Sleep Scheduling Schemes Integrating Relay Node and User Equipment in LTE-A

Chun-Chuan Yang*, Jeng-Yueng Chen, Yi-Ting Mai, and Hsieh-Hua Liu

***Abstract*—**By introduction of Relay Nodes (RNs), LTE-Advanced can provide enhanced coverage and capacity at cell edges and hot-spot areas. The authors have been researching the issue of power saving in mobile communications technology such as WiMax and LTE for some years. Based on the idea of Load-Based Power Saving (LBPS), three efficient power saving schemes for the user equipment (UE) were proposed in the authors' previous work. In this paper, three revised schemes of the previous work in order to integrate RN and UE in power saving are proposed. Simulation study shows the proposed schemes can achieve significantly better power saving efficiency than the standard based scheme at the cost of moderately increased delay.

***Keywords*—**DRX, LTE-A, Power Saving, RN

I. Introduction

As a candidate 4G system, *LTE-Advanced* (*LTE-A*) has become the fastest developing mobile communication technology in recent years. Comparing with its previous version of Release 8 [1], LTE-A (Release 10 [2] and up) aims to provide higher capacity and speed with some enhanced features, including the introduction of the *Relay Nodes* (RNs). RN was first included in Release 10 in order to extend the coverage of high data rates and improve the cell-edge throughput. With the help of RN, the radio link between *eNB* (the base station) and *UE* (the user equipment) has become two hops as displayed in Fig. 1. The link between eNB (also called the *donor eNB* or *DeNB*) and RN is referred to as the *backhaul link*, while the link between RN and UE is referred to as the *access link*. With respect to the usage of spectrum, RN's operation can be divided into *inband* and *outband* types. An RN is said to be *inband* if the backhaul link and the access link are on the same carrier frequency, *outband* if not. RN-related research issue includes architecture design [3-5], mobility support [6], resource allocation and scheduling [7-8], etc.

In addition to the improvement of channel capacity and radio coverage, energy saving also plays an important role in modern mobile communications. *Discontinuous Reception Mode* (*DRX*) [9] is supported in LTE in order to conserve UE's power. The authors have been researching power saving mechanisms for some years. The idea of *Load-Based Power Saving* (*LBPS*) and associated schemes were proposed for IEEE 802.16 [10-11]. Extension work of LBPS for UE power saving in LTE was also proposed [12]. In this paper, revised LBPS schemes integrating RN and UE power saving are proposed. The type of RN focused in the paper is *Type 1* RN, which control its cell with its own identity as if it is a Release 8 eNB. Moreover, Type 1 RN provides half duplex with inband transmissions. Simulation study has demonstrated that via the proposed schemes a good level of power saving at both RN and UE can be effectively achieved.

The remainder of the paper is organized as follows. The authors' previously proposed LBPS schemes are briefly surveyed in section II. The revised LBPS schemes integrating RN and UE in LTE-A are presented in section III. Performance evaluation is presented in section VI. Finally, section V concludes this paper.

II. Previous Work

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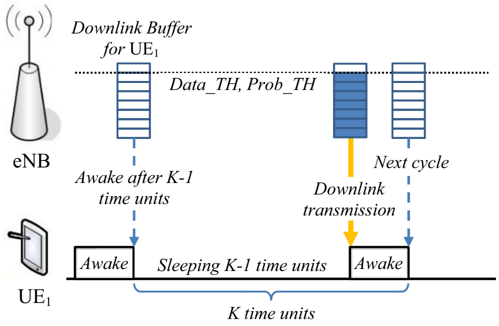

Fig. 2 Load-Based Power Saving

The basic idea of LBPS is to take advantage of traffic modeling in determining the length of the sleep period. The traffic in LBPS is assumed to be *Poisson* process in order to take advantage of the multiplexing property. Taking a single user node (e.g. a single UE in LTE) with its downlink traffic as an example, the base station estimates the traffic load and calculates the length of the sleep period in order for the accumulated data in the base station's buffer reaching a predefined level as illustrated in Fig. 2. The predefined level consists of two threshold parameters: *Data_TH* and *Prob_TH* as shown in Fig. 2. The length of the sleep period is calculated by making the amount of accumulated data exceeding *Data_TH* with probability higher than *Prob_TH*. Please refer to the authors' previous work [10] for detail of the calculation.

The value of *Data_TH* could be any value theoretically, but in practice it is suggested to set its value as the amount of data which can be served within the basic time unit of transmission scheduling (e.g. a *Transmission Time Interval or Subframe* in LTE) in order to get a good balance between power saving and delay performance. In LTE, the amount of data which can be served in a subframe is fluctuated and affected by the link quality. Therefore, applying LBPS in LTE requires estimation of the capacity in a subframe. In the authors' previous work [12], *Channel Quality Indicator* (*CQI*) were used in estimating subframe capacity, and two types of CQI reporting namely

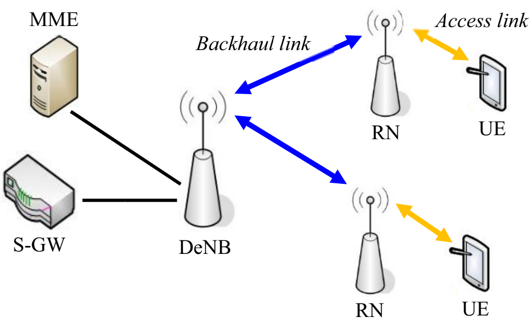

Fig.1 Using RN in LTE-A

Wideband reporting and *Full-Sub-band reporting* were addressed.

For the general case of multiple users in the network, three LBPS schemes namely *LBPS-Aggr*, *LBPS-Split*, and *LBPS-Merge* were proposed to deal with multiplexing users in sleep scheduling. *LBPS-Aggr* is the simplest scheme which

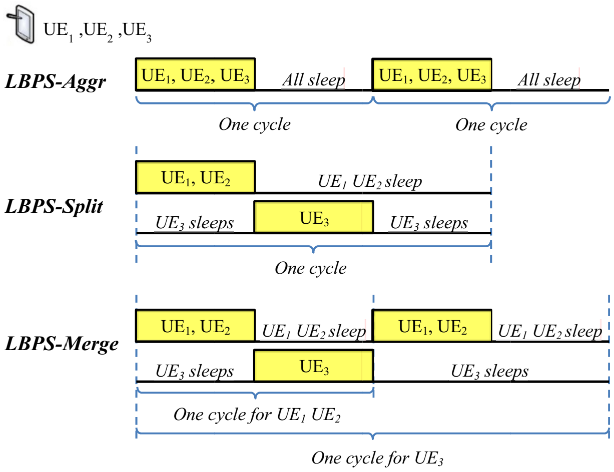

Fig. 3 LBPS Schemes

treats all traffic as an aggregate flow in determining the length of the sleep period and synchronizes all UEs in sleep scheduling as illustrated in the upper part of Fig. 3. The idea of *LBPS-Split* is motivated by the following observation on the sleep pattern of *LBPS-Aggr*. If we place the awake subframe of some UEs in a different part of a cycle, the cycle length could be extended since the load of each split group is less than the total load used in *LBPS-Aggr*. As illustrated in the middle part of Fig. 3, a larger cycle is made by splitting UEs into two groups (UE_1+UE_2 and UE_3), resulting in better power saving performance.

LBPS-Merge is motivated by the idea that given a predefined level for data accumulation, the best case for a UE in terms of power saving is to make the UE a single-member group which results in the largest sleep period for the UE. Since different group in general has different cycle length, in order to efficiently find a feasible sleep schedule for all groups, the cycle length for each group in *LBPS-Merge* is converted to the closest and smaller power of 2. In the case that a feasible sleep schedule cannot be found for the current state of grouping, iterated merging operation of some groups is performed until a feasible sleep schedule is found. As illustrated in the lower part of Fig. 3, there are two groups in the sleep schedule, the group of UE_1+UE_2 with 2-subframe cycle and the group of UE_3 with 4-subframe cycle.

III. Integrated Sleep Scheduling

A. Basic idea

With the introduction of RN for the radio link, downlink transmission first goes through the backhaul link and then the access link. That is, before RN can serve UEs in a subframe, it must first receive data from DeNB in a previous subframe. Therefore, the awake subframe for receiving data on the backhaul link must be taken into consideration in designing sleep scheduling for RN. Furthermore, as mentioned in Section I, we focus on Type 1 RN, and a Type 1 RN is in charge of transmission scheduling for its underlying UEs, which makes RN the better position than DeNB to perform LBPS schemes and issue DRX commands to UEs. We also assume the quality

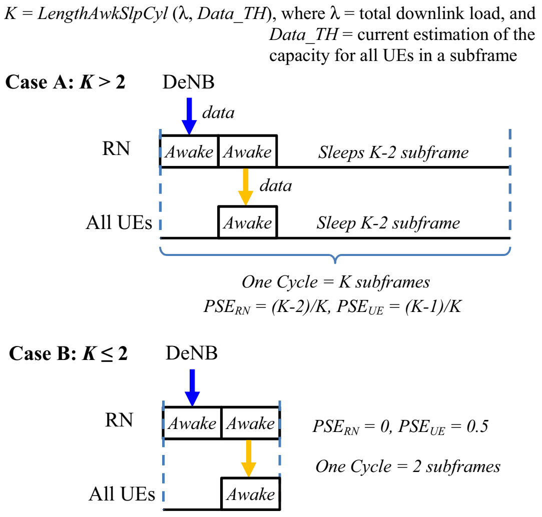

Fig. 4 The Scheme of *LteA-Aggr*

and capacity of the backhaul link is much better than the access link as in the case of fixed RN to simplify the design of the LBPS schemes.

There are naturally two strategies to integrate RN and UEs in sleep scheduling: *UE-first* and *RN-first*. In the UE-first strategy, power saving for UEs is the first concern and LBPS schemes determine the sleep schedule for UEs as in the case without RN. With one awake subframe in a sleep cycle for the backhaul link, the sleep period of RN is then assigned to the common sleeping period of all UEs. On the other hand, a predefined threshold for power saving performance of RN is given in the RN-first strategy. The threshold places a limit on RN's sleep cycle length, which further affects the sleep pattern of all UEs. Therefore, the LBPS schemes need to be revised in order to accommodate the new requirement imposed by the RN's threshold. In this paper, we focus on the UE-first strategy, and three revised LBPS schemes namely *LteA-Aggr*, *LteA-Split*, and *LteA-Merge*, are presented in the following sections.

B. LteA-Aggr

As the simplest version of LBPS, *LteA-Aggr* treats all UEs as a single group in determining the synchronous sleep schedule. The length of a sleep cycle in *LteA-Aggr* is calculated according to the total downlink load of all UEs and the current estimation of the capacity in a subframe as follows:

The length of the next sleep cycle K

= *LengthAwkSlpCyl* (λ, *Data_TH*), where λ = the total downlink load for all UEs, and *Data_TH* = the current estimation of the capacity for all UEs in a subframe.

Please refer to the authors' previous work [12] for detail calculation of the function of *LengthAwkSlpCyl*. The scheme of *LteA-Aggr* is illustrated in Fig. 4, in which the worst case for RN power saving (Case B in Fig. 4) is when the calculated cycle length K less than or equal to 2, resulting in zero power saving for RN and 50% power saving for UEs. Note that the definition of *power saving efficiency* (denoted by *PSE*) in this paper is the ratio of the sleeping period.

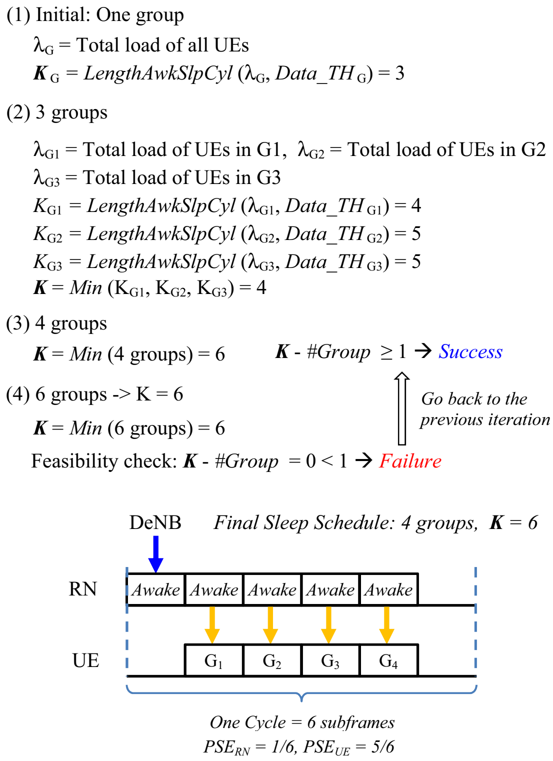

Fig. 5 Example of *LteA-Split*

C. LteA-Split

Starting from a whole group of UEs as in *LteA-Aggr*, *LteA-Split* takes advantage of splitting operation to extend the sleep cycle length. The splitting operation is aiming at maximizing the cycle length of each split group for better power saving efficiency. Fig. 5 is used as an example for illustration of the typical *LteA-Split* protocol. The first iteration of the example results in the cycle length of 3 (i.e. K_G=3), and a splitting operation is then performed in the second iteration. The cycle length of the second iteration (i.e. K=4 in the case) is the minimum value of K among the three split groups. The splitting operation stops when two consecutive iterations resulting in the same cycle length as iteration (3) and (4) in Fig. 5. Iteration (4) is where the original version of *LBPS-Split* stops. In *LteA-Split*, one subframe for the backhaul link is necessary for a feasible sleep schedule, which means the cycle length must be larger than the number of split groups at least by one. Iteration (4) fails to pass the feasibility check and the result of the previous iteration, i.e. *4 groups* and *cycle length=6* of iteration (3), is used for the final sleep schedule, as displayed in the lower part of Fig. 5.

Note that the worst case of *LteA-Split* in terms of power saving is when there is no space for splitting in the very beginning, which makes *LteA-Split* behave the same as *LteA-Aggr*.

D. LteA-Merge

Starting from each UE forming a single-member group, *LteA-Merge* allows UEs to have different cycle length in sleep schedule. As mentioned in section II, the cycle length

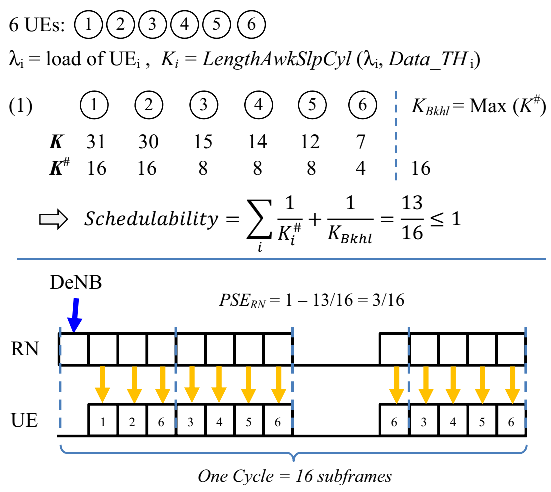

Fig. 6 Example of *LteA-Merge*: $PSE_{RN} > 0$

calculated by the function of *LengthAwkSlpCyl* is converted to the closest and smaller power of 2 to simplify the check of schedulability. The major difference between *LteA-Merge* and its original version of *LBPS-Merge* is the requirement of one subframe for the backhaul link in a sleep cycle, which also leads to the change of the equation of schedulability check. In the original version of *LBPS-Merge*, the equation of *schedulability* is defined as follows:

$$Schedulability_{LBPS\text{-}Merge} = \sum_i \frac{1}{K_i^{\#}} \leq 1,$$

where $K_i^{\#}$ is the converted value of the cycle length of group *i*.

Considering the requirement of the subframe for the backhaul link, one more item is added to the equation of *schedulability* in *LteA-Merge* as follows:

$$Schedulability_{LteA\text{-}Merge} = \sum_i \frac{1}{K_i^{\#}} + \frac{1}{K_{Bkhl}} \leq 1,$$

where K_{Bkhl} is the cycle length for the backhaul link.

The value of K_{Bkhl} is set as the maximum cycle length among all groups in each iteration. An example of *LteA-Merge* is given in Fig. 6, in which no merging operation is required since the value of *schedulability* (i.e. 13/16) in the first iteration is already less than 1. Moreover, it is easy to know from the example that RN's power saving efficiency for a sleep schedule equals (*1 – schedulability*). Therefore, if the *schedulability = 1* in the last iteration in *LteA-Merge*, there would be no space for RN power saving (i.e. $PSE_{RN} = 0$). To illustrate the case, Fig. 7 shows a series of merging operation for another example of *LteA-Merge* in order to find a feasible sleep schedule, resulting in zero power saving for RN. Note that the value of K_{Bkhl} changes during the merging process in the example. Also note that the two types of merging operation namely the *non-degraded merge* and the *degraded merge* used in Fig. 7 are defined in authors' previous work of *LBPS-Merge* [12]. The worst case for *LteA-Merge* in terms of power saving is when all UEs are finally merged into a whole group making the same result as *LteA-Aggr*.

It's worth mentioning that in order to take advantage of *multi-user diversity* in resource allocation in a subframe, the constraint of minimum group size could be added in *LteA-Merge* as well as in *LteA-Split* to set a limitation for the merging/splitting process.

IV. Performance Evaluation

Simulation study is conducted to evaluate the performance of the three proposed schemes as well as a standard-based contrast scheme. Three types of UEs are defined for simulating different cases of channel quality. An *H-type* (high link quality) UE is assumed to use 64QAM modulation with CQI value ranging from 10 to 15. An *M-type* (medium link quality) UE uses 16QAM with CQI ranging from 7 to 9. An *L-type* (low link quality) UE uses QPSK with CQI ranging from 1 to 6. In addition to the proposed schemes, a contrast scheme based on standard DRX (denoted by *Std. DRX*) is also simulated. Parameters used in the simulation are summarized in Table 1.

TABLE I
Simulation Parameters

Channel capacity	20 MHz (#RB = 100)
#DeNB, #RN, # UE	1, 1, 40 (UE with equal load)
Type of UE	*H-type*: CQI 11~15 *M-type*: CQI 6~10 *L-type*: CQI 1~5
Packet Size	799 bits
DATA_TH	Estimated Capacity × 0.8
Prob_TH	0.8
Minimum Group Size	2
Contrast scheme *Std. DRX*	On duration = 1ms Inactivity timer = 10ms Short DRX Cycle = 80ms Short Cycle timer = 2 Long DRX Cycle = 320ms

The results of *PSE* (*Power Saving Efficiency*) for different UE cases are displayed in Fig. 8~10, and the corresponding results of the average delay (denoted by *AvgDelay*) are displayed in Fig. 11~13. Note that the result of *RN's PSE* for *Std. DRX* is zero in all UE cases, which is not displayed in Fig. 8~10. Following observations can be made from these figures.

(1) *LteA-Split* and *LteA-Merge* outperform *LteA-Aggr* and *Std. DRX* in terms of *UE's PSE* as well as *RN's PSE* at the cost of slightly increased *AvgDelay*, which demonstrates the benefit of grouping UEs (either by splitting or merging) in sleep scheduling.

(2) As displayed in Fig. 8 and Fig. 9, *LteA-Split* outperforms *LteA-Merge* in most cases in terms of *UE's PSE* and *RN's PSE*, since the conversion of the cycle length (to a power of 2) in *LteA-Merge* results in lower *PSE* for both UE and RN.

(3) *RN's PSE* for *Std. DRX* is zero even in very light load, since for 40 UEs the probability of all UEs entering the sleep period at the same time is very close to zero making RN never get the chance of power saving in the simulation.

(4) As shown in Fig. 10, *UE's PSE* of *Std. DRX* is better than the proposed schemes for some input loads in the

case of *All-L UEs*, since the packet arrival rate with fixed size (799 bits) is very low triggering the inactivity timer of *Std. DRX* to expire more frequently and achieve higher *UE's PSE* at the cost of high *AvgDelay* as shown in Fig. 13.

V. CONCLUSION

In this paper, the authors focus on integrated power saving for both RN and UE in LTE-A. The strategy of UE-first for integrating RN and UE in sleep scheduling is adopted. Based on previously proposed *Load-Based Power Saving* (*LBPS*) schemes, three revised LBPS schemes namely *LteA-Aggr*, *LteA-Split*, and *LteA-Merge* are proposed. Simulation study shows by taking advantage of grouping UEs either by splitting or merging in sleep scheduling, *LteA-Split* and *LteA-Merge* outperform *LteA-Aggr* as well as the standard-based contrast scheme in terms of both UE's and RN's power saving efficiency at the cost of moderate increase in average access delay. The future work of the research is to design integrated LBPS schemes for RN-first strategy.

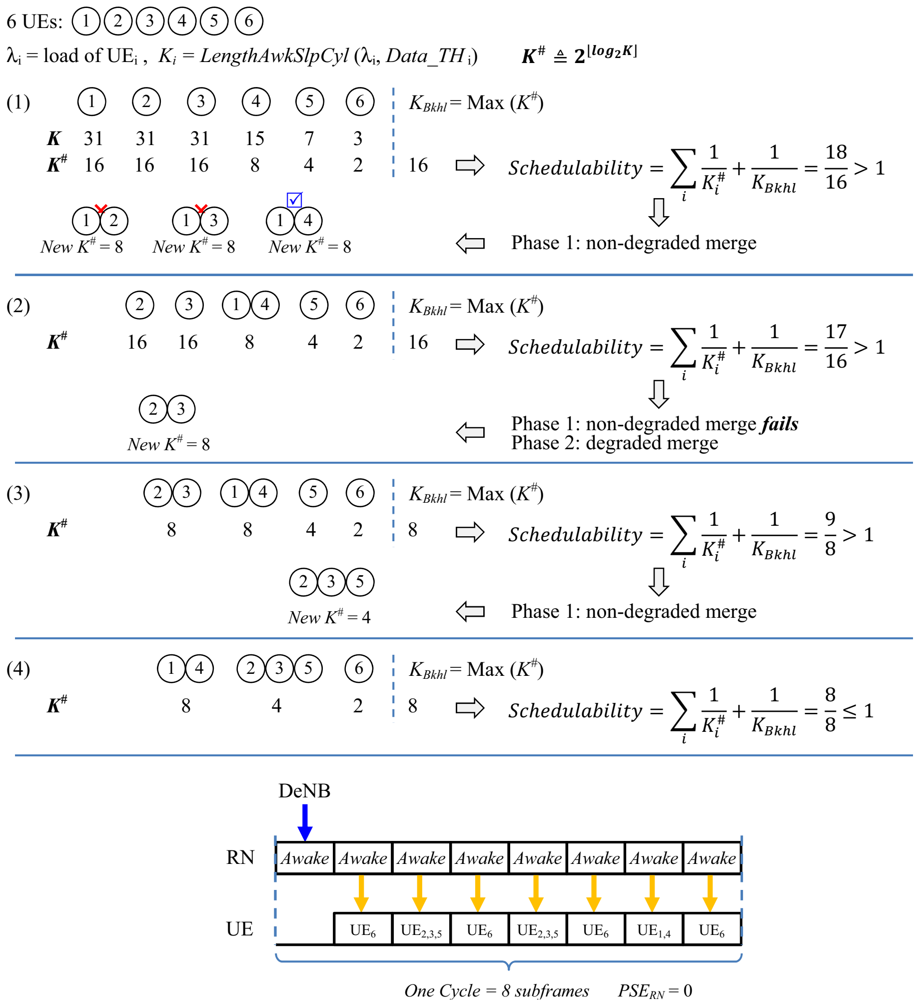

Fig. 7 Example of *LteA-Merge*: $PSE_{RN} = 0$

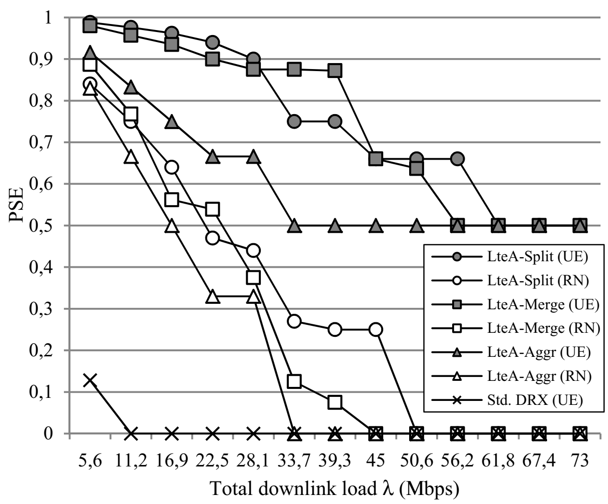

Fig. 8 *PSE* in the case of *All-H* UEs

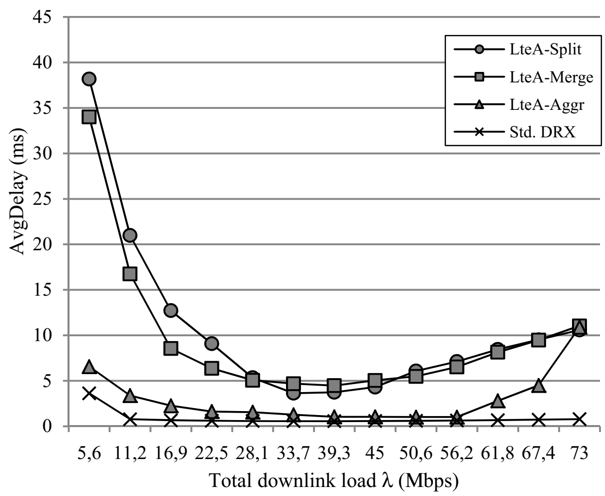

Fig. 11 *AvgDelay* in the case of *All-H* UEs

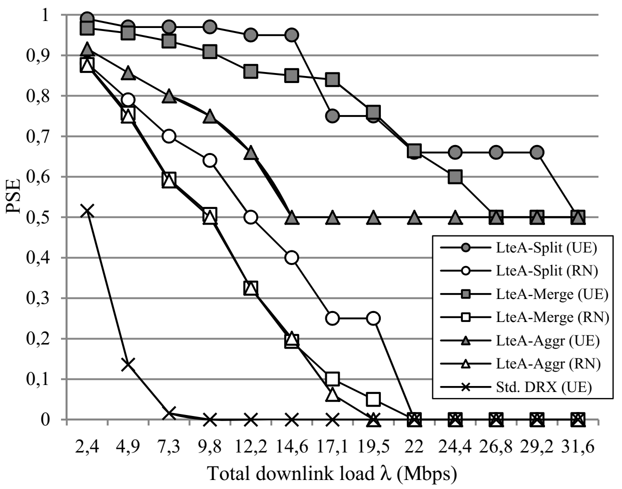

Fig. 9 *PSE* in the case of *All-M* UEs

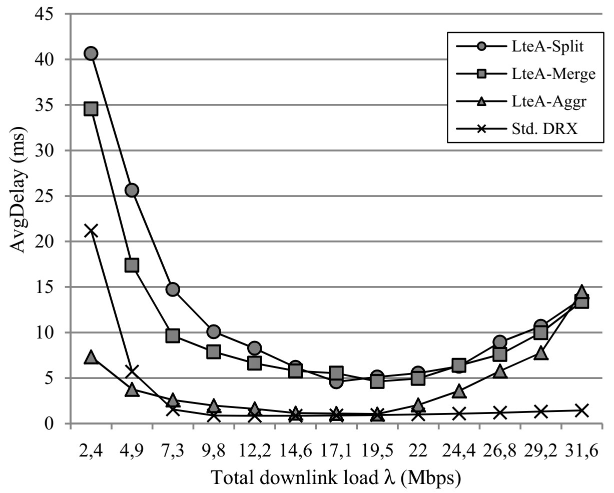

Fig. 12 *AvgDelay* in the case of *All-M* UEs

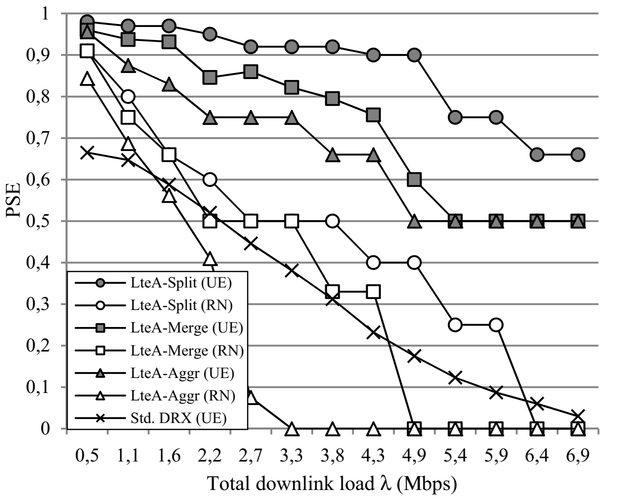

Fig. 10 *PSE* in the case of *All-L* UEs

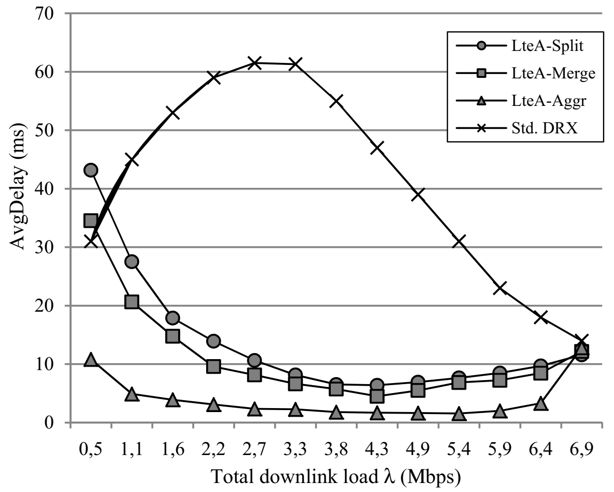

Fig. 13 *AvgDelay* in the case of *All-L* UEs

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