Performance Modeling and Evaluation of Novel Scheduling Algorithm for LTE Networks

Salman A. AlQahtani* and Mohammed AlHassany

***Abstract*— Long Term Evolution (LTE) is a cellular network technology developed to support a diversity of data traffic with high rates. A key scheme in LTE traffic processing is the packet scheduler, which is responsible for allocating resources to active flows in both the time and frequency dimensions. The scheduling scheme used largely impacts the throughput of individual users, as well as the throughput of the cell. The main contribution of this study is two folds. First, the performance of six scheduling schemes designed for an LTE network in terms of the user's throughput and fairness is modeled, evaluated and compared. The findings from our performance evaluation drew conclusions about the performance of the six schedulers and noted the strengths and weakness that are common to the schedulers under study. Second, a novel scheduling scheme is proposed and compared to the Best-CQI and RR uplink schedulers for LTE. Simulation results show that the newly proposed scheme allows fair distribution of available LTE resources while at the same time keeps the system capacity utilization as good as possible.**

***Index Terms*— Fairness, LTE network; Performance modeling; scheduling; throughput**

I. Introduction

LONG Term Evolution (LTE) is the evolution of an existing 3G mobile network towards a higher capacity, a lower latency and a more efficient core network and radio access. It will provide the additional capacity and lower cost-per-bit needed to sustain the exponential growth of mobile data. Therefore, LTE aims at better higher data rates, spectral flexibility, improved coverage, low latency and better battery lifetime. To achieve these goals, LTE employs the enabling technologies of Single Carrier Frequency Division Multiple Access (SC-FDMA), Orthogonal Frequency Division Multiple Access (OFDMA) and Multiple Input Multiple Output (MIMO). LTE employs SC-FDMA for uplink direction and OFDMA for downlink direction, taking into account the power consumption issues of user equipment data transmissions [1-2]. OFDMA divides the total bandwidth into a number of orthogonal subcarriers. The OFDM symbol, made of 12 subcarriers called the Resource Block (RB), is the elementary unit used for data transmission [3-4].

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As one of the core functionalities in radio resource management, packet scheduling (PS) plays an important role in optimizing the performance of LTE system. Scheduling is considered as a MAC (Medium Access Control) layer scheme. Different PS algorithms have been proposed and deployed that aim at utilizing scarce radio resources efficiently. A PS can be developed to allocate each User Equipment (UE), with relatively better channel conditions, a portion of the available resources. Such a scheduling scheme is named Channel-Dependent Scheduling (CDS). An LTE uplink scheduler needs to take into consideration a range of requirements in terms of Guaranteed Bit Rate (GBR), delay and target Bit Error Rate (BER). 3GPP Release 8 specified that scheduling the uplink channel would take place at the base station, or eNodeB, to enhance the system's response [2].

An efficient scheduling algorithm is a vital differentiator among the different LTE systems. The 3GPP standard does not specify a certain scheduling mechanism for either the uplink or the downlink direction. Accordingly, several scheduling proposals working under different objectives have been introduced in the literature [5-18] including schedulers that best utilize the available resources to increase the network's performance in terms of bandwidth utilization and data throughput. The selection of scheduling scheme is very important in order to achieve optimum performance despite any flexible bandwidth selection or MIMO technology antenna.

In this paper, the main contributions are to present the performance comparisons of six types of LTE scheduling schemes and to develop a new scheduler scheme. The comparison results of the existing six schedulers can be used to identify which scheduling scheme is suitable to the LTE system prior to new deployment and can enhance the existing LTE network performance. The comparison results are also used as a reference for the implementation and studying of the new proposed LTE scheduler.

The remainder of this paper is organized as follows. The related works and research contributions are presented in Section II. In Section III, we provide an overview of the LTE schedulers. We offer a brief overview and evaluation of schedulers proposed for LTE in this study. Then, the proposed new scheme is presented. In Section IV, we present the simulation environment together with the parameters used and the metrics chosen as the basis for evaluation. The following section analyzes the results obtained. Finally, we conclude in

Section V.

II. Related Work And Research Contribution

A. Review Stage

LTE Scheduling schemes have been discussed by many researchers [5]–[18]. Some scheduling schemes have been made based on maximizing basic objectives such as fairness and throughput. In [5], two Proportionally Fair (PF) schedulers that allocate RBs using a localized scheme and an interleaved allocation are proposed. In [6], a heuristic localized gradient scheme (HLGA) that allocates contiguous RBs to each UE is proposed. The HLGA scheme was proposed with H-ARQ awareness where it reserves a subset of RBs to be used by the H-ARQ process for previous unsuccessful transmissions. To include allocation 'pruning,' the work in [16] was extended in [7] where the number of RBs is adjusted based on the state information of the buffer size at the UE's end. This study showed an improvement in the utilization of available resources because of adding the buffer awareness of the scheduler. Three CDS schedulers are also proposed in [8] with PF-based utility functions: Recursive Maximum Expansion (RME), First Maximum Expansion (FME) and Minimum Area Difference (MAD). The performance of these proposed schedulers was evaluated and compared to a reference RR scheduler and the results showed that their performance in terms of spectral fairness and efficiency are improved.

Two variants of the RME scheduler are introduced in [9] as an extension to the work in [8]. A binary search tree-based PF scheduler for LTE uplink was proposed in [10]. In this schedule, the available RBs are divided into fixed-sized Resource Chunks then these Resource Chunks are distributes among the available UEs. The performance of the scheduler showed a significant improvement in terms of throughput and noise rise compared to the RR scheduler. An adaptive transmission bandwidth-based scheduler was introduced in [11], where it dynamically changes the resources assigned per UE in every scheduling interval.

A SINR-based PF metric in Frequency Division combined with a throughput-based PF metric in Time Division is proposed in [12] as an extension of the work in [11]. The work in [13] designed practical Multi-User resource allocation schemes for the LTE uplink in which the term resource refers to power levels , RBs, modulation and coding schemes and choice of transmit antennas. In [14-15], a Kwan Maximum Throughput (KMT) scheduler is proposed that tries to maximize the overall throughput.

Comparing these proposed scheduling schemes is important to the exploration of the strengths and weaknesses of these schedulers. An evaluation environment for observing the aggregate performance of the different schedulers is offered in previous work [16]. However, the evaluation presented in [16] did not address the QoS characteristics of the schedulers and did not discuss their connection-level performance. In [17], the throughput conditions are investigated for two of the most popular scheduling methods, Round Robin and Proportional Fair, to demonstrate a good comparison for downlink transmission. In [18], three uplink schedulers are compared: the Recursive Maximum Expansion (RME) scheme, the First Maximum Expansion (FME) scheme, and the Riding Peaks scheme. To our knowledge, such a performance comparison is yet to be made for other important uplink LTE schedulers. Given the rising number of commitments (to both LTE and LTE-Advanced) [1], it becomes invaluable to further investigation of the important schedulers presented in recent research and proposed for LTE [5-18] becomes invaluable because of rising number of commitments to LTE and LTE-Advanced [1].

Our main contribution in this paper is to present a comparative performance evaluation of LTE packet schedulers proposed thus far. Then, a new proposed LTE scheduler is studied and compared with two of these six schedulers. The performance evaluation of six scheduling schemes and new scheme are compliant to 3GPP's most recent releases but have not yet been compared with each other. The six schedulers are Best CQI (BCQI), Proportional Fair (PF), Max-Min, Kwan Maximum Throughput (KMT), Resource Fair (RF) and Round Robin (RR).

III. Overview Of LTE Schedulers

A. LTE Resource Model

Orthogonal Frequency Division Multiplexing (OFDM) is the core of LTE transmission. The bandwidth is divided into sub-bandwidth in the form of subcarriers. Furthermore, the user's data transmits through time in the form of frames. Fig. 1 illustrates the time-domain frame structure that is adopted for LTE uplink as well as downlink [2-3]. Although the discussions of the frame structure below focus on uplink frame structure, it is assumed to equally apply to LTE downlink. The uplink and downlink channels in the air interface are divided into a number of elements as shown Fig. 1. A frame is 10 ms in length and each frame, in time domain, is divided into 10 subframes. A subframe duration is 1 ms in length and each subframe is also divided into two slots where each slot is 0.5 ms in length. In frequency domain, each slot is divided into a number of resource blocks. The number of OFDM symbols in a resource block depends on the cyclic prefix being used. Each slot contains 6 or 7 OFDM symbols in normal cyclic prefixes and extended cyclic prefixes, respectively. The frequency domain structure of a time slot is divided into regions of 180 kHz that contain a contiguous set of 12 subcarriers. From these, there is a time-frequency grid. The smallest unit is the resource element bandwidth of one subcarrier that lasts one OFDM symbol duration.

The basic unit of exchanging user information in both downlink and uplink of LTE system is known as resource block (RB)[3]. Therefore, a resource block (RB) or the Physical Resource Block (PRB) is the radio resource that is available for a user in the 3GPP LTE system and is defined by both frequency and time domains. The number of RBs in a slot depends on the system bandwidth. A RB is 0.5ms in length (one slot) and contains 12 subcarriers (a bandwidth of 180 kHz) from each OFDM symbol. The MIMO technique is also supported in LTE to utilize either spatial multiplexing or diversity. The former is used to increase capacity and the latter is to reinforce the communication system against fading channels and to increase the SNR at the receiver.

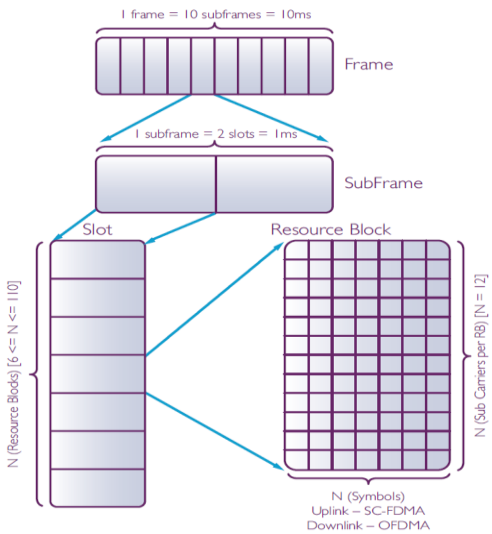

Fig.1. LTE frame structure

B. LTE Six schedulers Under Study

The packet scheduler in LTE is responsible for allocating shared radio resources among UEs. The packet scheduler allocates radio resources to UEs both on the downlink (from the eNodeB down to the UE) and also on the uplink (from UE up to the eNodeB). The decision to assign the data packets in the eNodeB or UE buffers to the available RBs in the cell is taken from the scheduler, which is located in the MAC layer of the eNodeB. The order in which packets are emptied from the transmission buffers from both eNodeB and UE is decided by the scheduling strategy. The scheduler in LTE system assigns resources to UEs in groups of RB [2-4]. A generic description of the scheduler is represented in Fig. 2

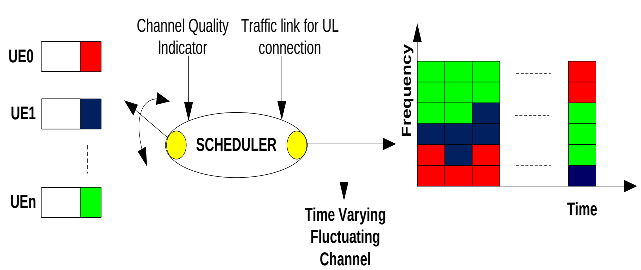

Fig.2. A Generic Description of the Scheduler

A packet scheduler performs its allocation decision to maximize the satisfaction level system requirements. A scheduler measures system satisfaction based on a desirable performance metric such as per UE's experienced data rate, fairness in resource allocation among UEs, average packet delay experienced by UEs, etc. The choice of what performance metric to optimize influences how the scheduler resolves resource contention among UEs. In general, the goals of scheduling algorithms are to provide efficient resource sharing, better performance in terms of fairness throughput, resource utilization and throughput. In the following subsection, we will provide a more detailed discussion of our study on six scheduler algorithms designed for LTE networks

- **Round Robin Scheduler (RR):**

RR is simple and easy to implement scheduling scheme. This is why it is used by many systems. In this scheduling strategy, the UEs are assigned the shared resources in turn (one after another). Thus, every UE is equally scheduled without taking the CQI into account. RR is a fair scheduling scheme because every UE is given the same amount of RB. The scheduling is only based on the available RBs, and the RB may be grouped into number of RBs for each UE packet during scheduling process. It is on a first come first served basis. Although RR gives every UE an equal chance to obtain RBs, the overall throughput is much lower than in other schedulers because this scheduler does not take the channel conditions into its considerations. In LTE, different UEs have different services with different QoS requirements and it is very difficult to allow every UE to take up the same RBs for the same possibility because it will decrease the resources efficiency.

- **Best CQI Scheduler (BCQI):**

This scheduler scheme assigns RBs to the UE with the best channel conditions. To perform scheduling, UE generates the channel quality indicator (CQI) informations and it feeds them back to the eNodeB periodically in quantized form but with a certain delay. These CQI informations contain the value of the signal-to-noise and interference ratio (SINR) measured by the UE. A higher value of CQI indicates a better channel condition. The best CQI is selected for scheduling based on the CQI received. BCQI scheduling scheme can increase cell throughput at the expense of worst fairness. In this scheduling mechanism, UEs located far from the base station are unlikely to be scheduled.

- **Kwan Max. Throughput Scheduler (KMT)**

The smallest resource unit that an uplink LTE scheduler can assign to a UE is called scheduling block (SB) and it consists of two consecutive RBs. In this KMT scheduler, UEs, the modulation and coding scheme and scheduling blocks are jointly assigned. The KMT scheduler performs assignment of resources in two steps in order to reduce complexity. In the first step, each two RBS (i.e SB) are assigned to the UE who can support the highest bit rate. In the second step, the best MCS for each UE is determined. The idea behind KMT scheduler is to assign a disjoint subset of SBs to each UE, thereby a joint multiuser optimization problem is reduced into U (number of simultaneous users) parallel single-user optimization problems. [14] gives more details about this scheduler.

- **Proportional Fair Scheduler (PF):**

Proportional Fair scheduler is a compromise between RR and Maximum Rate schedulers. Its main targets are to provide maximum rate and meanwhile to prevent UE starvation. A priority function is used to position The UEs. Then, the UE with the highest priority is assigned resources. A scheduling scheme , P, is PF if and only if, for any feasible scheduling scheme , S, it satisfies the following equation:

$$\sum_k \frac{T_k^{(S)} - T_k^{(P)}}{T_k^{(P)}} \leq 0$$

where $T_k^{(S)}$ is the temporal average rate of user k given by scheduler S.

This scheduling algorithm assigns the RBs to the UE with the best relative channel quality, i.e., a combination of CQI and level of fairness desired. There are various versions of PF scheduling based on values that it takes into account. The main goal of this scheduling algorithm is to achieve a balance between maximizing the cell throughput and fairness by letting all users achieve a minimum QoS (Quality of Service). Such an algorithm is designed to be better in terms of average user throughput, as well as being fair to most of the users and meeting the minimum QoS requirements during the scheduling process.

- **MaxMin Scheduler:**

Maximizing the minimum of the UE throughputs is the main task of MaxMin scheduler. MaxMin scheduler is a scheduler scheme that is able to maximize the minimum data rate of resources. The fairness of MaxMin provides lower average throughputs where UE located far from base station (least expensive data flow) is assigned all the capacity that it can use. Based on Pareto optimal, without decreasing the rate of other UE that has a lower rate, the rate of one UE cannot be increased.

- **Resource Fair Scheduler (RF):**

The RF scheduler scheme allocates an equal amount of resources for all UEs. It mainly aims to maximize the sum rate of all UEs while ensuring fairness with respect to the number of RBs assigned to a UE. To achieve this goal the following additional constraint is imposed:

$$b_k = \frac{N}{K} \quad for \quad all\ k$$

If N/K is non-integer, some UEs will get $\left\lfloor \frac{N}{K} \right\rfloor$ while others UEs get $\left\lceil \frac{N}{K} \right\rceil$. This decision should be made randomly in order to guarantee fairness.

C. LTE Novel Scheduling Scheme (RR-CQI)

In order to find a trade-off between LTE system throughput and fairness we propose a new uplink LTE scheduler, named as RR-CQI, which combines the main features of Best-CQI and RR schedulers. The proposed RR-CQI scheduler has two phases of operations. First phase is just a random round robin scheduler such that each UE will get (N_RB/N_UE) RBs, where N_BR is the number of RB and N_UE is the number of UEs. If the result is integer, then every user will get the same number of RBs and if the result is non-integer, then every UE will get a floor of result and extra RBs will be distribute on users in random fashion. This phase will guarantee the fairness between users in terms of RBs distribution among UEs.

The second phase exploits the channel state information feedback (i.e. CQI) to improve the system throughput. In this second phase the UEs are first arranged randomly in a sequence, and then the defined sequence is used to choose the best RBs for each user based on CQI for all users in the current transmission time interval TTI. The randomness of the sequence will prevent one specific user form staying with the same RBs selection order in each TTI. The proposed scheduling scheme assumes that in a real LTE system, the eNodeB would receive the CQI feedback as a matrix with dimensions N_UEs x N_RB. The value of each field in the matrix is the CQI feedback of each user for each RB. The main flowchart of the proposed scheme is shown in Fig. 3.

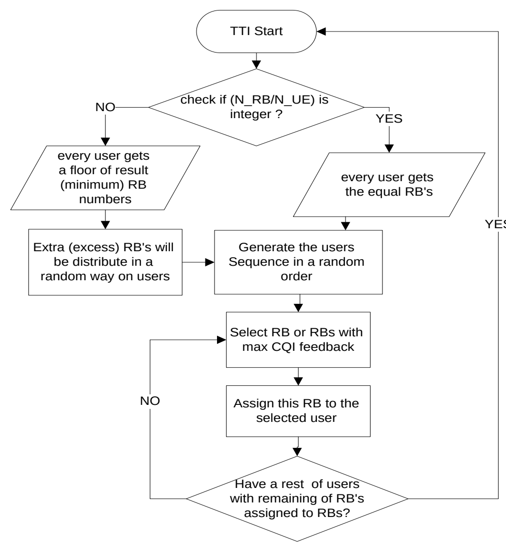

Fig.3 Proposed scheme flowchart.

IV. Results And Discussions

This section describes the work done to evaluate and compare the above six schedulers' performance and discusses the results obtained from experiments conducted using the LTE simulator developed in [19]. We first compare six previously proposed schedulers in terms of their achieved throughput and fairness then the new proposed RR-CQI scheme is studied and compared using the same performance measures in different subsection. Before the discussion on the simulation results, the simulation assumptions and the definitions of the performance metrics are given. They are as follows.

A. Performance measures

The main purpose of the simulations was to compare the performance of six different scheduling schemes in addition to our proposed scheme in terms of resource utilization and fairness between UEs. To evaluate the performance of the LTE system under the use of these schedulers, the following metrics were employed to quantify the performance of the system.

1) **Throughput**: This is measured as the total number of bits successfully transmitted over the air interface from the UE up to the eNodeB over the total simulation time. That means the system average throughput is the sum of average throughput of all users.

$$Throughput = \frac{B}{t_{sim}}$$

Where B represents the total amount of received bits and tsim represents the total simulation time.

2) Fairness: This term measure the fairness among UEs of the same class, and it used to determine whether UEs are receiving a fair share of LTE system resources. In the literature, many approaches to measure fairness are presented. One of the most famous one is Jain's fairness index [20]. In [20][21], Raj Jain fairness index is used to measure the fairness among UEs as given below:

$$f(R_1, R_2, \ldots\ldots, R_K) = \frac{\left[\sum_{k=1}^{K} R_k\right]^2}{K\sum_{k=1}^{K}(R_k)^2}$$

Where there are K UEs in the LTE system and Rk is the number of RBs given to UEi. When all UEs have the same throughput, the value of fairness index is 1 and this indicates the highest fairness. Here, we assume absolute fairness, which means that we do not take the SNR differences into account in our measure of fairness.

B. Simulation setup

To evaluate and compare the selected six different LTE schedulers and our new proposed scheduler, we used a standard compliant LTE physical layer simulator that is available in [22]. The simulator used is divided into three main building blocks: transmitter, channel model, and receiver

One or several instances of these basic building blocks can be employed depending on the type of simulation. The channel model is used to link the transmitter and receiver blocks [4]. A single cell SISO environment with no inter-cell interference is assumed. The eNodeB is has an omnidirectional antenna and is situated at the center of the cellular grid. The UEs are assumed to be uniformly distributed within the cell coverage. An urban environment with a NLOS communication path is assumed. Table I shows the simulation parameters used in the LTE simulator based on the 3G LTE specifications presented in [4]. The Traffic Models presented in [4] is assumed. The simulation of different schedulers is repeated six times because there were six (6) types of scheduler chosen previously. Once done, the simulation execution is repeated with the rest of experiment scenario that covers a different number of UE and a different value for SNR. The same simulation scenario is used again to study the performance of the proposed scheme. The simulation results of the proposed scheme are then compared with the results of BCQI and RR schedulers.

TABLE I: Simulation Parameters

Parameter	**Value**
LTE bandwidth	10MHz
Number of RBs, N	100
Number of subcarriers	600
Number of subframes	varies
Number of UEs K	varies
Number of BS	1
Channel Model	3GPP TU
Antenna setup	1 transmit, 1 receive (1 x 1)
Receiver	Zero Forcing ZF
Schedulers	• Round Robin (RR) • Best CQI (BCQI) • Approximate Max. Throughput (AMT) • Kwan Max. Throughput (KMT) • Proportional Fair (PF) • MaxMin. • Resource Fair • Proposed (RR-CQI)

C. Comparison Results of Six Schedulers under Study

In this subsection, we present the results obtained from the experiments that were conducted on the six schedulers using the simulator developed in [22]. The experiments conducted on the LTE schedulers were designed to analyze the following aspects of the system performance under different scenarios:

- Total throughput and fairness achieved as a function of the number of UEs present in the cell for six schedulers.
- Total throughput and fairness achieved with different average SNRs for six schedulers.

We first studied the total throughput and fairness achieved by the six schedulers as a function of the number of UEs present in the cell. The results are shown in Fig. 5 and Fig. 6. Fig. 5 shows the sum throughput of each scheduler versus a different number of users under a fixed average SNR of 10dB. This figure shows the benefits of multiuser diversity in the scheduling process. These selected schedulers pursue different goals for resource allocation. As the number of UEs increases in the same cell, the throughput for BCQI, KMT and PF gradually increases. This is due to the effect of multiuser diversity. Also the increasing rate of throughput of BCQI is larger than that of other schedulers. In fact, the BCQI scheduler maximizes the total throughput by assigning resources to the users with the best channel conditions and completely ignores fairness. This is reflected in Fig. 5 and Fig. 6 and shows that the BCQI scheduler has the highest LTE system throughput and the lowest fairness. KMT has the best throughput after BCQI, but it has a similar fairness with BCQI. In contrast, RF and RR have the worst throughput and they have better fairness than BCQI and KMT as shown in Fig. 5 and Fig. 6. The RF scheduler assigns resources so that an equal throughput for all users is guaranteed which maximize Jain's fairness index. RR scheduling cyclically assigns the same amount of resources to each user regardless of feedback information. Ignoring the mobile feedback results in the worst throughput performance. In addition, as the number of UEs increase, their chance for getting the service will decrease because they wait for their turns. In another word, RF and RR schedulers may not successfully serve packets at their full size or accept certain requests due to both tighter constraints of frequency and power resources within a shorter period and the lack of utilization of QoS and CSI to make proper scheduling decisions.

The PF scheduler scheme emphasizes multiuser diversity by scheduling the UE who has the best current channel condition relative to its own average. The PF scheduling mechanism guarantees an equal amount of RBs for all UEs while trying to maximize the total cell throughput. From Fig. 5 and Fig. 6, at the lower part of the range of users, PF performs better than MaxMin. However, with a higher number of users, MaxMin outperforms PF. At a higher number of users, KMT outperforms both PF and MaxMin schedulers in terms of throughput only while the PF and MaxMin achieve the best tradeoff between fairness and throughput. Fig. 5 and Fig. 6 show that the PF and MaxMin schedulers outperform the RF scheduler in terms of throughput and fairness, thereby resulting in a better tradeoff between fairness and throughput.

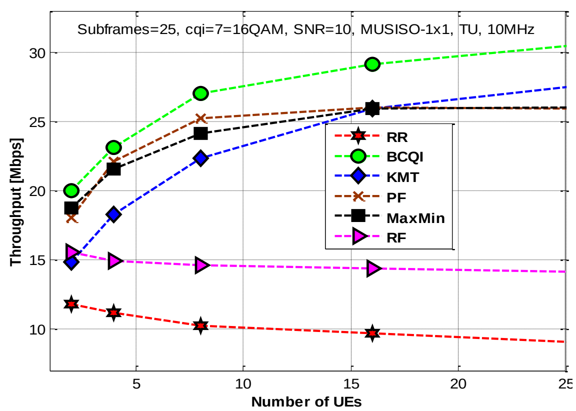

Fig.5 Throughput versus number of UEs with different schedulers.

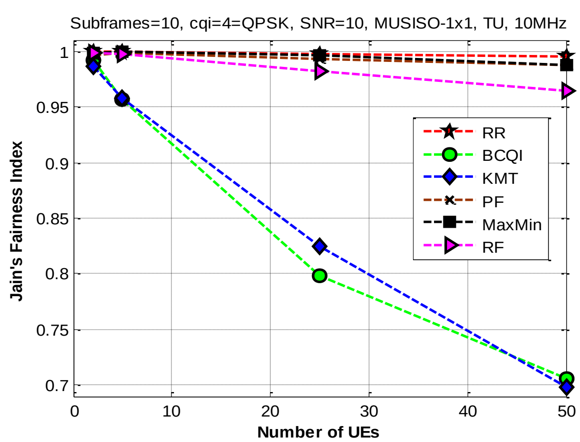

Fig.6 Fairness achieved versus number of UEs with different schedulers.

We now come to consider the case with a fixed number of UEs and we compare the performance of six different schedulers versus SNR in terms of throughput and fairness. The results are shown in Fig. 7 and Fig. 6. Fig. 7 shows the sum throughput of all the UEs versus their average signal-to-noise ratio (SNR) when applying different schedulers. BCQI still has the best throughput and lowest fairness. However, at a high SNR value (40 dB), all schedulers except RR achieve the same throughput. This is because of good channel conditions. The throughput gain for BCQI is larger for lower SNR values and diminishes gradually as the SNR increases. The RR scheduler has the best fairness and worst throughput. However, the RR scheduler's throughput does not improve much with SNR because the SNR value is not considered in RR scheduler decisions. This explains the fact that RR's aim of maximizing fairness does not necessarily guarantee that the UEs utilize the equally allocated RBs with equal efficiency.

The fairness of schedulers that take the channel condition into consideration improves as the SNR value increases. Fig. 8 shows that KMT and BCQI still have the lowest fairness at low values for SNR. However, as the SNR value increases, the fairness value for BCQI and KMT increases because the signal quality for UEs improves and the chance of getting the service by all users increases. In addition, looking at Fig. 7 and Fig. 8, The PF and MaxMin schedulers still outperform the RF scheduler in terms of throughput and fairness, thereby resulting in a better tradeoff between fairness and throughput.

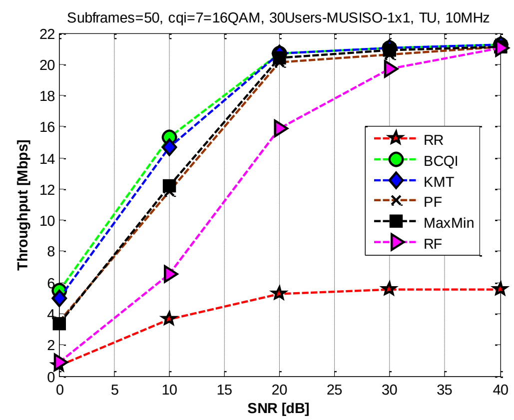

Fig.7 Throughput versus SNR with different schedulers.

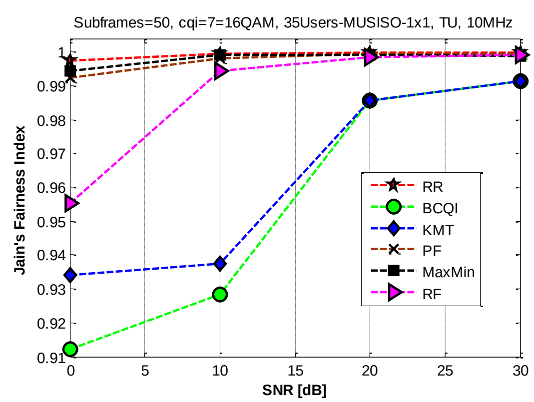

Fig. 8 Fairness achieved versus SNR with different schedulers

In general, with reference to the LTE system throughput, the BCQI has the highest throughput for all conditions. The BCQI scheduler is known as the max throughput scheduler or the scheduler that considers throughput a priority. The rate maximizing schedulers (KMT, BCQI, MaxMin and PF) behave similar and outperform the others schedulers in terms of throughput. This is because the rate maximizing schedulers only serve UEs with good channel conditions. The RR scheduler does not take into account the channel condition for resource allocation and because of this it performs worst. The situation more or less reverses in terms of fairness, as Fig. 6 and Fig. 8 show. In summary, for all performance criteria cases, PF was selected as the optimum scheduler in most of the scenarios compared with others.

D. Performance Results of theProposed Scheduler (RR-COI)

In this subsection, we present the results obtained from the experiments that were conducted on the proposed new scheduler using the simulator developed in [22]. Based on the results obtained from the previous section, we found that the BCQI is the highest throughput for all conditions while the RR scheduler has the best fairness. Since the main goal of our proposed scheme is to process these two conflicts terms in a better way, we compared the performance of the new RR-CQI scheduler with BCQI and RR schedulers. The experiments conducted were designed to analyze the following aspects of the system performance under different scenarios:

- Total throughput and fairness achieved as a function of the number of UEs present in the cell for RR-CQI, RR and BCQI schedulers.
- Total throughput and fairness achieved with different average SNRs for RR-CQI, RR and BCQI schedulers.

The results are shown in Fig. 9 and Fig. 10. Fig. 9 shows the sum throughput of RR-CQI, RR and BCQI schedulers versus a different number of users under a fixed average SNR of 10dB. This figure shows that the throughput achieved by the proposed RR-CQI is better than that of RR scheduler but lower than that of BCQI. The improvement in throughput compared to RR scheduler is because of considering the CQI feedback when assigning the RBs to UEs. Also, the new scheduler has lower throughputs compared to BCQI because the RBs are distributed over all UEs.

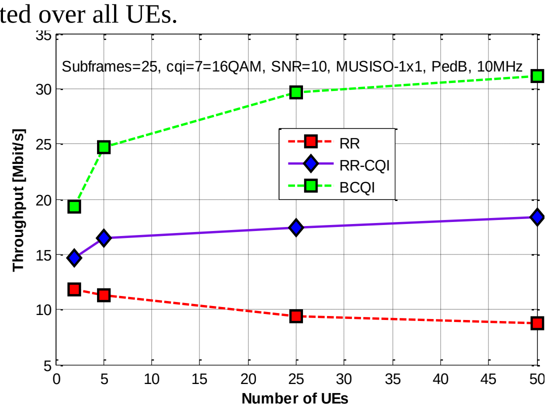

Fig. 9 Throughput versus number of UEs for RR-CQI, RR and BCQI schedulers

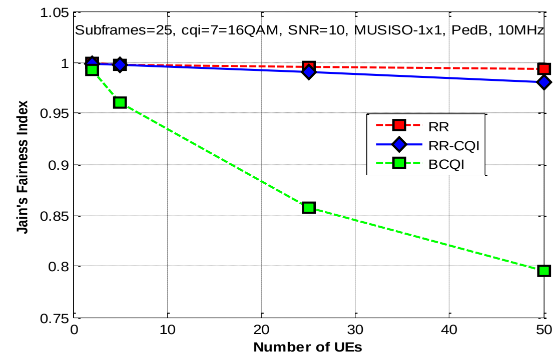

Fig. 10 Fairness achieved versus SNR for RR-CQI, RR and BCQI schedulers

The RR scheduler assigns resources so that an equal throughput for all users is guaranteed, thereby maximizing Jain's fairness index. As shown in Fig. 10, the new scheduler does the same things but with considering the CQI condition when assigning the RBs to UEs and with distributing the remaining RBs over number of UEs randomly. These new modification makes the fairness achieved by the new RR-CQI scheduler is close to RR scheduler.

The throughput and fairness index of RR-CQI scheduler as function of SNR value are shown in Fig. 11 and Fig. 12. Since the RR-CQI take the channel condition into consideration, its throughput improves as the SNR value increases. This improvement matches the BCQI scheduler. Fig. 12 shows that RR-CQI still has farness as good as RR scheduler fairness.

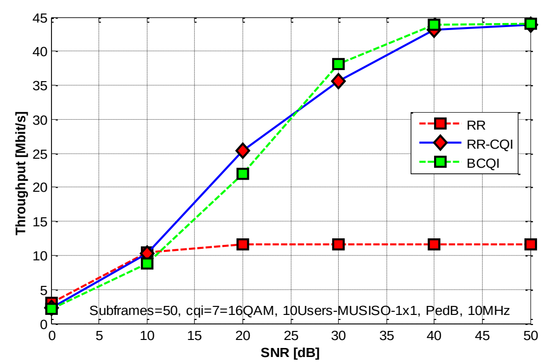

Fig. 11 Throughput achieved versus SNR for RR-CQI, RR and BCQI schedulers

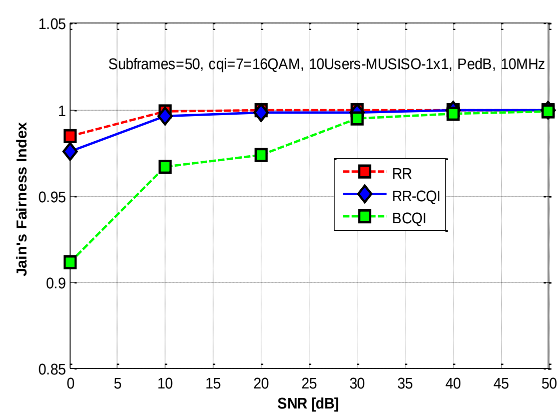

Fig. 12 Fairness achieved versus SNR for RR-CQI, RR and BCQI schedulers

In summary, the new proposed RR-CQI scheduler outperforms RR in terms of throughput because it takes into account the channel state for resource allocation and it distribute the extra RBs randomly. In terms of fairness, the RR-CQI outperforms BCQI scheduler because it distributes the available RBs equality between UEs. Generally, it can be observed that the newly proposed scheduling scheme has improved cell performances in terms of system throughput compared to RR scheduler and in terms of fairness compared to BCQI scheduler.

V. Conclusion

The focus of this paper was to provide a comparative study on LTE scheduler schemes. Scheduling algorithms for LTE by many authors have been discussed. Six schedulers from those proposed schemes were selected and examined in this study. In this paper, simulation was used as a method to evaluate the performance of selected scheduling schemes. These schedulers include Round Robin (RR), MaxMin and Proportional Fair (PF) scheduling, Best CQI (BCQI), Kwan Maximum Throughput (KMT) and Resource Fair (RF). Performance for these six scheduling schemes was evaluated and compared in terms of throughput and fairness. Simulation in different environments and scenarios was implemented for specific sizes of users and specific SNR values. In addition, varying the user size and SNR value were included to observe performance. The results show that PF and MaxMin schedulers deliver a good compromise between fairness and throughput. Also we found that it is clearly a bad choice to not take channel conditions into account when allocating resources, as the RR scheduler does. This is because neither high fairness nor high throughput can be achieved.

Based on the observation from the results of the selected six schedulers, we proposed a new LTE scheduler scheme that can address the system throughput and fairness in better way. This new proposed scheduler combines the features of RR scheduler with fair resource allocation and the feature of BCQI in terms of considering CQI when assigning the RBs to UE. The simulation results of this new scheduler indicated that this new scheduling scheme provides better balance between system throughput and fairness issues. Specifically, it allows fair distribution of available LTE resources while at the same keeping the system capacity utilization as good as possible.

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