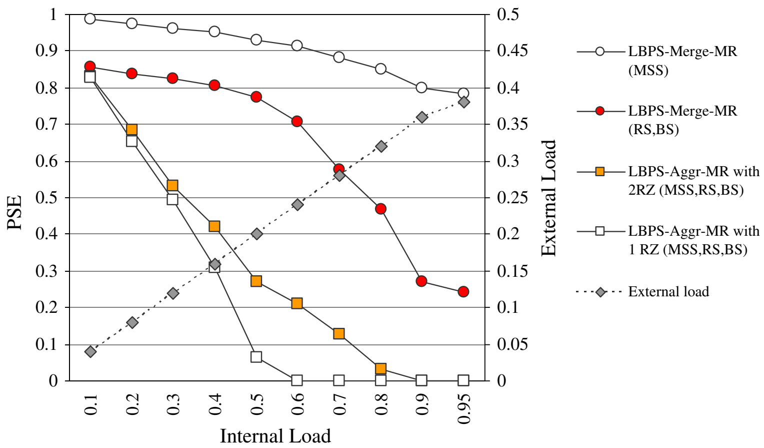

Fig. 19 LBPS-Merge-MR versus LBPS-Aggr-MR *PSE* for *Topo-3-Case C*

tive time frames for 2-hop transmission in each sleep cycle, which makes the PSE results even worse.

As an illustrating example, Fig. 19 shows the *PSE* results for comparing LBPS-Merge-MR with LBPS-Aggr-MR in *Case C* of *Topo-3* (similar results are found in other cases). It is shown that the *PSE* result of MSS as well as *PSE* of RS and BS by LBPS-Merge-MR is significantly better than that of LBPS-Aggr-MR (with either *1RZ* or *2RZ*). The reason is due to the flexibility of LBPS-Merge-MR to select different cycle length and different frame configuration (i.e. different number of relay zone in a time frame) for MSSs.

5 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 focused on non-real-time traffic are proposed in the paper: LBPS-Aggr-MR and LBPS-Merge-MR. LBPS-Aggr-MR synchronizes the sleep schedule for BS, RS, and MSS, while different sleep cycle lengths 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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