New Adaptive Resource Allocation Scheme in LTE-Advanced

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Abstract. To cope with the increasing demand of multimedia applications, Long Term Evolution Advanced (LTE-A) networks were introduced. Indeed, this promising technology supports a high transmission rate, a wide range of voice (VoIP) as well as video services and data. Moreover, LTE-A guarantees lower latency and higher spectral efficiency compared with Long Term Evolution (LTE). However, it is necessary to efficiently benefit from scarce network resources in order to achieve high performance. Therefore, we propose, in this paper, a new scheduling algorithm for LTE-A uplink systems entitled Adaptive Resource Allocation Process (ARAP) that supports uplink multiuser transmissions. The main contribution of this work is to allocate the Physical Resources Blocks (PRBs) to Real Time (RT) and non-Real Time (NRT) users using various criteria. Our proposed algorithm aims to at providing a fair distribution of PRBs, maximizing the system throughput and reducing queuing delay of the RT packets. Simulation and analysis showed that ARAP has a significant positive impact on delay and throughput performance.

Keywords: QoS · Scheduling · LTE-A · ARAP · Throughput

1 Introduction

The Long Term Evolution Advanced (LTE-A) is the enhanced version of Long Term Evolution (LTE) compatible with all versions of the LTE systems. Indeed, an LTE user can easily communicate in the LTE-A network. The International Telecommunication Union (ITU) defined the requirements of the 4G system, called International Mobile Telecommunications-Advanced (IMT-A). Indeed, the 4G system supports higher system capacity compared with LTE. The LTE-A supports a downlink data rate of 1 Gbps and an uplink peak data rate of 500 Mbps [1]. This network specifies that a User Equipment (UE) supports bandwidth up to 100 MHz. To support this high capacity, many techniques were introduced for LTE-A. For instance, we can cite the Carrier Aggregation (CA), Coordinated Multiple Point (CoMP), MIMO-Advanced technology and relay nodes [2]. In CA, multiple LTE Component Carriers (CCs) that

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belong to various frequency bands can be aggregated. So, a higher throughput can be achieved using this technique. An overview of technical issues regarding CA for LTE-A systems was presented in [3].

Call Admission Control (CAC), scheduling and resource allocation in LTE-A are implemented at the evolving NodeB (eNodeB). Indeed, this station is responsible for controlling the frequency and time domain resource in both uplink and downlink transmissions.

The resource in LTE-A is defined by a couple of frequency and time domains named as Physical Resource Blocks (PRB). The management of these PRBs is handled by the scheduling algorithm. The later selects a UE to be scheduled in the next Transmission Time Interval (TTI) based on its QoS requirements. Then, for the resource allocation step, the eNodeB needs some channel quality information perceived by each UE. This channel quality information is obtained by Sending Sounding Reference Signal (SRS) and Channel Quality Indicator (CQI) values. These values are computed by the eNodeB of each PRB for each UE.

In the LTE-A standards, any guideline of scheduling and allocation algorithm has to be defined [4]. Later on, different service flow criteria were used in literature to design and test scheduler. In this paper, we propose a scheduling algorithm for LTE-A. To design and simulate our scheduling algorithm, we select 'Vienna LTE-A' simulator [5, 6]. This simulator contains delay budgets, channel conditions and other LTE-A services parameters.

The rest of this paper is organized as follows: First, Sect. 2 discusses some of the relevant research works. In Sect. 3, we describe the principle of our proposed scheduling scheme called Adaptive Resource Allocation Process (ARAP). Then, Sect. 4 presents the performance evaluation of ARAP in terms of Packet Drop Rate (PDR), throughput and fairness. Finally, Sect. 5 concludes the paper and discusses the future research challenges.

2 Related Work

2.1 Review of Existing Scheduling Schemes

In this section, give an overview of the existing LTE-A scheduling algorithms.

In [7], the authors focused on the CC method selection for macro-cell LTE-A UEs. The UEs aggregate different CCs having various frequency bands with different radio propagation characteristics. To achieve higher performance, the authors proposed load balancing scheduling schemes for the inter-band CA processes.

In [2, 8], two classical packet scheduling schemes were studied. These schemes are Proportional Fairness (PF) and maximum CQI (MAX C/I) exploiting multi-user diversity. The PF allocates PRBs to UEs based of their instantaneous data rate and acquired time average throughput. This scheme takes into account fairness among users. The MAX C/I aims at maximizing the total system throughput. Then, it allocates PRBs to users having the highest channel qualities.

In [9], Zhao et al. proposed a modified version of PF called Similar PF (SPF). This scheduling algorithm, based on the classical PF scheme in crossing CC joint scheduling, calculates the user weight on each CC and adopts the PF scheduling to calculate the scheduling weight at each TTI.

In [10], Y.-L. Chung et al. developed a new scheduler. Their work aims at designing an Efficient Packet Scheduling Algorithm (EPSA) in LTE-A networks. The proposed scheme takes into consideration the QoS requirements, such as delay and throughput performance. The QoS requirements are studied in both types of traffics: RT and NRT. The scheduler guarantees portion of reserved PRBs for RT packets without neglecting the NRT packets.

In [11], the authors modified the scheduler proposed in [10]. The proposed scheme reserves portion of PRBs to Guaranteed Bit Rate (GBR) and the rest of PRBs for Non GBR (NGBR) and selects a specially period to transmit NGBR packets.

A new scheduling algorithm was introduced in [12]. The authors presented a quantized water-filling packet scheduling algorithm for high data rate users in LTE-A with CA systems. In this work, several QoS performances were provided, especially to enhance the delay performance.

Another algorithm, developed for LTE-A system was presented in [13]. In this work, the traffics are classified into various service classes flows. They attribute different scheduling priorities to each class. After the classification step, the authors followed the Hebbian learning process to assign PRBs to different class of service an adaptively.

The authors in [14] proposed a new scheduling algorithm named Adaptive Hybrid Scheduling Algorithm (AHSA). This algorithm is based on adapting Kwan [15] and PF schedulers in the LTE-A network. The authors analyzed the effect of this algorithm in terms of users' fairness and throughput on the cell performance of PF and Kwan schedulers. They showed that the AHSA scheduler overcomes the uplink delay effect on the scheduler performance.

2.2 Discussion of Reviewed Works

From the overview of the afore-mentioned works, we conclude that:

- Some authors did not consider the QoS requirements of different applications and multiclass traffics as it is the case in [2, 7, 8].
- Some schedulers did not take into account fairness among users, which is the case of schedulers elaborated in [10, 11].

Hence, there is a need for a scheduler that supports both RT and NRT traffics and handles all services flow by considering the priority of each class of service and fairness among users. To tackle these objectives, we designed a new scheduler called Adaptive Resource Allocation Process (ARAP). Mainly, we used a threshold value named ∂ to efficiently manage the RT and NRT queues. Based on ARAP, flows are served based on the RT and NRT queues status and their priority. Our proposed scheduler handles the differentiation between RT and NRT traffics classes. It aims at improving the throughput as well as the fairness. The principle of our proposal as well as its performance analysis will be discussed in the next sections.

3 Proposed Scheme

The objective of our resource allocation algorithm is to optimize the use of the resources, maximize the system throughput and ensure the fairness of resources sharing.

The packets, coming to the network from mixed traffic, are classified into two queues (one for RT packets and one for NRT packets). This classification is useful because the latency of each packet depends on the type of its traffic, by respecting the delay budget (the upper delay bound). These two queues will be served on the basis of ARAP.

Let $tpck_{RT}$ be the RT packet delay and $D_{max(RT)}$ be the RT packet delay budget. Evidently, each RT packet delay must not exceed its delay budget (i.e: $tpck_{RT} < D_{max(RT)}$). If this condition is not respected, the packet will be removed from the RT queue. The same strategy is applied for the NRT traffic. Let $tpck_{NRT}$ be the NRT packet delay and $D_{max(NRT)}$ be the delay budget. Then, condition $tpck_{NRT} < D_{max(NRT)}$ will be respected. $LENG_{RT}$ is the length of RT packets in the queue and THR_{RT} represents the RT queue threshold size. RT packets, which are buffered in the RT queue, are delivered every TTI. However, NRT packets are delivered whenever the condition $LENG_{RT} < THR_{RT}$ is satisfied.

To improve the QoS for RT traffics, we define a new parameter, called ∂. It represents the portion of PRBs reserved for the RT traffic. This parameter is given as follows (Eq. (1)):

$$\partial_{t+1} = \begin{cases} \mathbf{min}(\partial_t + \mathcal{B}, \partial_{max}) & \textit{if } \boldsymbol{LENG_{RT} \geq THR_{RT}} \\ \mathbf{max}\,(\partial_{min}, \partial_t - \mathcal{B}) & \textit{if } \boldsymbol{LENG_{RT} < THR_{RT}} \end{cases} \quad 0 < \mathcal{B} < 1 \tag{1}$$

The ratio of the reserved PRB for RT traffic, in time t + 1, depends on $LENG_{RT}$. Indeed, ARAP increments or decrements the reserved resources for RT traffic based on the RT queue occupation ratio (in previous time t). However, parameter $\mathcal{B}$ is the increment/decrement of the reserved PRBs for the RT traffics. We suppose that parameter $\mathcal{B}$ is a constant value varying between 0 and 1. ∂_{min} is proposed to guarantee a minimum of reserved PRBs for RT class. However, ∂_{max} value is introduced to ensure a minimum number of PRBs for the NRT class in order to avoid starvation. If the $LENG_{RT}$ is equal or higher than THR_{RT}, there will be a significant number of RT packets that are not served. Subsequently, we must increase the number of the reserved PRBs for RT traffics to guarantee a certain level of QoS for these RT packets. However, if the $LENG_{RT}$ is lower than THR_{RT}, then the reserved PRBs for the RT traffic can decrease with $\mathcal{B}$ value to serve the NRT packets waiting in NRT queue. Therefore, our scheme allows decreasing the queuing delay of the RT packets and minimum PDR for RT and NRT traffics by increasing the PRBs allocated to NRT traffic when $\boldsymbol{LENG_{RT}}$ is lower than the threshold. Thereafter, ARAP algorithm serves the RT packets without totally neglecting the NRT packets.

The served users are selected PF metric as defined by (2):

$$\text{metric } (\mathrm{i}^*) = \frac{\mathrm{r_i}}{\mathrm{R_i}} \tag{2}$$

Where r_i is the instantaneous throughput of user i and R_i is the average throughput of user i.

Figure 1 illustrates the main ARAP steps and the steps of ARAP scheme are as follows:

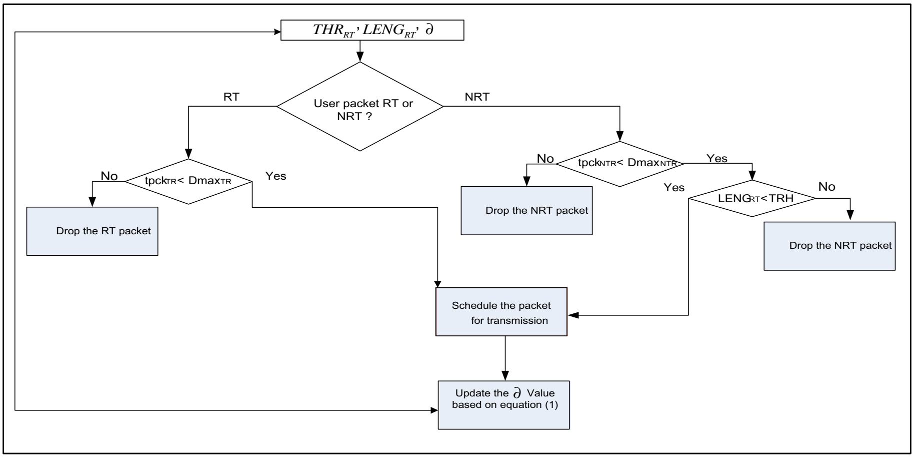

Fig. 1. ARAP design

- Step 1: Deliver RT packets buffered in the RT queue if $tpck_{RT} < D_{max(RT)}$ in the current scheduling s.
- Step 2: Deliver NRT packets buffered in the NRT queue if $tpck_{NRT} < D_{max(NRT)}$ and $LENG_{RT} < THR_{RT}$ in $s + 1$ iteration.
- Step 3: Update the ∂ according to Eq. (1)
- Step 4: Drop the RT and NRT packets if their delay constraint does not respect $D_{max(RT)}$ and $D_{max(NRT)}$, respectively
- Step 5: Repeat the first four steps until all PRBs will be allocated or the RT and NRT queues will become empty.

4 Performance Evaluation

In this section, we present the simulation model and the experimental results obtained by applying the algorithm proposed in Sect. 3.

4.1 Simulation Model

In LTE-A, the evolved NodeB (eNodeB) is responsible for performing the tasks of resource allocation and the Packet Scheduling (PS). The latter is considered as the most important step of Radio Resource Management (RRM) [4]. It contains Time Domain (TD) and Frequency Domain (FD) scheduling algorithms. At each TTI, in the UL direction, the Channel State Information (CSI) is measured directly from the Sounding Reference Signal (SRS) signals issued by the UE. The eNodeB considers this information to decide which UE will be served in the next TTI.

Our scheme is simulated using 'Vienna LTE-A' simulator which supports both networks: LTE Release 8/9 and LTE-A. In the latter considers simultaneously two CCs. We define a number of UEs that varies between 10 and 70. The users' positions are uniformly distributed at the beginning of simulation. The random-walk model is considered as the mobility model.

Requests arrive at eNodeB as Poisson processes with parameter λ. Then, service time is measured by an exponential distribution with mean 1/μ. The total system bandwidth, where two adjacent CCs are considered, is equal to 10 MHz. The simulation duration is 1000 TTIs. We compare our proposed scheme with RR, BCQI and ASHA. More details on the simulation parameters are given in Table 1.

Table 1. Simulation parameters

Parameters	Value
System bandwidth	10 MHz
Subcarrier spacing	15 kHz
Number of subcarriers per PRB	12
Number of available PRBs	50
Transmission time interval (TTI)	1 ms
Total number of used subcarriers	600
Carrier frequency	2.5 GHz
Frame duration	10 ms
Number of users	10–70
Simulation Time	1000 TTIs
Link adaptation ACM Modulation	BPSK, QPSK,16-QAM, 64-QAM
$\partial_{\min}, \partial_{\max}$	0.2, 0.8
Scheduling algorithms	RR, BCQI, AHSA and ARAP

4.2 Simulation Results

In this section, we evaluate the performance of ARAP, RR, BCQI, and AHSA in terms of PDR, number of served users, fairness, and throughput.

4.2.1 Packet Drop Rate (PDR)

The PDR of traffic flow f can be measured as shown in Eq. (3) [16].

$$PDR_f = \frac{(\text{Npkt\_tx})_f \times (\mathbf{1} - \boldsymbol{PER})_f}{total\_\text{Npkt\_tx}_{.}} \tag{3}$$

where $\text{Npkt\_tx}_{.}$ is the number of the transmitted packets of the traffic flow f and $\text{total\_Npkt\_tx}_{.}$ is the total number of transmitted packets of all traffics. PER is the average packet error probability when the traffic flow f transmitted.

The PDR of RT and NRT traffics is presented in Figs. 2 and 3, respectively. As shown in the former, our proposed scheme provides the minimum PDR which can be explained by the fact that ARAP handles the packets buffered in each queues (RT and NRT) adaptively. For the RT traffic, when the number of packets buffered exceeds threshold THR_{RT}, then more PRBs will be allocated to the RT traffic. Therefore, the number of RT dropped packets is minimized. We note that the PDR of ARAP is slightly higher than that of AHSA when the number of users is between 40 and 50. Indeed, the number of PRBs allocated for RT traffic is dynamic. However, AHSA scheduling strategies are generally based on PF and Kawn methods, which makes the number of PRBs, used by RT traffic, relatively fixed.

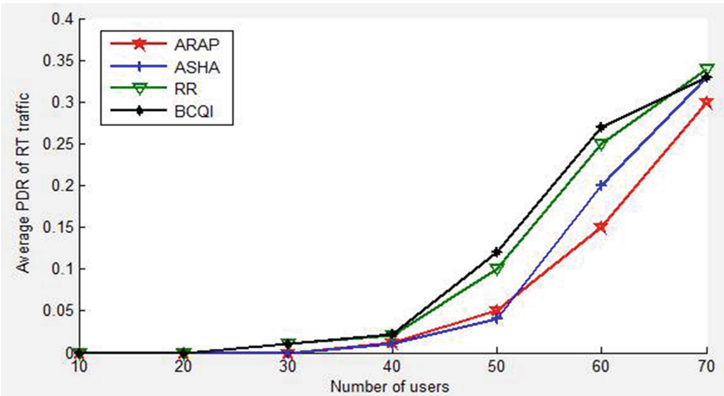

Fig. 2. Average PDR of RT traffic

If the number of RT packets buffered in RT queue is less than threshold THR_{RT}, ARAP decrements the number of PRBs allocated to the RT traffic and assigns more PRBs to NRT traffic. Thus, the NRT packets, dropped by ARAP, is lower than that of the other schedulers (see Fig. 4). We note that the PDR of the NRT traffics is higher than that of the RT traffics because ARAP serves the RT traffics at each TTI t. However, the NRT traffics will be transmitted only when the condition ($\boldsymbol{LENG_{RT} < TRH_{RT}}$) is satisfied.

4.2.2 Number of Served Users

The number of served users as a function of the total number of users is shown in Fig. 4. From this figure, we clearly observe that ARAP serves an interesting number of users because it can schedule more users by giving the needful PRBs for each one.

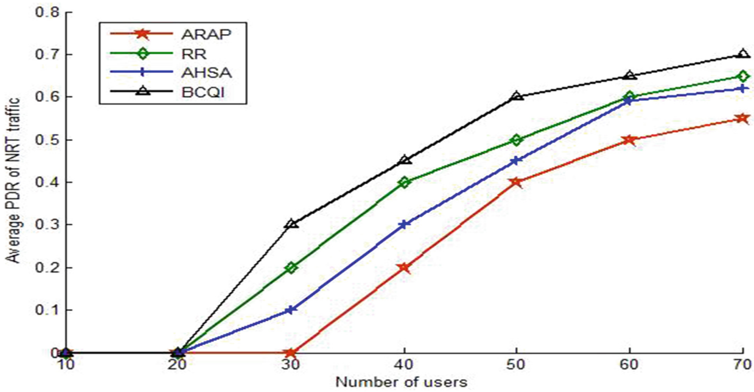

Fig. 3. Average PDR of NRT traffic

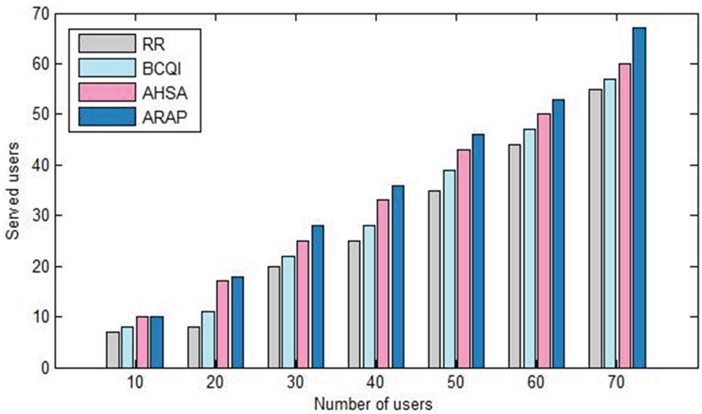

Fig. 4. Number of served users

This allows accepting greater number of users and maximizing the total number of the used PRBs. Indeed, the PRBs is effectively used thanks to the concept of resource allocation algorithm which adjusts appropriately the allocation of resource.

4.2.3 System Throughput

The system throughput is measured as the total number of bits successfully transmitted per second [17].

Figure 5 shows the average system throughput of RR, BCQI, AHSA and ARAP algorithms as a function of the number of UEs. Evidently, BCQI provides the best throughput because it always favors the UEs having the most efficient MCSs. We also observe that ARAP outperforms AHSA and RR schedulers. Indeed, ARAP can serve much more users compared to other algorithms (see Fig. 4). which requires harness the maximum of the available resources blocks which the overall throughput. Moreover, we can classify ARAP scheme as a QoS-aware scheduler. This category of schedulers

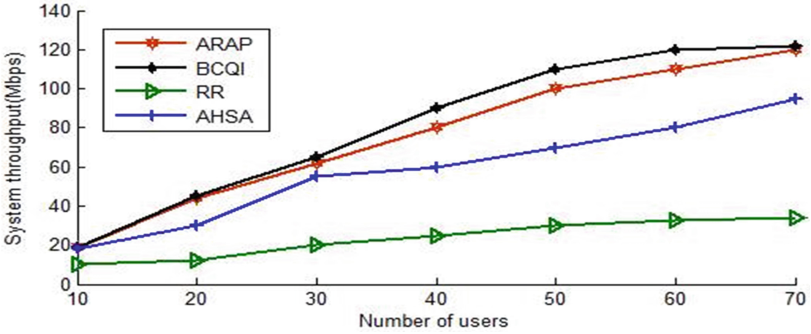

Fig. 5. System throughput

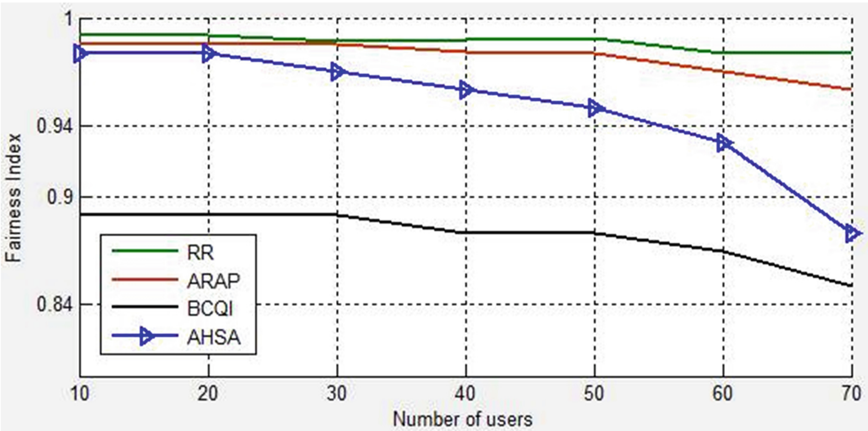

Fig. 6. Fairness index

distinguishes various UEs and allocates more PRBs to higher priority traffics. In this case, ARAP assigns more PRBs for RT traffics if the number of packets, buffered in RT queue, exceeds the threshold THR_{RT}. Briefly, results shown in Fig. 6 prove that ARAP approach has an important positive impact on global system throughput behavior.

4.2.4 Fairness Index

The fairness of the approaches was evaluated using the Jain's fairness index. The definition of this index is stated in [4, 18]. This fairness index is calculated as follows:

$$\boldsymbol{F}\left(\mathbb{C}^1, \mathbb{C}^2, \mathbb{C}^3, \ldots \cup \mathbb{C}^n\right) = \frac{\left(\sum_{\mathbf{j=1}}^{\mathbf{n}} \mathbb{C}^{\boldsymbol{i}}\right)^{\mathbf{2}}}{\boldsymbol{n} \times \sum_{\mathbf{j=1}}^{\mathbf{n}} \left(\mathbb{C}^{\boldsymbol{i}}\right)^{\mathbf{2}}} \quad (4)$$

where n represents the total number of UEs and $\mathbb{C}^{i}$ denotes the number of resources assigned to user i. Jain's fairness index returns a value between 0 and 1. The latter corresponds to the best fairness in the system. Figure 6 shows the fairness results obtained by applying RR, BCQI, AHSA and MURPA. We notice that when the number of users increases, it is expected that the fairness index decreases as more UEs compete for the same number of PRBs. The maximum value of Jain's fairness index is obtained when the RR scheduler is used. This result is logical because RR assigns almost the same number PRBs for all UEs. Moreover, we observe that the ARAP and RR curves are close which can be explained by the fact that ARAP adjusts its scheduling decision depending on the previous queue status (depending on threshold THR_{RT} value). Then, ARAP schedules the RT traffic without neglecting the NRT traffic.

5 Conclusion

In this paper, we proposed a new scheduler, named ARAP, to joint together the benefits of the classification services. Indeed, we used a threshold value ∂, to efficiently manage the RT and NRT traffics. Based on ARAP, flows are served based on the RT and NRT queues status and on their priority. Indeed, the RT flows can be served at each TTI. However, the NRT flows can be served only if the condition $LENG_{RT} < THR_{RT}$ is satisfied. Simulation results proved that ARAP serves flows having lower delays and better throughput compared to RR and AHSA schedulers. Particularly, ARAP has a significant positive impact on PDR and throughput performance. Moreover, our scheduling algorithms outperforms RR and AHSA in term of the number of the served users and fairness.

As future work, we plan to extend the proposed ARAP when entering the Remote Radio Head (RRH) in the system. In this case, the LTE-Advanced with several RRHs may use an efficient scheduler to avoid packet losses and flow accumulation in queues.

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