A PDR-Based Scheduling Scheme for LTE-A Networks

Ayman Hajjawi[1], Mahamod Ismail[1], Nor Fadzilah Abdullah[1], Rosdiadee Nordin[1], and Özgür Ertuğ[2]
[1]The National University of Malaysia (UKM), Bangi, 43600, Malaysia
[2]Gazi University, Ankara, Turkey
Email: ertug@gazi.edu.tr, ayman_2747@yahoo.com; {mahamod, adee}@eng.ukm.my; fadzilah.abdullah@ukm.edu.my

Abstract —Carrier Aggregation (CA) technology is one of the enhancements keys which supports high bandwidth up to 100 MHz in Long Term Evolution Advanced (LTE-A) networks. CA technology has been developed by The 3rd Generation Partnership Project (3GPP) to serve mobile users with high data rate up to 1 Gbps for downlink and 500 Mbps for uplink. However, 3GPP has not defined a firm provision to handle scheduling process so that scheduling becomes an open issue. This paper proposes a novel scheduling algorithm based on Packet Drop Rate (PDR) and cooperative game theory mechanisms. In the first stage, the classes are classified based on the PDR including both Real-Time and Non Real-Time classes. In the second stage, the proposed algorithm forms a coalition between classes, allowing them to share bandwidth. Then, the available resources are distributed as a proportion among classes to guarantee the minimum requirements for high priority applications and give a chance to low priority applications to be served. The proposed scheme is evaluated in terms of throughput, delay, and fairness and compared with Proportional Fairness (PF) and Exponential-rule (EXP-rule) algorithms. The proposed scheme outperforms the other two comparative algorithms in terms of throughput, delay and fairness index.

Index Terms—Scheduling, resource allocation, LTE-A, 4G, QoS, RT applications

I. INTRODUCTION

Long Term Evolution (LTE) was proposed by The 3rd Generation Partnership Project (3GPP) in order to support higher data rate up to 100 Mbps for downlink and 50 Mbps for uplink [1]. However, because of the need of high date rates and low latency, Carrier Aggregation (CA) technology has been introduced to expand the bandwidth which results in higher data rate and lower delay [2].

Scheduling affects the performance of the network because it is responsible for bandwidth resources distribution among the users, which also affects the Quality of Services (QoS) provision [3]. 3GPP has not defined a single scheduling algorithm that is able to handle the packet scheduling for both downlink and uplink sides. So that scheduling becomes an open issue that considerably attracts researchers [4], [5]. Designing a scheduler is a challenging issue since the network supports different types of traffic with different QoS requirements. The main issues which should be considered during the design process are fairness, throughput and complexity.

LTE utilizes Orthogonal Frequency Division Multiple Access (OFDMA) and Multiple-Input and Multiple-Output (MIMO) technologies which significantly improve the network's performance [6], [7]. The smallest allocated bandwidth unit in LTE is called resource block that is 0.5 in terms of time and 180 KHz in terms of frequency as illustrated in Fig. 1. Each physical frame is composed of 10 sub-frames with 10 ms each. Every single channel is divided into sub-channels and each sub-channel (180 KHz) consists of 12 sub-carriers [8], [9].

However, scheduling can be designed in two forms: Independent-Components Carrier (ICC) and Cross-Component Carrier (Cross-CC) [10]. ICC scheduler allocates the available resources independently nevertheless the other Component Carriers (CCs) status. On other words, each CCs has its own scheduler and it doesn't consider other CCs characteristics as shown in Fig. 2.

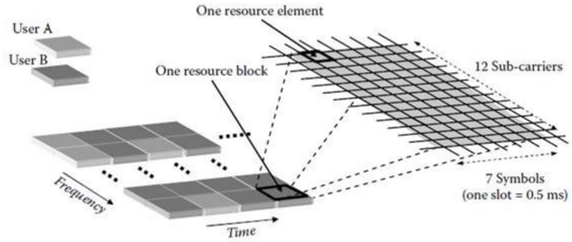

Fig. 1. LTE resource block

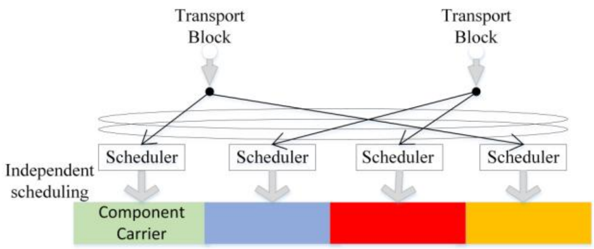

Fig. 2. Independent- Component Carrier (ICC) scheduler

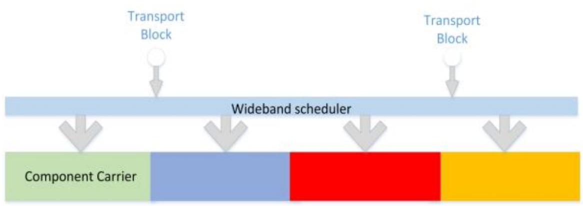

Fig. 3. Cross- Component Carrier (Cross-CC) scheduler

Manuscript received May 25, 2016; revised September 21, 2016
Corresponding author email: ayman_2747@yahoo.com
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On the contrary, Cross-CC scheduling is proposed for multiple CCs as illustrated in Fig. 3. However, Cross-CC scheduling has proved better performance over IC scheduling in terms throughput and delay [11].

This paper proposes a scheduling algorithm based on Packet Drop Rate (PDR) and cooperative game theory (Shaply algorithm). In the first stage, the proposed algorithm determines the PDR for all classes and allocates the bandwidth resources to the classes based on the PDR. In the second stage, the bandwidth resources are allocated to the users in the class based on Shaply algorithm. Forming Coalitions among classes using cooperative game theory adds several advantages to the resource allocation such as allowing bandwidth sharing among the classes. In other words, when a class allocated extra resources, it is allowed to give the extra resources to other classes. This concept has significantly improved the resources allocation. Moreover, the resources are allocated among users as proportion which prevents Non-Real Time (NRT) applications from being starved. In addition, a queuing algorithm is proposed to prioritize the users with the tightest delay requirements.

The rest of the paper is organized as follows. Section 2 is dedicated to explain and addresses the weakness of the recent works. The system model is illustrated in Section 3 and the simulations scenario with its main parameters is presented in Section 4. Section 5 provides full analysis and discussion of the results and section 6 concludes the paper.

II. Related Works

Several algorithms have been proposed to enhance the user's satisfaction. Take, for example, Best Channel Quality Indicator (BCQI) scheme which allocates resources to the users with highest Signal to Noise Ratio (SNR) value [12]. In fact, this approach causes a huge starvation to the users with bad channel conditions (e.g. users who are located far from the base station). Classical schedulers such as Proportional Fairness (PF) approach that improves the fairness among users in term of throughput [13], [14]. To do so, PF calculates the past average throughput achieved by the user and the expected throughput of the same user as in (1). Such scheduler cannot be practically implemented because it doesn't have any delay form. Furthermore, in the case there are two users, one with good channel conditions and the other is a bad channel user. PF scheme distributes the Resources Block (RBs) to user who has been starved in the last TTI and ignores the user with good channel conditions, which results in a huge system throughput degradation.

$$M_{k,i} = \frac{r_{k,i}(t)}{R_i(t)} \quad (1)$$

where $R_i(t)$ is the average throughput for user k and $r_{k,i}(t)$ is the expected throughput for user k. The authors in [15], [16], proposed Round Robin (RR) which allocates time resources equally among users. RR scheme is considered a fair scheduler in term of time where all users are allocated equal amount of time as shown in (2).

$$m_{i,k}^{RR} = t - T_i \quad (2)$$

where t is the current time and T_i refers to the last time when the user was served. RR scheduler is not appropriate choice to be implemented in real LTE-A networks because it doesn't have any delay form. Another scheduling scheme, Maximum Throughput (MT), that was a successful approach which could significantly improve the overall system throughput [17]. In contrast, it failed to serve the users with low SNR since it allocates the available resources to the users with the highest Signal to Noise Ratio (SNR). The authors in [18], proposed resource pre-emption approach that provides priority service according to the QoS requirements in order to handle the differentiation between QoS and non-QoS flows. The main idea behind is that, all flows are grouped in priority classes and the class whose priority is the highest served first until all high class priority flows served then low priority class flows are served. Such a scheme causes a huge starvation to low priority class service. Ref. [19], [20] proposed a scheduler that takes into consideration both RT and NRT applications, and showed acceptable performance for both RT and NRT. But the main weakness is the complexity, where the scheduling decision should be taken within only 1 ms. Ref. [21], [22] proposed scheduling algorithms which basically allocates resources based on the PDR in the first level and delay queuing algorithm to prioritize users with tightest delay requirements in the second level. This scheme concerns about both RT and NRT applications and serves users within their delay constraint, but NRT applications are still starved since in the second level the proposed scheme focus only on RT users. Here in this paper, in the first level, the proposed scheme calculates the PDR for all classes. In the second level, the resources are distributed as proportion in order to prevent NRT application from being starved. At the same time, it guarantees the minimum requirements for RT applications.

III. System Model

The proposed algorithm is divided in two stages where in the first stage the PDR is calculated for all classes based on self-learning technique. Then, the RBs are allocated to the users as proportion based on cooperative game theory (Shaply algorithm).

In the first stage, the PLR value is determined for all classes as in (3).

$$PDR = \frac{1}{k}\sum_{k=1}^{k} - \frac{n_k^{dropped}}{n_k^{total}} \quad (3)$$

where $n_k^{dropped}$ is the total number of packets dropped for user k and n_k^{total} is the total number of packets sent to user k. a, b, c represent the weights of the classes, here in this work we consider three classes namely Real-Time, Non-Real Time and Best Effort classes as in (4).

$$a+b+c=1 \tag{4}$$

The value of a, b and c are initially calculated as a ratio of the number of active users in each service to the active users in whole system as shown in (5).

$$a=\frac{A}{A+B+C},\ b=\frac{B}{A+B+C},\ c=\frac{C}{A+B+C} \tag{5}$$

where A, B and C are the active number of users in RT, NRT and BE applications respectively. The number of allocated resources of the above applications are represented by α, β and γ respectively and calculated as in (6).

$$\begin{aligned}\alpha &= (\text{round off } a)\times M\\ \beta &= (\text{round off } b)\times M\\ \gamma &= (\text{round off } c)\times M\end{aligned} \tag{6}$$

where M is the total number of RBs. The PDR value is calculated for RT and NRT applications at each Transmission Time Interval (TTI) and kept in vectors R_T and N_RT. The calculated PDR values for RT and NRT applications of the current and previous TTIs are compared with the PDR threshold (p_{th}). The resource allocation strategy is changed due to the PDR changes. But in case when the PDR value change is so small, there is no need to change the resource allocation strategy. To achieve such a goal, the proposed algorithm utilizes trend indicators (I_RT and I_NRT) which indicate the increases or decreases of the PDR values and change the resource allocation strategy after a specific number of the PDR value changes.

In the second stage, after the bandwidth resources allocated to the classes based on the PDR, the bandwidth resources are allocated to the users in the class based on Shaply algorithm (game theory). However, game theory was proposed in economics where a group of players form a coalition to distribute the joint profits among their coalition [23]. A fair allocation algorithm is based on Shaply algorithm which was introduced to improve the fairness level and decrease the complexity. This concept is considered as fairness standard in economics and later on the authors in [24] , implemented Shaply in heterogeneous wireless networks. To calculate Shaply, let us define a faction $\varphi_i(v)$ as the value player i in the game with function v. Shaply is considered as the average payoff to a player if the player enters the coalition randomly as in (7).

$$\varphi_i(v)=\sum_{S\subseteq N}\frac{(|S|-1)!(n-|S|)!}{n!}(v(S)-v(S\setminus\{i\})) \tag{7}$$

where S is the number of players in the coalition, n is the total number of players, $v(S)$ is the coalition utility including player i, and $v(S\setminus\{i\})$ is the utility excluding player i. The aforementioned technique is based on three concepts, Efficiency, which means that the users or classes obtain a better allocation at the expense of others. Symmetry indicates that the final allocation decision doesn't depend on the time the user enters the game which shows how much Shaply is fair. The additivity concept shows how the values of different coalitions must be related to each other [25]. The users are prioritized according to their delay expiration, where the priority is given to the users with the tightest delay as in (8).

$$T_{co}(t)=T_{bj}(t)-\text{HOL}_j(t) \tag{8}$$

where $T_{co}(t)$ is defined as the difference in time between delay budget ($T_{bj}(t)$) and Head Of Line delay ($\text{HOL}_j(t)$).

IV. Simulation Scenario

The simulation tool used in this scenario is Vienna LTE-A simulator which is an open tool. The cell radius is 500 m and the number of users is 100 who are randomly distributed throughout the cell. The scheduling considered here is Cross-Carrier scheduling that uses multi Component Carriers. The Two CCs are used with operation frequency of 2.1 GHz and 800 MHz. Table I shows the main simulation parameters.

TABLE I: SIMULATION PARAMETERS

Parameter	Value
Cells No	Single cell
Users location	random
Path loss model	Cost231 model
System bandwidth	10MHz
TTI	1ms
Users speed	Up to 3 km/h
Base station radius	500 m

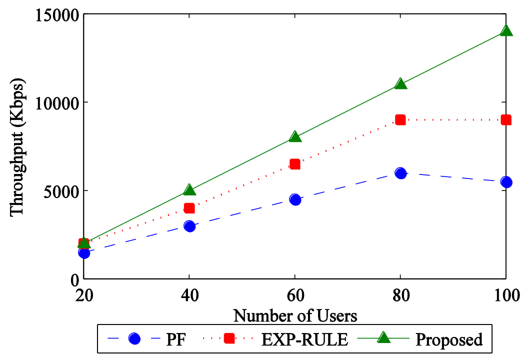

Fig. 4. Overall system throughput

V. Results and Discussion

The results are evaluated for overall system performance to show the robustness of the proposed algorithm. Fig. 4 shows a comparison between the comparative algorithms for overall system throughput.

The proposed algorithm illustrates the highest overall system throughput followed by EXP-Rule and PF respectively. PF scheme distributes the RBs to user who has been starved in the last TTI. EXP-Rule scheme performs well up to 80 users after that it gradually drops.

In terms of delay, the proposed algorithm illustrates the lowest delay compared to the other two schemes. The reason behind is that the proposed algorithm prioritizes users with tightest delay requirements first. EXP-rule scheme has performed better than PF, which illustrates the highest delay since it doesn't concerns about delay as shown in Fig. 5.

In terms of fairness index, the proposed scheme illustrates the highest fairness index for all classes. However, the proposed algorithm allocates the resources as a proportion among classes which prevents the NRT classes from being starved and thus achieves higher level of fairness. PF scheme also shows the lowest fairness performance whereas EXP-Rule performs better than PF as illustrated in Fig. 6.

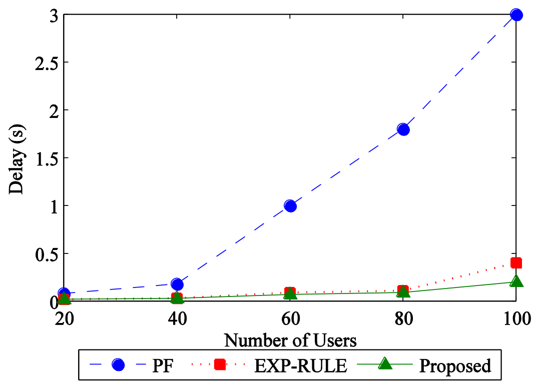

Fig. 5. Overall system delay

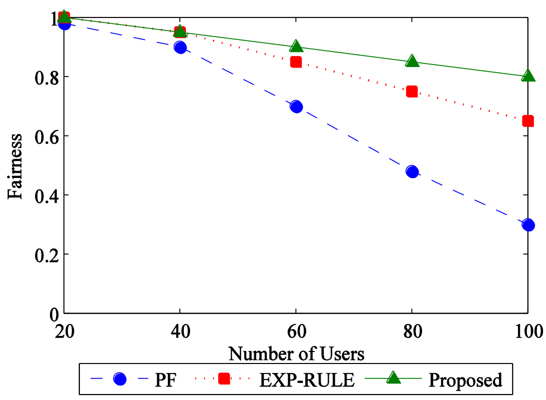

Fig. 6. Fairness index

VI. Conclusions

This paper has proposed a novel scheduling algorithm based on PLR and shapely algorithm which efficiently distributes the resources among classes. The results have been evaluated in terms of throughput, delay and fairness index and compared with PF and EXP-Rule algorithms. The proposed scheme has the highest throughput in low and overloaded scenarios whereas PF scheme has shown the lowest performance for the same parameters. EXP-Rule scheme has performed closely to the proposed algorithm in low loaded situation whereas in overloaded ones it has performed better than PF scheme.

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Ayman Hajjawi was born in Menbij, Syria, in 1987. He received the B.S. degree in Communications Engineering from Ittihad University, Syria, in 2010 and the M.S. degree in Telecommunications Systems from Technical University of Malaysia Malacca (UTEM), Malaysia, in 2013. His research interests include QoS in 4G & 5G networks. He is currently a Ph.D. fellowship student at the Department of Electronic, Electrical and System Engineering, The National University of Malaysia (UKM).

Mahamod Ismail was born in Selangor, Malaysia, in 1959. He received the B.S. degree in Electronics and Electrical Engineering from the University of Strathclyde, United Kingdom, in 1985 and the M.S. degree in Communications Engineering and Digital Electronics from the University of UMIST, Manchester, United Kingdom, in 1987. He is currently a professor at the Department of Electrical, Electronic and System Engineering. His research interests include mobile communications and wireless networking with particular interest on radio resource management for 4G and beyond.

Nor Fadzilah Abdullah received her PhD in Electrical and Electronic Engineering from University of Bristol UK in 2012, the M.Sc in Communications Engineering from University of Manchester, UK, and B.Sc in Electrical and Electronics degree from Universiti Teknologi Malaysia, in 2003 and 2001 respectively. She is currently a Senior Lecturer at Universiti Kebangsaan Malaysia (UKM), Bangi as well as an Honorary Staff of University of Bristol, United Kingdom. Her research interest includes 5G, millimeter wave, vehicular networks, MIMO, space time coding, Fountain code as well as channel propagation modeling and estimation.

Rosdiadee Nordin received his B. Eng. from Universiti Kebangsaan Malaysia in 2001 and Ph.D. from University of Bristol, United Kingdom in 2011. He is currently a lecturer in Department of Electrical, Electronics and System Engineering in Universiti Kebangsaan Malaysia. His research interests include Multiple-Input Multiple-Output (MIMO), Orthogonal Frequency-Division Multiple Access (OFDMA), resource allocation, green radio, intercell interference, cooperative diversity and indoor wireless localization.

Özgür Ertuğ received his B.Sc. degree in electrical engineering from University of Southern California, in 1997, M.Sc. degree in electrical and computer engineering at Rice University, Houston, Texas, 1999, and Ph.D. in electrical and electronics engineering (Telecommunications and Signal Processing) at Middle East Technical University, Ankara, Turkey. Currently, He is Associate Professor at the Electrical and Electronics Engineering Department, Gazi University, Ankara, Turkey. He also provides subcontract R&D and consultancy to TÜBİTAK, Ministries, EU and high-tech ICT companies. His main research interests lie in algorithm and architecture design as well as theoretical/simulation-based performance analysis of wireless/wired communication/signal processing systems/networks and communications/signal processing for defense and security systems. He is the author of about 60 refereed publications in international/national books, journals and conferences in these areas and holds 1 patents pending.