COMPARISON BETWEEN SCHEDULING TECHNIQUES IN LONG TERM EVOLUTION

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ABSTRACT: Long-Term Evolution (LTE) is a recently evolving technology characterized by very high speed data rate that allows users to access internet through their mobile as well as through other electronic devices. Such technology is intended to support variety of IP-based heterogeneous traffic types. Traffic scheduling has a very significant impact in LTE technology by assigning the shared resources among users very efficiently. This paper discusses the performance of three types of scheduling algorithms namely: Round Robin, best Channel Quality Indicator (CQI) and Proportional Fair (PF) schedulers representing the extreme cases in scheduling. The scheduling algorithms performances on the downlink were measured in terms of throughput and block error rate by using a MATLAB-based system level simulation. Results indicate that the best CQI algorithm outperforms the other algorithms in terms of throughput levels but on the expense of fairness to other users suffering from bad channel conditions.

ABSTRAK: Teknologi baru Evolusi Jangka Panjang (LTE) sentiasa berubah dan ia bercirikan kelajuan kadar data sangat tinggi yang membolehkan pengguna mengakses internet melalui telefon bimbit dan peranti elektronik lain. Teknologi seperti ini bertujuan menyokong pelbagai jenis trafik heterogen berasaskan IP. Penjadualan trafik memainkan peranan penting dalam teknologi LTE bagi mengagihkan sumber perkongsian secara paling berkesan di kalangan pengguna. Kertas ini membincangkan prestasi tiga jenis algoritma penjadualan iaitu: pusingan Robin, penunjuk kualiti saluran (CQI) terbaik dan penjadualan berkadar adil (PF) yang merupakan kes ekstrem dalam penjadualan. Prestasi penjadualan Algoritma di pautan turun diukur dari segi daya pemprosesan dan kadar ralat blok melalui simulasi sistem menggunakan MATLAB. Hasil kajian menunjukkan algoritma CQI adalah yang terbaik berbanding hasil algoritma lain dari segi tahap daya pemprosesan tetapi algoritma ini menyebabkan pengguna lain mengalami keadaan saluran buruk.

KEYWORDS: *LTE; round robin; best CQI; proportional fair; scheduling; resource blocks*

1. INTRODUCTION

LTE is the future technology of mobile broadband. It is expected that the majority of user equipments (UEs) will be served by LTE networks. LTE has a very high data rate that may approach the 100 Mb/s speed for downlink and 50Mb/s for the uplink. 3GPP LTE has adopted the multicarrier Orthogonal Frequency Division Multiplexing (OFDM) as the downlink transmission scheme. OFDM multicarrier transmission scheme splits up the transmitted high bit-stream signal into different sub-streams and sends them over many different sub- channels [1]. OFDM simply divides the available bandwidth into multiple narrower sub-carries and transmits the data on these carries in parallel streams. Each sub-carrier is modulated using different modulation scheme, e.g. QPSK, QAM, 64QAM and an OFDM symbol is obtained by adding the modulated subcarrier signals [2]. The down link physical resource is represented by multiple time-frequency resource available for data transmission which are called Physical Resource Blocks (PRBs). A Resource Block (RB) consists of a fixed number of adjacent OFDM subcarrier and represents the minimum scheduling resolution in the frequency domain. A scheduler is located in the Base Station (BS) and it assigns the time and frequency resources to different users in the cell. Users in the center of the cell have CQI and modulation scheme better than users in the cell edge due to their proximity from the BS, hence, in some schedulers it results in unfair treatment (e.g., assignment of the RBs) to the UEs having low CQI levels (due to poor wireless channel conditions dominated mainly by distance loss between the BS and the UE) thus leading to lower throughput levels and overall degraded performance. This work intends to study the traffic flow interaction with the scheduler type, and to highlight the effect of different schedulers on the individual UE as well as the whole LTE network throughput and BLER performance. Therefore, we selected three types of scheduling techniques of contradicting characteristics to investigate their suitability to the LTE downlink Scheduling process. Namely, Round Robin (RR), Proportional Fair (PF), and Best CQI techniques were selected and their performance will be measured in terms of their average throughput and Block Error Rate (BLER) for the individual UEs and the overall network. This paper is divided into 5 sections. Section 2 introduces the background theory about the structure of the LTE frame and the downlink RBs and the Modulation and Coding Schemes (MCS) and their relative CQI levels. Section 3 introduces the three different scheduling algorithms and the simulation model and parameters. Section 4 discusses the performance evaluation results and the paper is concluded in section 5.

2. BACKGROUND THEORY

2.1 LTE Downlink Frame Structure and RBs

LTE transmission is segmented into frames each one consists of 10 subframes and each subframe is further divided into two slots each 0.5 ms, making the total time for one frame equivalent to 10 ms. Each time slot on the LTE downlink system consists of 7 OFDM symbols. The very flexible spectrum allows LTE system to use different bandwidths ranging from 1.4 MHz to 20 MHz where higher bandwidths are used for higher LTE data rates. The physical resources of the LTE downlink can be illustrated using a frequency-time resource grid as shown in Fig 1. A Resource Block (RB) has duration of 0.5 msec (one slot) and a bandwidth of 180 kHz (12 subcarriers). It is straightforward to see that each RB has 84 resource elements in the case of normal cyclic prefix and 72 resource elements in the case of extended cyclic prefix [2].

2.2 MCS and CQI levels Mapping

The selection of the MCS is a key issue in the Scheduling process. Therefore it is worth the discussion further here. In LTE downlink with Adaptive Modulation and Coding (AMC) being used, the selection of an appropriate MCS level for UE's transmission has to do with its associated current channel state or condition. Firstly, the UE estimates the instantaneous channel condition to determine Channel Quality Indicator (CQI) index and then sends a feedback to the BS or the eNodeB. Consequently, the eNodeB uses this CQI index to choose a certain level of MCS and allocates accordingly corresponding RB-pairs for this UE. The relationship between CQI index and the MCS is shown in Table 1, where efficiency represents the transmitted bits on each OFDM symbol [3]. It can be noted that larger CQI indices represent higher MCS levels, which in turn means more efficient usage of channel resources and fewer RB-pairs being occupied for transmission.

However, differences in modulation and coding rates produces different BLER performances. The relationship between SNR and BLER curves of each CQI index were studied extensively in the literature indicating clearly that CQI is a reflection of channel quality as SNR, where a high CQI reflects good channel condition, under which a high level of MCS could be selected to achieve high bit rate and efficiency [4].

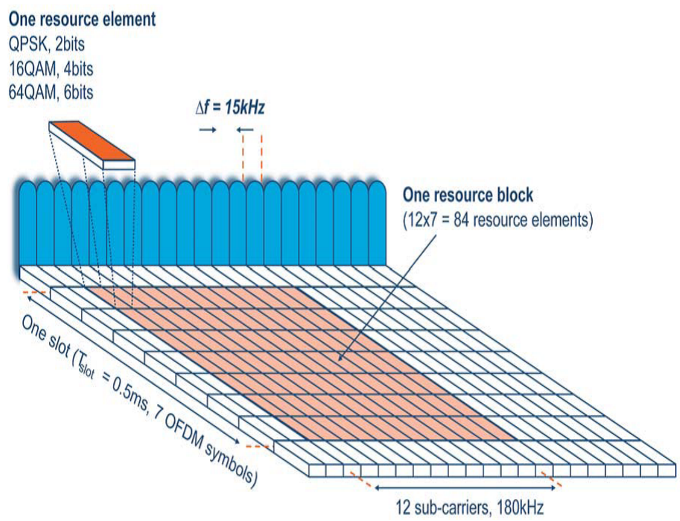

Fig. 1: LTE downlink physical resource based on OFDM [5].

Table 1: Mapping of CQI versus MCS [3].

CQI index	**modulation**	**Code rate x 1024**	**efficiency**	**CQI index**	**modulation**	**Code rate x 1024**	**efficiency**
0		Out of range		**8**	16 QPSK	490	1.9141
1	QPSK	78	0.152	**9**	16 QPSK	616	2.4063
2	QPSK	120	0.234	**10**	64 QPSK	466	2.7305
3	QPSK	193	0.377	**11**	64 QPSK	567	3.3223
4	QPSK	308	0.602	**12**	64 QPSK	666	3.9023
5	QPSK	449	0.877	**13**	64 QPSK	772	4.5234
6	QPSK	602	1.176	**14**	64 QPSK	873	5.1152
7	16 QPSK	378	1.477	**15**	64 QPSK	948	5.5547

3. SCHEDULING ALGORITHMS AND SIMULATION MODEL

Since this study compares the performance of three types of scheduling algorithms, this section will present a brief overview of these algorithms which are: Round Robin, best Channel Quality Indicator (CQI) and Proportional Fair (PF). In addition, the simulation model used in this study will be described.

3.1 Round Robin (RR) Scheduling Algorithms

Round Robin scheduling is a non-aware scheduling scheme that lets users take turns in using the shared resources (time/RBs), without taking the instantaneous channel conditions into account. Therefore, it offers great fairness among the users in radio resource assignment, but degrades the system throughput performance. Round Robin scheduling can be implemented on both into two ways, namely the Time Domain Round Robin (TDRR) and Time and Frequency Domain Round Robin (TFDRR). In TDRR the first reached user is served with the whole frequency spectrum for a specific time period (1TTI), not making use of the information on his channel quality and then these resources are revoked back and assigned to the next user for another time period. The previously served user is placed at the end of the waiting queue so it can be served with radio resources in the next round. This algorithm continues in the same manner [5]. In TFDRR multiple users are allowed to be scheduled within one TTI in a cyclic order [8, 9].

The principal advantage of Round Robin scheduling is the guaranty of fairness for all users. Furthermore Round Robin is easy to implemented, that is the reason why it is usually used by many systems. Since Round Robin ignores the channel quality information, it usually results in lower user and overall network throughput levels.

3.2 Best CQI Scheduling Algorithm

As the name implies, this scheduling strategy assigns resource blocks to the user with the best radio link conditions. In order to perform scheduling, terminals send Channel Quality Indicator (CQI) to the base station (BS). Basically in the downlink, the BS transmits reference signal (downlink pilot) to terminals. These reference signals are used by UEs for the measurements of the CQI. A higher CQI value means better channel condition. Best CQI scheduling [2] can increase the cell capacity at the expense of the fairness. In this scheduling strategy, terminals located far from the base station (i.e. cell-edge users) are unlikely to be scheduled.

3.3 Proportional Fair (PF) Scheduling Algorithm

Proportional Fair scheduler is a commonly used scheduling algorithm for Time-frequency shared multi-user systems. Originally it was implemented in Time Domain Scheduling (TDS) systems and latter it was adopted to LTE to exploit the OFDMA capabilities in TDS and Frequency Time Scheduling (FDS) systems. The main purpose of combined TDS and FDS systems is to achieve a good trade-off between Overall system throughput and data-rate fairness among the users by exploiting multi-user diversity [6].

The commonly known parameter Allocation Fairness (*FA)* in Proportional Fair scheduling refers to the amount of resources allocated within a given time window. The below equation describes the Allocation Fairness *FA* in a PF Scheduler [6].

$$FA(\Delta T) = \frac{\left(\sum_{m=1}^{M} A_m(\Delta T)\right)^2}{\left(M \times \sum_{m=1}^{M} A_m(\Delta T)^2\right)} \tag{1}$$

where $0<FA(\Delta T) \leq 1$ (When $FA(\Delta T)$ = 1, all users received identical share of resources), M is number of considered users, m= 1,2,….,M is the user index, and $A_m(\Delta T)$ is the number of allocation units scheduled to the user m in time interval ΔT.

In order to find a trade-off between throughput and fairness a new scheduling algorithm that operates somewhere between the Best CQI scheduling and the Round Robin scheduling is examined. This scheduling algorithm demonstrates an acceptable throughput level while providing some fairness between users. The scheduling algorithm assigns RBs to the user that maximizes the CQI in the first slot period of each sub frame; whereas in the subsequent second slot period the scheduler assigns the RB in turn to each user. Such alternation generates a compromise between the fairness and the throughput that can be reached. The granularity of this proposed scheduling algorithm was set to 1 resource block (RB). A resource block is the smallest element of resource allocation assigned by the BS scheduler. Figure 2 illustrates the flow chart of the modified scheduling algorithm. At the beginning of the scheduling process the BS compares the CQI from different terminals and selects the user with the highest CQI. If there is more than one terminal with the highest CQI, a random one is picked by the scheduler. In the first time slot the terminals with higher CQI are scheduled. In the second time slot the terminals are scheduled cyclically in turn. On the third slot period the process is repeated again alternately [2].

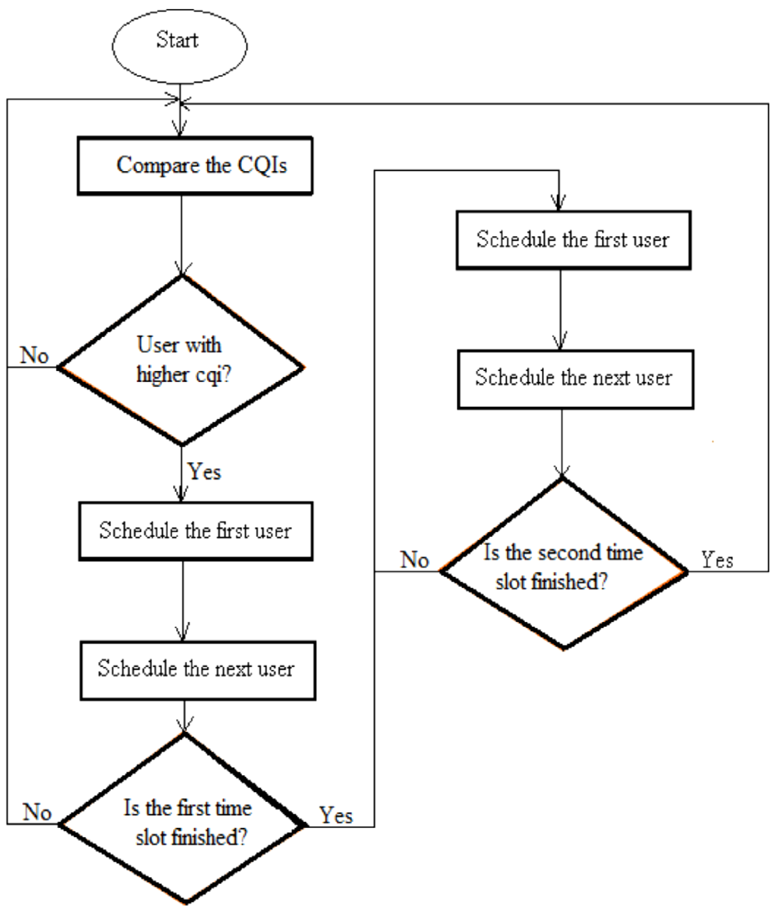

Fig. 2: Flow chart of Proportional Fair (PF) Scheduler [2].

3.4 Simulation Model

In order to highlight the effect of different schedulers on the individual UE as well as the whole LTE network throughput and BLER performance, the LTE system level simulator introduced in [7] was used with simulation parameters shown in Table 2. Twenty UEs are distributed randomly on the network of 7 (tri-sector RBs) cells area. The simulation time was run for 1000 TTIs while the individual and global throughput and BLER were calculated.

Table 2: Simulation Parameters [7].

PARAMETER	VALUE
Frequency	2 GHz
Bandwidth	5 MHz
Thermal noise density	-174 dBm/Hz
Receiver noise figure	9Db
nTX X nRX antennas	2 X 2
TX mode	Open Loop Spatial Multiplexing (OLSM)
Simulation length	1000 TTI
Inter eNodeB distance	500 m
Minimum Coupling Loss	70 dB
Macroscopic pathloss	128 .1 + 37 .6 log 10 (R)
Shadow fading type	lognormal, 2D, space-correlated shadow fading map, μ= 0 ; σ = 10 (dB) , "claussen"
Shadow fading correlation	Inter-site: 0.5
Microscale fading	PedB, trace_length = 30s
UEs position	UEs located in target sector only, 20UEs/sector.
BS Antenna pattern	A(θ) = -min [12 (θ /65^o) ^2,20 dB]; 180≤ θ ≤180
BS antenna gain	15 dBi, LTE antenna, urban area (2000 MHz)
Scheduler	Proportional Fair, Round Robin, Best CQI

4. PERFORMANCE EVALUATION AND ANALYSIS

In order to highlight the relationship between Throughputs and Block error rate (BLER) with the respective CQI levels, the first experiment was run as follows. There are 15 CQI levels in the LTE network and the simulator generates 20 UEs and they are randomly distributed in the cell as shown before on Fig. 3. By selecting any UE whose located is very close to eNodeB such as UE20, as it is shown in Fig 5, a high throughput was achieved corresponding to a CQI level of 15 (see Fig.4 for CQI distribution of node UE20). In other words, level 15 of CQI is used most of the time and is frequently updated to the eNodeB 5. This means that the UE20 is in a very good condition to receive the maximum date rate. Such high CQI level is also reflected in the low BLER due to favorable channel conditions as will be shown later.

Figures 5 and 7 plot the system throughput and BLER over time. The blue line depicts the UE throughput in Mb/s for the selected stream and UE, as well as the BLER as measured by the ACK/NACK ratio (green line) and the BLER value applied by the link quality Model (black line). Although the system is calibrated to deliver BLER ≥ 0.1, the actual results are influenced by the uplink delay and time variability of the channel [7].

Figures 4 and 5 plot the sent CQI report for the selected RB and stream (blue), mean CQI for the whole frequency band (red) and CQI of to the Transport B lock (TB) sent to the UE, if scheduled. The distribution of the CQIs for the selected UE and RB during the simulation time (blue), and of the TB CQIs (red). All time-dependent data is averaged by using a rectangular window of configurable length [7].

On the other CQI level extreme, UE1 is located furthest from the eNodeB. The signal power varies frequently due to poor channel condition and the CQI level frequently changes between 0 and 6, as shown in Fig 5. The modulation technique is QPSK for the first six levels of CQI resulting in low (4 times lower) achievable throughput level and somewhat higher BLER in comparison to UE20 case in Fig 7. It is important to note that scheduling algorithm choice does not affect the CQI level that is a function of channel condition and UE location in the cell.

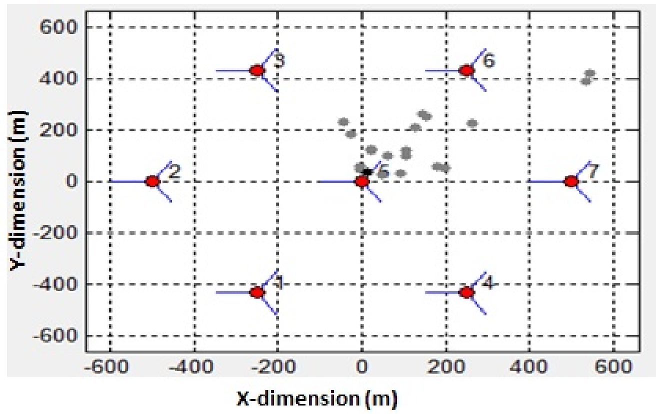

Fig. 3: (X,Y) Position of UE 20 near eNodeB (*meters*).

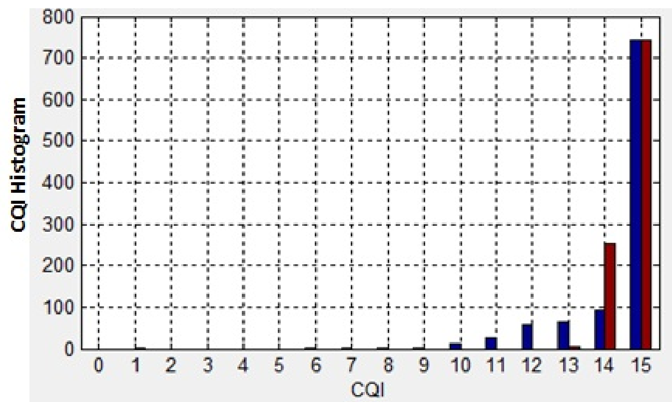

Fig. 4: CQIs distribution when UE20 close to eNodeB, RB1.

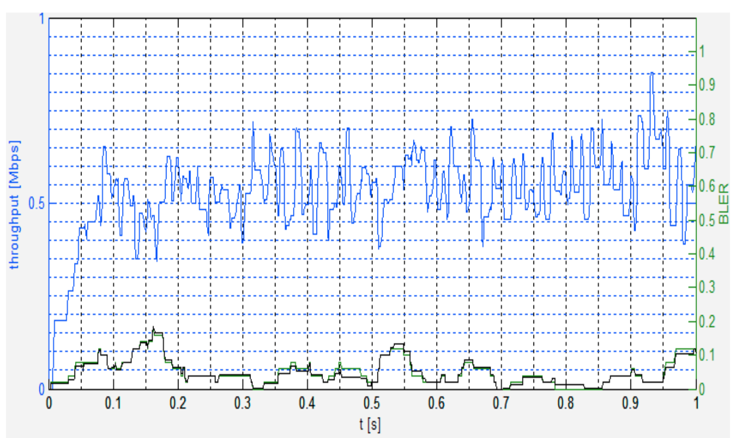

Fig. 5: Throughput, BLER when UE20 near eNodeB 5.

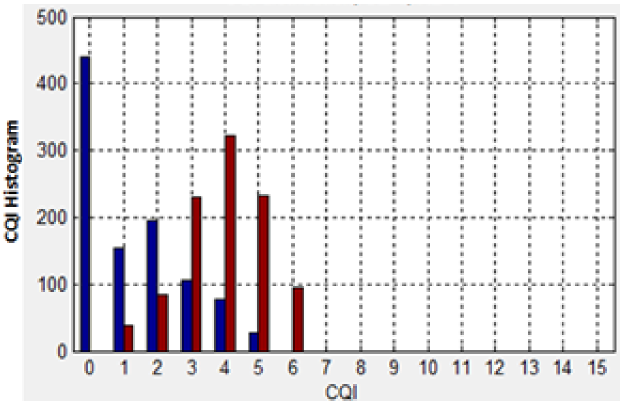

Fig. 6: CQIs distribution when UE1 far from eNodeB, RB1.

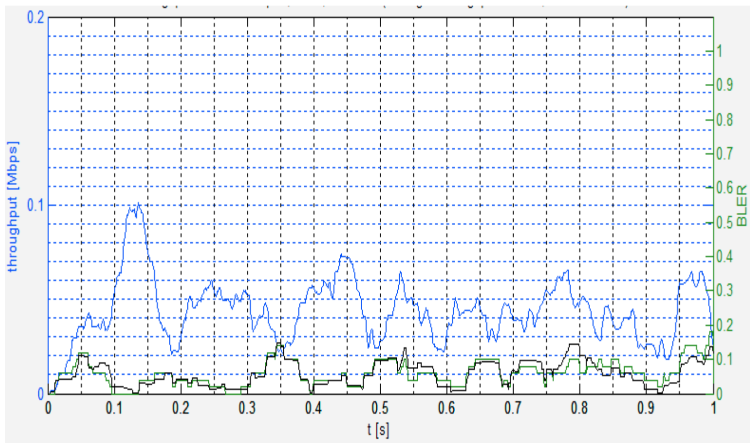

Fig. 7: Throughput, BLER when UE1 is far from eNodeB.

LTE system level simulator was designed to calculate single achievable UE throughput, UE BLER as well as cell throughput and cell BLER. We opted to evaluate the global network performance so we decided to calculate the throughput and BLER levels achieved averaged over all UEs in the network regardless of their respective locations within their cells. The three scheduling techniques were applied for the same simulation scenario and their performances were investigated.

Figure 8 shows the average UE throughput for all UE population in the network within duration 1 second. The figure shows the three scheduling types; best CQI, proportional fair and round robin, respectively. Ignoring the first 50TTIs used to warm up the simulator, it is clear that best CQI scheduling algorithm produces very high throughput level compared to the other two (almost 1.6 times proportional fair and 7 times round robin) due to its greedy nature. It's interesting to note that although proportional fair algorithm gives a fairer chance of being scheduled for each individual node over a specified window of time (1000 TTIs in our case), Best CQI achieves better averaged performance per user.

Although no mobility is considered in this study but UE mobility around the cell improves its performance and its chances in accessing the network transmission queue. It's probably more advisable to use best CQI in highly mobile LTE networks such as those supporting vehicular communication links over highways while using proportional fair or one of its derivatives for typical urban low-mobility networks. Such claim needs to be validated further using simulation study and it's out of the scope of our study.

In addition to that, best CQI achieves a low averaged BLER levels in comparison to proportional fair and round robin, as shown in Fig. 9, indicating similar pattern to the throughput.

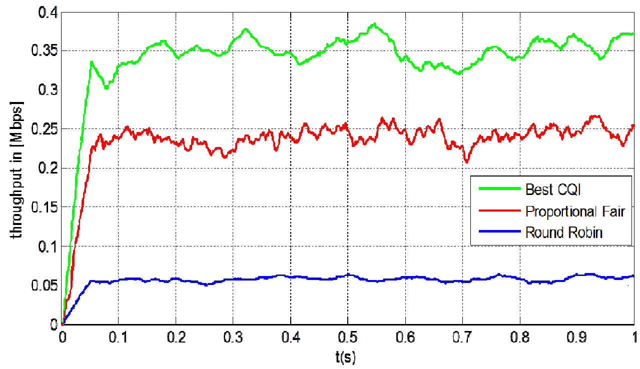

Fig. 8: Average UE throughput for 20 users , best CQI proportional fair and round scheduling algorithms.

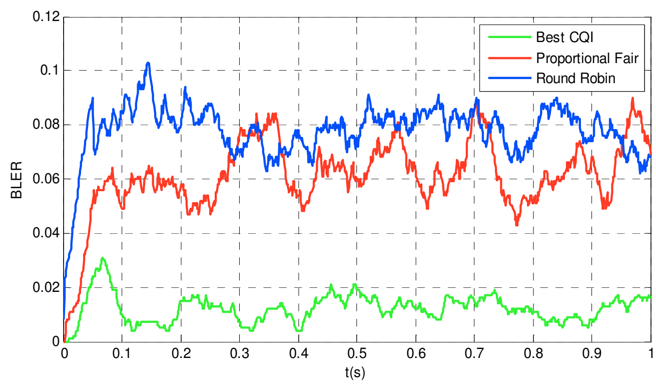

Fig. 9: Average UE BLER for 20 users , best CQI, proportional fair and round scheduling algorithms.

On a final note, it is interesting to note that in round robin scheduling scheme all resources are assigned to one user at a time and all other user have to be in the waiting queue until their turn comes and the resources are freed, hence, overall system performance will be degraded considerably. This scheme would have lowest rank in the scheduling algorithms list. Although it offers a great fairness among the users in radio resource assignment but it is not practical for LTE technology as one user is served at a time and thus degrading the whole system throughput considerably. One would consider the effect of specific traffic type and its flow dynamics on the scheduling algorithm performance since the time events would results in different channel behavior (at different time snapshots) and hence different overall system performance.

5. CONCLUSION

The three scheduling algorithms represent the extremes in terms of fairness to UEs and channel exploitation greedily. The greedy best CQI gives the best result in throughput and BLER among the other two, but at the expense of limited access to those suffering bad channel conditions. Each algorithm has its advantages and disadvantages and typically a trade-off has to be achieved in scheduler design.

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