# Buffer-Based Channel dependent UpLink Scheduling in Relay-Assisted LTE Networks

Mahima Mehta, Suman Khakurel, Abhay Karandikar
Infonet Lab., Department of Electrical Engineering
Indian Institute of Technology Bombay, Mumbai, India
Email: {mahima,suman,karandi}@ee.iitb.ac.in

***Abstract*—We consider the problem of UpLink (UL) scheduling in relay-assisted Long Term Evolution (LTE) networks and propose a Buffer-based Channel dependent Scheduler (BCS) for the same. Our objectives are to minimize packet loss due to buffer overflow and increase resource utilization efficiency while ensuring fairness among users. This is achieved by utilizing the Buffer Status Report (BSR) available in Third Generation Partnership Project (3GPP)-LTE. The proposed scheduler comprise three-phases. Phase I partitions the resources between eNB (Base Station in LTE) and Relay Nodes (RNs) while Phase II, between different RNs. This resource partitioning is entailed by Phase III which implements buffer-based channel dependent resource allocation. We perform simulations to illustrate reduction in packet drop probability and increment in resource utilization efficiency when BSR is incorporated in scheduling decision. Further, our simulations show that BCS provides higher degree of fairness and lower outage probability compared to opportunistic and round robin scheduler. We also investigate the impact of buffer based resource partitioning on packet drop probability.**

## I. Introduction

Orthogonal Frequency Division Multiple Access (OFDMA) has inherent immunity to the adverse consequences of frequency selective fading. However, due to multicarrier modulation, there is a large fluctuation in the envelope of OFDMA signal waveform. This results in high Peak to Average Power Ratio (PAPR), necessitating the requirement of power amplifier with large dynamic range which in turn leads to increased power consumption. The increased power requirement can be facilitated at base station (termed as evolved-NodeB (eNB) in Third Generation Partnership Project (3GPP) Long Term Evolution (LTE)) during DownLink (DL) transmission. However, during UpLink (UL) transmision, User Equipments (UEs) will be constrained by the limited battery power. Consequently, OFDMA has been regarded unsuitable for UL transmissions and Single-Carrier Frequency Division Multiple Access (SC-FDMA) has been recommended in 3GPP-LTE standard [1]. In SC-FDMA, time-domain data symbols are transformed to frequency-domain by Discrete Fourier Transform (DFT) before undergoing standard OFDM modulation. Unlike OFDMA, SC-FDMA brings additional benefit of low PAPR making it suitable as a radio access mechanism for UL.

The issues related to high power consumption during UL transmission have been alleviated by using SC-FDMA as radio access mechanism. However, the challenges in UL resource allocation still prevails since wireless network resources are scarce and scheduling parameters like channel conditions, buffer lengths of UEs etc. are locally unavailable at the eNB. The significance of communicating buffer state information (i.e. information about the amount of data buffered at UEs) to the scheduler at eNB is emphasized in 3GPP-LTE standard [2]. Approaches illustrating the use of buffer information in scheduling are discussed in [3], [4]. In [5], authors propose a queue aware UL bandwidth allocation scheme for IEEE 802.16 cellular system. Limited literature is available for buffer-based UL scheduling in relay-assisted LTE networks. A variant of opportunistic scheduling has been proposed in [6] which emphasizes the fact that limited buffer information in UL leads to inefficient resource utilization. We intend to address this problem by exploiting the Buffer Status Report (BSR) [2] available in 3GPP-LTE, which conveys the amount of data (in bytes) buffered at UEs to eNB.

In this paper, we propose a novel approach of Buffer-based Channel dependent Scheduler (BCS) for relay-assisted LTE Networks. The objectives of our scheduler are to minimize packet loss due to buffer overflow and increase resource utilization efficiency while ensuring fairness among UEs without significant compromise on sum throughput (sum of throughputs of all UEs in the network). When a UE is scheduled based on limited buffer information, it might not have sufficient number of packets to fully utilize the alloted resource. We quantify this difference by a metric, resource utilization efficiency, which is the ratio of number of packets served to the maximum number of packets that could have been served if the resources were fully utilized. We perform simulations to illustrate that our scheduler meets the aforementioned objectives. We also investigate the impact of buffer based resource partitioning on packet drop probability.

The rest of the paper is organized as follows. In Section II, we describe UL transmission scenario in LTE highlighting the significance of UL reference signal and buffer status reporting. In Section III, we describe the system model. Section IV elucidates on problem formulation and illustrates BCS for UL scheduling in relay-assisted LTE networks. Section V discusses the results and its inferences. Finally, we draw conclusions of this paper in Section VI.

This work is supported by the India-UK Advanced Technology of Centre of Excellence in Next Generation Networks (IU-ATC) project and funded by the Department of Science and Technology (DST), Government of India.

## II. Uplink Transmission Scenario in LTE based Cellular Networks

In LTE, the system resources are divided along frequency (sub-carriers) and time slots (symbols). LTE resources are scheduled in units of Physical Resource Blocks (PRBs). Each PRB consists of 12 subcarriers (each subcarrier with a bandwidth of 15 kHz) that last for 0.5 msecs. Before discussing the scheduling algorithm, we first briefly review the UL transmission scenario in LTE. An UL scheduler needs UE-eNB channel condition and buffer value from each UE to implement a buffer-based channel dependent resource allocation. UL reference signals and BSRs help eNB garner this information.

### A. Uplink Reference Signals

There are two variants of UL reference signal: Demodulation Signal (DS) and Sounding Reference Signal (SRS). Out of these two, SRS is used to facilitate frequency dependent scheduling. It is a known signal transmitted from UE to eNB over the entire frequency band. Therefore, it helps eNB estimate the UL channel quality for the purposes of channel dependent UL scheduling.

### B. Buffer Status Reporting

Unlike DL scenario, the data for transmission are buffered at different UEs or Relay Nodes (RNs) (for relay-assisted networks) in case of UL. These UEs or RNs can have multiple data flows based on applications like voice, data, video streaming etc. LTE defines these flows as Radio Bearers (RBs) with each RB having its own QoS requirement. A set of RBs with similar QoS attributes are grouped into one of the four possible Radio Bearer Groups (RBGs). 3GPP-LTE has advocated per RBG buffer status reporting and per UE grant allocation scheme [2], [3]. This ensures buffer status reporting with relatively low signaling overhead and more allocation flexibility. Conveying buffer status information to the scheduler at eNB helps implement buffer based schedulers.

## III. System Model

We consider a two-hop relay-assisted LTE Network. We assume a single cell scenario with three hexagonal sectors. The cell comprises three RNs placed near the cell edge and an eNB at the cell centre (Fig. 1). Relays are deployed in the system to ensure performance improvement. This is due to reduction in required transmit power at UE and better channel condition between RN and UE (due to UE's proximity to RN).

UEs are randomly positioned in the cell with uniform distribution. Each UE is associated either with eNB or RN based on experienced Signal-to-Noise Ratio (SNR) and accordingly, we call it direct or indirect UE. We assume a block fading channel model [7] where the channel condition remains constant for a block of symbols (termed as 'scheduling interval' in this paper) and varies only over scheduling intervals. We also assume that there is no delay in conveying BSRs.

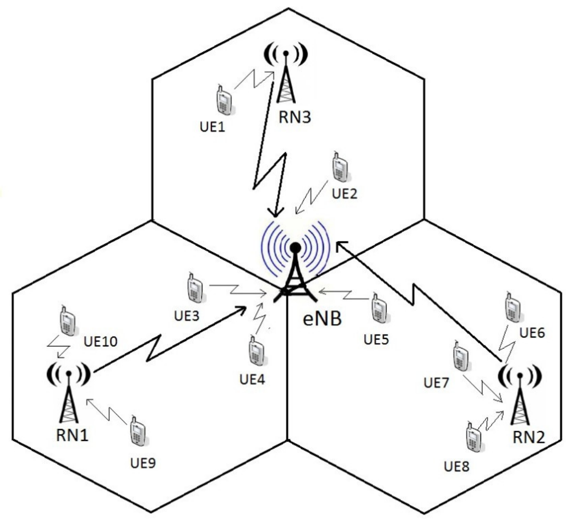


Fig. 1. System Model

## IV. Buffer-based Channel dependent Scheduling Algorithm for UL in relay-assisted LTE networks

### A. Problem Formulation

For a relay-assisted LTE network, UL scheduling is implemented at eNB. An eNB receives Scheduling Requests (SRs) from UEs seeking to transmit data in forthcoming time slots. These UEs can either be direct or indirect as mentioned in Section III. A resource partitioning scheme is required to apportion the PRBs among direct and indirect UEs. These apportioned PRBs need to be scheduled to individual UEs. This partitioning and scheduling must ensure that users with longer buffer lengths get higher proportion of resources. Otherwise, it will cause packet loss due to buffer overflow and reduction in resource utilization efficiency. In addition, we also need to ensure that throughput reduction is as low as possible.

### B. Power allocation and Throughput Calculation for SC-FDMA

Each UE is assumed to transmit at maximum power $P_u$ which needs to be divided amongst all the PRBs alloted to it. As shown in [8], equal power distribution scheme gives almost similar performance as that of optimal power allocation scheme using water-filling. Therefore, we choose a simple power allocation scheme which equally divides the power amongst the PRBs allocated to a UE.

If $T_{PRB,u}$ is the set of PRBs alloted to a user $u$ and $|T_{PRB,u}|$ is the cardinality of $T_{PRB,u}$, then the power corresponding to each PRB $n$ for the user $u$ is given by:

$$P_{n,u} = \frac{P_u}{|T_{PRB,u}|} \tag{1}$$

and the SNR over a single PRB, $\gamma_{n,u}$, is given by:

$$\gamma_{n,u} = \frac{P_{n,u}|h_{n,u}|^2}{PL_u \sigma_n^2}. \tag{2}$$

Here, $h_{n,u}$ is the amplitude channel gain over PRB $n$ allocated to user $u$, $\sigma_n^2$ is the noise power of PRB $n$ and $PL_u$ is the distance based path loss [9] in natural scale given by:

$$PL_u(dB) = 128.1 + 37.6 \log_{10}(d_u) \quad (3)$$

where $d_u$ is distance from user $u$ in kms.

For SC-FDMA throughput calculations, we consider the following expression representing Shannon's upper bound on the system capacity:

$$R_u(P_u, T_{PRB,u}) = \frac{BW|T_{PRB,u}|}{N} \times \log_2(1 + \gamma_u(P_u, T_{PRB,u})) \quad (4)$$

where $BW$ is the total bandwidth, $N$ is the total number of PRBs available at eNB and $\gamma_u(P_u, T_{PRB,u})$ is the SNR of user $u$ after Minimum Mean Squared Error Frequency Domain Equalization (MMSE-FDE) at the receiver [10] given by:

$$\gamma_u(P_u, T_{PRB,u}) = \left( \frac{1}{\frac{1}{|T_{PRB,u}|} \sum_{i \in T_{PRB,u}} \frac{\gamma_{i,u}}{\gamma_{i,u} + 1}} - 1 \right)^{-1}. \quad (5)$$

### C. Algorithm

Our scheduling algorithm comprises 3 phases. In Phase I, we divide the available resources $(N)$ into two chunks: one for direct UEs $(N_{eNB})$ and the other for indirect UEs $(N_{RNs})$ on the basis of their cumulative buffer lengths (sum of individual buffer lengths of UEs). These indirect UEs can be attached to one of the three relay nodes $(RN_1, RN_2$ or $RN_3)$. Therefore, in Phase II, we subdivide the chunk, $N_{RNs}$ into $N_{RN_1}$, $N_{RN_2}$ and $N_{RN_3}$ amongst three RNs in proportion to their cumulative buffer lengths. Finally, in Phase III, we implement buffer-based channel dependent scheme to allocate PRBs to individual UEs from the set of $N_{eNB}$, $N_{RN_1}$, $N_{RN_2}$ or $N_{RN_3}$ depending upon their associations.

*Phase I*: The first phase of the algorithm distributes the available resources among direct and indirect UEs in proportion to their cumulative buffer lengths. Therefore,

$$N_{eNB} = \frac{CBL_{eNB}}{CBL} \times N, \quad (6)$$

$$N_{RNs} = \frac{CBL_{RNs}}{CBL} \times N, \quad (7)$$

$$CBL = CBL_{eNB} + CBL_{RNs} \quad (8)$$

where $CBL_{eNB}$ and $CBL_{RNs}$ are the cumulative buffer lengths of all direct and indirect UEs respectively. $CBL$ is the cumulative buffer length of all UEs in the system.

*Phase II*: After Phase I, we obtain the set of PRBs reserved for direct UEs, i.e., $N_{eNB}$. However, total available chunk for RNs $(N_{RNs})$ needs to be distributed amongst individual RNs based on their cumulative buffer lengths as:

$$N_{RN_y} = \frac{CBL_{RN_y}}{CBL_{RNs}} \times N_{RNs}, \quad (9)$$

$$CBL_{RNs} = \sum_y CBL_{RN_y} \quad (10)$$

where $y \in \{1, 2, 3\}$ and $CBL_{RN_y}$ is the cumulative buffer length of $RN_y$.

*Phase III*: In phase III, $N_x \in \{N_{eNB}, N_{RN_1}, N_{RN_2}, N_{RN_3}\}$ is distributed amongst the corresponding users. We compute a scheduling metric $\triangle_{SM}$ of dimension $N_x \times U_x$ where $U_x$ is the total number of UEs in the user group $x$. We calculate individual components of $\triangle_{SM}$ as:

$$\triangle_{n,u} = \frac{R_{n,u}}{\max_{u \in S_x} R_{n,u}} + \frac{BL_u}{\max_{u \in S_x} BL_u}. \quad (11)$$

where $n = 1, 2, ..., N_x$ and $u = 1, 2, ..., U_x$. $BL_u$ is the buffer length of user $u$, $R_{n,u}$ is the instantaneous rate of user $u$ on PRB $n$ and $S_x$ is a set of users belonging to group $x$ $(\because U_x = |S_x|)$.

$\triangle_{n,u}$ gives equal weightage to channel condition and buffer length. It comprises two components: normalized rate and normalized buffer length. The value of each component can vary from 0 to 1. Thus, $\triangle_{n,u}$ can lie between 0 and 2. Normalized rate is an indicative of channel condition; it is the ratio of instantaneous achievable rate on a PRB to the maximum rate on that PRB during a scheduling interval. Normalized buffer represents the drift in buffer length compared to the maximum buffer length of UEs in a scheduling interval. Thus, a UE with higher buffer length and better channel condition will be preferred for resource allocation. We allocate PRBs to individual UEs based on the following steps:

1) Consider the set of PRBs available for allocation $T_{avail\_PRBs}$ = {1,2,3,.......,$N_x$}.
2) For every PRB $n$, we determine user $u^*$, such that:
$$(n, u^*) = \arg\max_u \triangle_{n,u}. \quad (12)$$
3) Allocate PRB $n$ to user $u^*$. and update the set of total PRBs alloted to user, i.e., $T_{PRB,u^*}$ = $T_{PRB,u^*}$ + $\{n\}$.
4) Remove PRB $n$ from the set of available PRBs, i.e., $T_{avail\_PRBs} = T_{avail\_PRBs} - \{n\}$.
5) Steps 2, 3 and 4 are repeated until the available PRBs are exhausted, i.e., $T_{avail\_PRBs}$= $\phi$.
6) Steps 1-5 are carried out for all four categories of $N_x$.

We also implement Buffer-Based Scheduler (BBS) which differs from BCS only in Phase III of scheduling, where individual components of scheduling metric are computed as:

$$\triangle_{n,u} = \frac{BL_u}{\max_{u \in S_x} BL_u}. \quad (13)$$

Our motivation behind implementing BBS is to illustrate the significance of scheduling based on both buffer information and channel condition over buffer information only.

## V. RESULTS AND INFERENCES

The simulation scenario considers a single cell of radius 1.5 kms. It is a 3-sectored cell and has 1 RN/sector. We simulate a Rayleigh channel for each UE. We consider the number of users to vary from 12 to 48 and each user has same rate requirement ($R_{min}$). The value of system bandwidth ($BW$) is considered to be 10 MHz and PRB bandwith is 180 MHz. Hence, the number of PRBs ($N$) is 50. The maximum transmit power of UE is taken to be 200 mW, packet size is 1000 bits and buffer size is 320 packets. We generate independent arrivals for all the users using Poisson distribution with a mean arrival rate of $2 \times 10^3$ packets/sec. Simulations are done in MATLAB and results are time-averaged over 10000 iterations.

We perform simulations to compare the performance of BCS with Opportunistic Scheduler (OS), Round Robin Scheduler (RRS) and BBS when applied to relay-assisted LTE network for UL scheduling. We investigate packet drop probabilities of all the aforementioned schedulers. A packet is said to be dropped when the number of unscheduled packets of a UE exceeds the maximum buffer size specified for it. We define packet drop probability as the ratio of total number of packets dropped to total number of packets arrived. Therefore,

$$Prob\{Pkt.drop\} = \frac{\sum_{u=1}^{U} Pd_u}{\sum_{u=1}^{U} Pa_u} \tag{14}$$

where $U$ is the total users in the system. $Pd_u$ and $Pa_u$ are the number of packets dropped and arrived at user $u$ respectively.

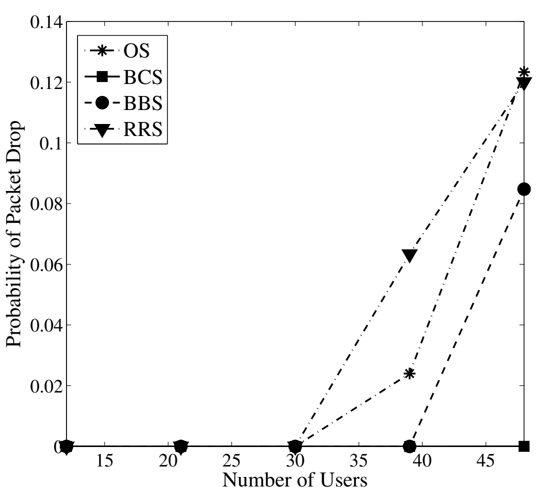


Fig. 2. Comparison of Packet drop probabilities for BCS, BBS, OS and RRS

In Fig. 2, we observe that BCS offers lower packet drop probability compared to BBS, OS and RRS. In general, sum throughput of the system is compromised when the scheduling objective is to minimize packet drop. To analyze this impact, we compare the sum throughput of BCS, BBS and RRS with OS, which provides maximum throughput to a system (Fig. 3). We observe that the sum throughput of BCS is close to OS. This is because of the fact that BCS performs resource scheduling based on both buffer status and channel condition. Therefore, BCS compromises lesser on sum throughput compared to BBS and RRS while providing least packet drop probability. Although the goal of BBS is to minimize packet drop, it is unable to do so because of channel unawareness.

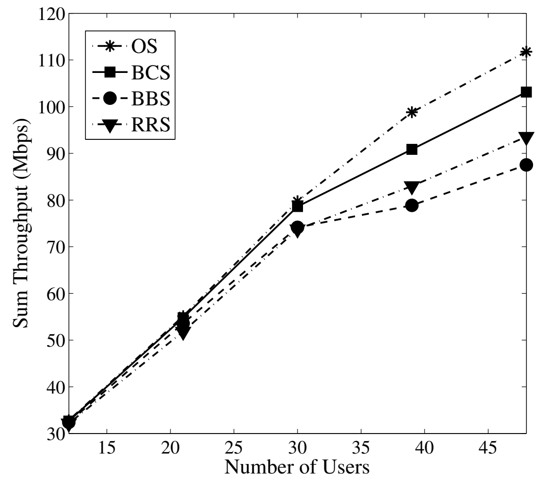


Fig. 3. Comparison of Sum Throughput for BCS, BBS, OS and RRS

To illustrate the significance of BSR [2], we compare the performance of BCS for two cases: Case I, BSR available in LTE and Case II, Limited Buffer Reporting (LBR) discussed in literature [6]. Comparison is in terms of packet drop probability and resource utilization efficiency. Resource utilization efficiency ($\eta$), as discussed in Section I, is computed as:

$$\eta = \frac{\sum_{n=1}^{N} Ps_n}{\sum_{n=1}^{N} Ps\_max_n} \tag{15}$$

where $Ps_n$ is the number of packets served using resource $n$ and $Ps\_max_n$ is the maximum number of packets that could have been served if the resource $n$ was fully utilized. $\eta$ varies from 0 to 1, where 1 represents maximum utilization efficiency. We observe that $\eta$ in Case I approaches one (Fig.4). We also observe that the packet drop probability in Case I is much less compared to Case II (Fig. 5). Thus, incorporating BSR in scheduling makes the system more efficient.

We also investigate the significance of buffer-based resource partitioning. For this, we compare the packet drop probability of BCS for two cases: Case I, buffer-based resource partitioning followed by buffer-based channel dependent scheduling and Case II, user based resource partitioning followed by buffer-based channel dependent scheduling. We can observe in Fig. 6 that the packet drop probability for Case II is higher compared to Case I. This reinforces the fact that the use of buffer state information in resource partitioning as well as scheduling helps reduce the packet drop probability.

In addition, we analyze the fairness aspect of our scheduler. We define a scheduler to be fair if it provides a fair distribution of resources among UEs. We use Jain's Fairness Index (JFI)

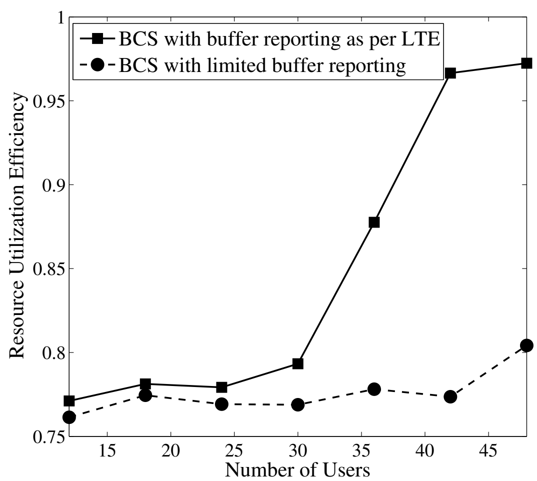


Fig. 4. Resource Utilization Efficiency for BCS with BSR and LBR

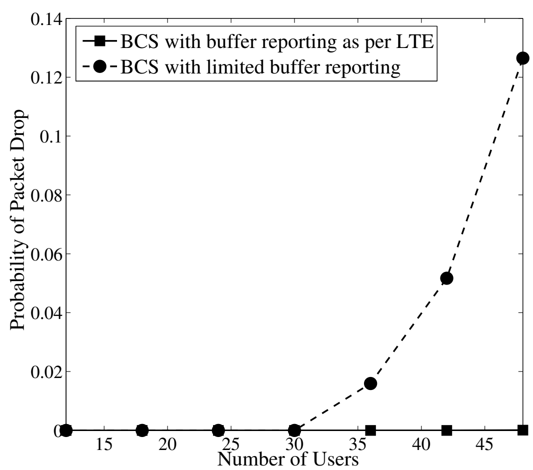


Fig. 5. Packet Drop Probability for BCS with BSR and LBR

to compute the fairness, which is given by:

$$JFI = \frac{(\sum_{u=1}^{U} R_u)^2}{U \sum_{u=1}^{U} R_u^2} \tag{16}$$

where $R_u$ is the throughput of the $u^{th}$ user. The value of JFI ranges from $1/U$ to 1. Fairness of a scheduler increases with the increase in JFI. We calculate JFI of BCS, OS, and RRS for two extreme values of $U$ considered in the simulation (i.e. 12 and 48). JFI of the schedulers are $0.98$, $0.92$, and $0.95$ for $U = 12$ and $0.97$, $0.84$, and $0.92$ for $U = 48$, respectively. We observe that BCS provides higher degree of fairness compared to other schedulers. This is so because an unscheduled UE will have a longer buffer length and hence, in case of BCS, higher probability of getting scheduled in the next interval. Also, we analyze the outage probability (ratio of number of UEs with $R_u < R_{min}$ to total number of UEs) of aforementioned schedulers. For $R_{min}$ = $1.5$ Mbps

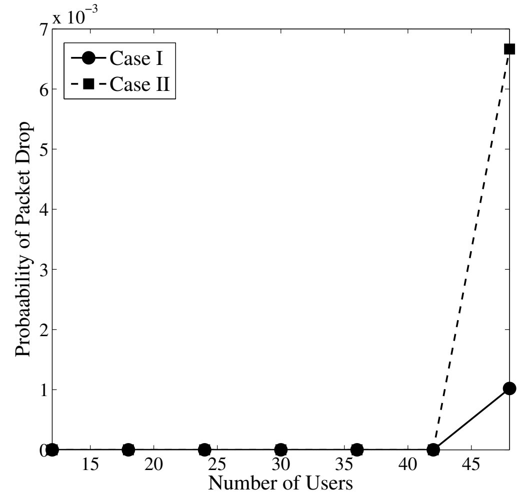


Fig. 6. Comparison of Packet Drop Probabilities for BCS with buffer (Case I) and user (Case II) based resource partitioning

and $U = 48$, outage probability of BCS, OS and RRS are $0$, $0.25$ and $0.29$, respectively. Hence, BCS offers lesser outage probability compared to OS and RRS.

## VI. Conclusions

In this paper, we have considered the UL scheduling in relay-assisted LTE networks. We have analyzed the significance of buffer state information in resource partitioning and scheduling. We have suggested a novel approach of implementing a scheduler that uses both buffer state and channel condition to make scheduling decision. Our simulation results indicated that the proposed scheduler provides reduction in packet drop probability and increment in resource utilization efficiency while ensuring fairness among UEs. In addition, they illustrated that BCS offers lesser outage probability compared to other schedulers considered in this paper.

## References

[1] 3GPP TR 25.814, "Physical Layer Aspects for Evolved Universal Terrestrial Radio Access (UTRA)," (Release 7), V7.0.0 (2006-06).
[2] 3GPP TS 36.321, "Evolved Universal Terrestrial Radio Access (E-UTRA) Medium Access Control (MAC) protocol specification," (Release 8), V8.5.0 (2009-03).
[3] K. V. Pradap, V. Ramachandran, and S. Kalyanasundaram, "Uplink Buffer Status Reporting for Delay Constrained Flows in 3GPP Long Term Evolution," in *Proceedings of WCNC*, 2009, pp. 1250–1255.
[4] G. Youjun and L. Guangyi, "Two-Level Buffer State Report Scheme for 3GPP LTE System," in *Int. Conference on WiCom*, Sept. 2009, pp. 1–5.
[5] D. Niyato and E. Hossain, "Queue-Aware Uplink Bandwidth Allocation and Rate Control for Polling Service in IEEE 802.16 Broadband Wireless Networks," in *IEEE Trans. on Mobile Computing*, vol. 5, 2006.
[6] M. Al-Rawi, R. Jantti, J. Torsner, and M. Sagfors, "On the Performance of Heuristic Opportunistic Scheduling in the Uplink of 3G LTE Networks," in *Proceedings of PIMRC*, Sept. 2008.
[7] A. Goldsmith, *Wireless Communications*. Cambridge Univ. Press, 2005.
[8] K. Kim, Y. Han, and S. L. Kim, "Joint Subcarrier and Power Allocation in Uplink OFDMA Systems," *IEEE Communications Letters*, vol. 9, no. 6, pp. 526–528, June 2005.
[9] 3GPP TR 36.942 V1.12.0, "Radio Frequency (RF) System Scenarios," Tech. Rep. Release 8, 2007.
[10] J. Lim, "Adaptive Radio Resource Management for Uplink Wireless Network," June 2006.