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Comparative Performanceof Subcarrier Schedulers in Uplink LTE-A under High Users' Mobility

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Abstract: This paper evaluates the effects of high mobility of Users Equipment (UEs) on the performances of different data rate services using four scheduling algorithms in the uplink of LTE system using the uplink Vienna simulator.The uplink reports Channel Quality Indicator (CQI), Precoding Matrix Indicator (PMI) and Rank Indicator (RI) to inform the evolved node base station (eNodeB or eNB) about the current channel state. We simulate 20 and 30 UEs switch at high mobility and different service demands. Simulation results show that under 100 kmh^{-1}speed the Best CQI and Proportional Fair schedulers are the best in performance for low delay and the Round Robin algorithm is the worst scheduling algorithm among other schedulers.

Keywords: LTE, Uplink, AMC, Best CQI, high mobility, Scheduling, system - level (SL) simulation.

1. INTRODUCTION

In LTE-A, the Quality of Service (QoS) determines the throughput and the delay constrains, among other factors. Delay constrain is vital for some applications such as when the UE uses Voice over Internet Protocol (VoIP) service and/or online gaming [1].

The wireless channel is suffering from fast fading due tomultipath and Doppler shift. These variations take place on top of slower fading due to changing relative positions and obstacles. It is even more critical for the high-speed UEs where environmental conditions change rapidly. In our work we focus on the uplink of LTE-A where the CQI is used to identify the channel conditions and UE capability to establish a better communication link for a UE with a specific QoS [2]. There are 4-bit CQIs allowing three different types of modulation and various coding rates the choice of which depends on the CQI. Each CQI is associated with a certain level of Signal to Noise Ratio (SNR) allowed for a target Block Error Rate (BLER) which should be below or equal to 10 % [1].

In 1948, Claude Shannon derived an upper theoretical limit on the data rate that can be reliably achieved from a communication system corrupted by Additive White Gaussian Noise (AWGN) [2]:

$$C = FB \log_2(1 + SNR) \qquad \ldots\ldots\ldots\ldots (1)$$

Where C is the channel capacity in bits/sec, B is the bandwidth in Hz. SNR is the signal-to-noise ratio. The term F reflects a loss in capacity due to Cyclic Prefix (CP)[3]:

$$F=\frac{11*(Tframe-Tcp)}{14*Tframe} \qquad \ldots\ldots\ldots\ldots (2)$$

The fraction 11/14 takes into consideration the reference symbol losses. Out of the total 14 OFDM symbols in the subframe, 11 are used for data, while 3 carries the demodulation Reference Signals (RS) and Sounding Reference Signals (SRS) [3].

The LTE system has been designed to use key enabling technologies such as Orthogonal Frequency Division Multiple Access (OFDMA), Link Adaptation (LA) through Adaptive Modulation and Coding (AMC), Hybrid Automatic Repeat Request (HARQ) mechanism implemented on the physical layer, a Transmission Time Interval (TTI) of 1ms boosted with fast Packet Scheduling (PS) algorithms in the eNB [2].

A key part of LTE-A for achieving high spectral efficiency and throughput is scheduling, which controls the allocation of the common or shared resources among users at eachTTI and requires information about the CQI to exploit time, space, frequency and multi-user diversity [1][3]. Scheduling is closely related to link adaptation which deals with how to set the transmission parameters

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of a radio link to handle variations of the radio-link quality. Both scheduling and link adaptation exploit the channel variations through appropriate processing prior to transmission of the data. However, due to the random nature of the variations in the radio-link quality, perfect adaptation to the instantaneous radio-link quality is never possible [4]. HARQ, which requests retransmission of erroneously received data packets, is therefore useful [4]. This can be seen as a mechanism for handling variations in the instantaneous channel quality after transmission and well complements scheduling and link adaptation. Hybrid ARQ also serves the purpose of handling random errors due to noise in the receiver [4].

The multiple access technique in uplink LTE-A is Single Carrier Frequency Division Multiple Access (SC-FDMA) [1]. This permits the handset to offer spectral efficiency and throughput comparable to downlink while avoiding problems caused by high peak- to- average power ratio. Resource allocation and mapping subcarriers in SC-FDMA is performed, in LTE, in Resource Blocks (RB). Each RB contains 12 subcarriers that occupy a bandwidth of 180 kHz and requires time duration of 0.5ms [4]. Depending on the network's CP, normal or extended, each RB contains 7 or 6 symbols respectively [4]. Two consecutive RBs make up a 1ms sub-frame.

The topic addressed in this paper is a performance comparison of the most common uplink schedulers for high speed UE scenario in LTE-A system. The work is focusing-on the performance of the system in term of real-time constrains such as delay in VoIP and video gaming. This topic is new and was not addressed by researches before.

In the rest of the paper, section two introduces an overview of some popular uplink LTE-A schedulers. Section three describes the details of the simulation environment along with traffic models. Section four provides discussion of the results obtained. Finally, Section five contains conclusion and future work.

2. Overview of LTE uplink Scheduling

A. LTE uplink scheduler

One of the simple principles of LTE radio access is shared-channel transmission: time–frequency resources are dynamically shared among users [4]. In general, the scheduler is part of the MAC layer and controls the assignment of downlink and uplink resources in terms of resource-block pairs [2]. RBs correspond to a time–frequency units of 1ms and 180 kHz, respectively.

The target of Packet Scheduling is the Radio Resource Management (RRM), which involves algorithms and strategies for controlling parameters such as data rates, transmit power, handover criteria, modulation scheme, beam forming and error coding scheme [2].

To activate the functions of the RRM in the LTE uplink, RRM must use the scheduling in MAC layer to organize sharing radio resources by optimizing resource efficiency while satisfying QoS requirements and attaining an acceptable degree of fairness [4].

The scheduler in uplink assigns resources to UEs in amounts of RB, with each RB spanning 12 SC-FDM subcarriers [2]. The scheduler forwards the packets to be saved in a buffer (queuing system). The buffer space is divided into many queues; each is used to hold the packets of one flow for addressed source and destination IP. In each case, the network scheduling algorithm determines how the network scheduler manages the buffer [2].

Every TTI, the scheduler achieves the allocation decision, which is valid for the next TTI. This is carried out to the UEs by using the Physical Uplink Control Channel (PUCCH).

The procedures described below demonstrate RRM steps that relate to the uplink PS and the whole process of scheduling and allocation decisions as seen in Figure 1. The process is repetitive every TTI:

- Each UE decodes the RSs, computes the CQI, and sends it back to the eNB. The SRS are transmitted on the uplink to allow for the eNB estimating the uplink channel state at different frequencies. The channel-state estimates can be used by the network scheduler to assign RBs for uplink transmission, besides to select different transmission parameters such as the instant data rate and different parameters related to uplink transmission. Each UE sends the CQI computed to the eNB. Then the eNB receives CQI information, uses this information for the allocation decisions and computes the RB mapping.

- The AMC module selects the best Modulation and Coding Scheme (MCS) to be used in transmitting data by scheduled users. The AMC information concerning each user along with allocated RBs is sent to the UEs via PUCCH.

- Each UE reads the PUCCH (at the instance it has been scheduled) and accesses to the suitable Physical Uplink Shared Channel(PUSCH) payload.

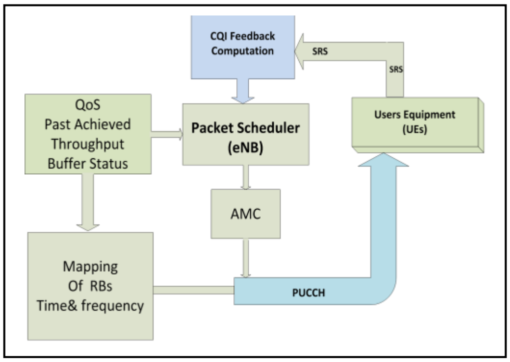

Figure 1.Packet Scheduler model [5]

B. Traffic Models

To compare the PS performance in different traffic scenarios, several traffic models are employed. These traffic models shave some QoS requirements. In our scenario, the users are randomly allocated one traffic model (TM) with confident probability based on the standardization, LTE physical layer framework for performance verification and setting according to the requirements of customers verified by the operators over the cell, that is, they have an SNR ranging randomly between -5 and 35dB [6]. Nevertheless, in order to be able to compare the results, simulations are carried out with the same SINR realization. Otherwise, it would be impossible to compare different schedulers with different SINR realizations.

VoIP performance and capacity are other parameters to be evaluated both for DL and UL [2]. The percentage of users with interruption should be less than 2%, where a user suffers interruption if less than 98% of VoIP packets have been delivered successfully [2]. VoIP modulates packets at regular intervals equal to 20 ms between packets for active state while the time between packets for silent state is 160 ms.A packet is delivered successfully if transmission delay is less than to 50ms [2].

Additional two types of real-time (RT) service are video-streaming and online gaming. Their packet parameters are characterized by a reliable Cumulative Distribution Function (CDF). These applications are delay sensitive. They compete against VoIP, as all are RT-services and a maximum delivery time requires to be guaranteed [4].

Other popular applications are File Transfer Protocol (FTP is a communication protocol utilized to exchange files through a Transmission Control Protocol with Internet Protocol (TCP/IP) network), and Hyper Text Transfer Protocol (HTTP). They both are Non-Real-Time (NRT) traffic models, the size and the time between their packets are characterized by a CDF also. As their packets are larger than the packets of VoIP, these traffic scenarios are resource-demanding. The QoS requirements (QCI) are converted during LTE standardization into parameters and limitations as indicated in table I [5].

TABLE I: STANDARIZED QoS CLASS IDENTIFIER FOR LTE [5]

QCI	priority	Packet delay [ms]	Packet loss rate	service
1	2	100	10^{-2}	VoIP call
2	4	150	10^{-3}	Video call
3	3	50	10^{-6}	Online gaming
4	5	300	10^{-3}	Video streaming
5	1	100	10^{-6}	IMS Signaling
6	6	300	10^{-3}	Email, ftp
7	7	100	10^{-6}	voice
8	8	300	10^{-6}	http
9	9	300	10^{-6}	Video

C. Scheduler types

There are many scheduling algorithms proposed for the uplink of LTE-A, the most popularof which are briefly described below.

a) Round Robin: This scheduler distributes the resources equally to all UEs by assigning RBs to the semi-occupied Radio link control (RLC) queues in aperiodic order. RR is suitable for RT, services with constant data rate such as live video. But it is unsuitable for NRT, variable data rate services such as web browsing, because distant UEs with low SNRs will dominate the cell's use of resources [2].

b) Best Channel Quality Indicator: This scheduler is designed to assign resource blocks and provide priority of access to users having best radio linkconditions. In order to perform scheduling, UEs send CQI to the eNB then in the downlink, the eNB transmits reference signal to UEs whichis used by UEs for the measurements of the CQI. A higher CQI value means better channel condition. Best CQI scheduling can increase the cell capacity at the expense of the fairness. In this strategy, users located at larger distances from eNB have low probability to get access to the shared resources [7].

c) Proportional Fair Scheduler: First applied in Time Domain Scheduling (TDS) systems, then it adopted to LTE to exploit the OFDMA capabilities in Time Domain Scheduling and Frequency Time Scheduling (FDS) systems. This scheduler offers a tradeoff between the overall system throughput and data rate fairness. It increases the degree of fairness amongUEs by selecting users with relatively better channel quality [7].

d) The Maximum Throughput Scheduler: This strategy allocates resource to the UEs with the highest SNRs to transmit and receive at the highest data rates. Which is in turn, maximizes the cell throughput. Distant UEs, however, cannot get a chance to transmit or receive [2].

3. RELATED WORK

We provide a brief review of some research reported in the literature. In [8], many PS algorithms have been considered such as Round Robin (RR), Best CQ and Proportional Fair (PF). It is shown that the RR allows the users take turns in sharing resources, disregarding the instantaneous channel conditions, leading to lower overall system performance [8].

In [9], the authors utilized and exploited a mixed type of traffic flows and evaluated the schedulers in terms of user throughput, fairness and packet loss in low UE speed.

In [10], the authors proposed two scheduling schemes for the uplink of M2M LTE, which take into account both the channel conditions and the maximum allowed delay of each device requesting to be served. The first algorithm is basically an extension of the conventional channel-aware schedulers, but taking into account the maximum delay tolerance of each device. The second algorithm gives priority to devices with low delay tolerance and then tries to find the best RB in terms of channel quality in order to assign the resources.

In [11], the authors evaluated the performance of uplink scheduling algorithms for channel dependent and proportional fairness paradigms.

In [12], the authors compared the performances of an LTE-A uplink system in flat Rayleigh and pedestrian channels by Least Square (LS) and Adaptive Linear Minimum Mean Square Error (ALMMSE). In addition, they compared the performance of an LTE-A system in terms of BER and throughput related to SNR.

The topic addressed in this paper is a performance comparison of the most common uplink schedulers for high speed UE scenario in LTE-A system. The work is focusing-on the performance of the system in term of heavy mobility and real-time constrains such as delay in VoIP and video gaming. This topic is new and was not addressed by researches before.

4. SYSTEM MODEL AND CONFIGURATION

We consider the ITU Vehicular-A channel model since it accounts for scenarios involving users with wide range of mobility ranging from pedestrian to vehicles moving at high speeds up to 200kmh^{-1} [1].

To evaluate the effects of the high UEs mobility with different scheduler schemes in the uplink, the Vienna uplink-simulator is used [13]. The simulation setup consists of a single cell Single Input Single Output (SISO)system covered by three-sectors with either 20 or 30 usershaving average SNRs ranging from -5 to 35 dB in a 1 dB stepmoving in the cell with a speed 100 km h^{-1}in random directions. A site distance of 500m is chosen in a rural environment. The simulation parameters are summarized in Table II.

An important consideration for real-time applications is to assure QoS in terms of allowed BER particularly for video streaming and online gaming while for other applications such as VoIP, the QoS is expressed additionally and more importantly in terms of allowed delay constraint. A packet is considered to be delivered successfully if the transmission delay is less or equal to 50ms.

TABLE II.PARAMETERS USED IN THE SIMULATIONS

Parameters	**Settings**
Carrier frequency	2GHz
Bandwidth	1.4 MHz
Number of RBs/sub-frame	12
Number of subcarriers	72
Tx and Rx mode	SISO
Number of users/cell	20, 30 users
User speed km h−1	5, 100
Channel model types	VehA
Receiver type	Zero Forcing (ZF)
Scheduler type	BCQI, Max thr, PF and Round Robin
Scheduler assignment	Dynamic for all schedulers [13]
Down link delay	0 TTI
Time of simulation	5000 TTI

5. SIMULATION RESULTS AND DISCUSSION

We conducted simulations assuming 20 and 30 UEs per cell according to the setting displayed in Table II. The scheduler type and speed of UEs were the parameters chosen to evaluate the effects of mobility on throughput and delay in each run. The throughput results for 20 UEs are depicted in Figure two for the Best CQI, Proportional Fair, Maximum throughput and Round Robin. Figure three displays results for 30 UEs using the same scheduling types. A fraction of the transmitted packets versus delay is evaluated for VoIPusing the four scheduling algorithms. Results are depicted in Figure four for 20UEs, while Figure five shows corresponding results for 30UEs. Results shown for 20UEs reveal that the Best CQI and Maximum Throughput schedulers are the best in performance as far as throughput is concerned while the Round Robin scheduler performance is the lowest.The red columns shown in the Figures four and five are for the 40 TTI delay, belong to the fraction transmitted packets for each scheduler as tabulated in last column in table three. From Table III, the Proportional Fair and Best CQI provide the highest fractional transmitted packets for 40 TTI delay among the four schedulers considered.

The sum of throughput results for 20 UEs is depicted in Figure seven for the Best CQI, Proportional Fair, Maximum throughput and Round Robin. Figure eight displays results for 30 UEs using the same scheduling types. The fairness results for 20 UEs, 5 and 100kmh^{-1} are depicted in Figure eight for the Best CQI, PF, Maximum throughput and Round Robin. Figure nine displays results for 30 UEs using the same scheduling types

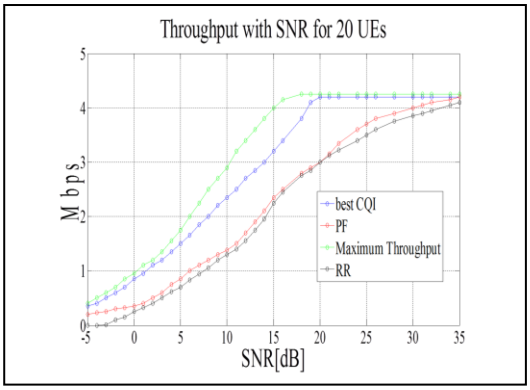

Figure 2. Cell throughput for four schedulers for (20 UEs)

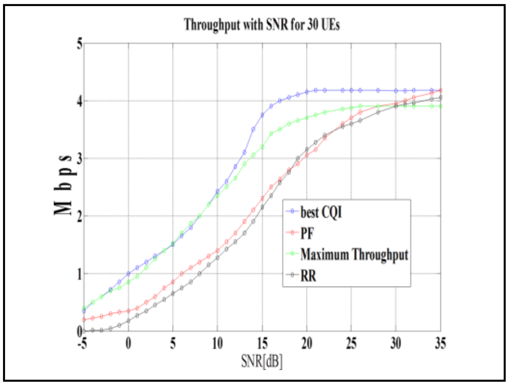

Figure 3. Cell throughput for four schedulers for (30 UEs)

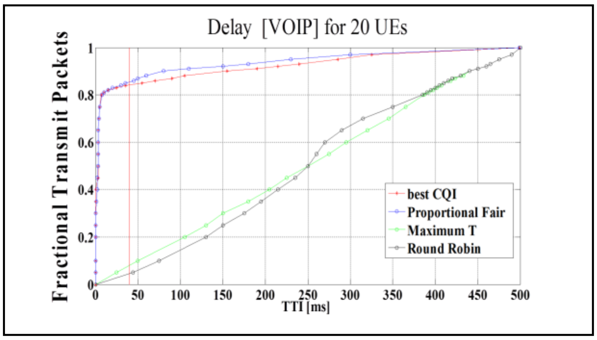

Figure 4. VoIP Delay for four schedulers for (20 UEs)

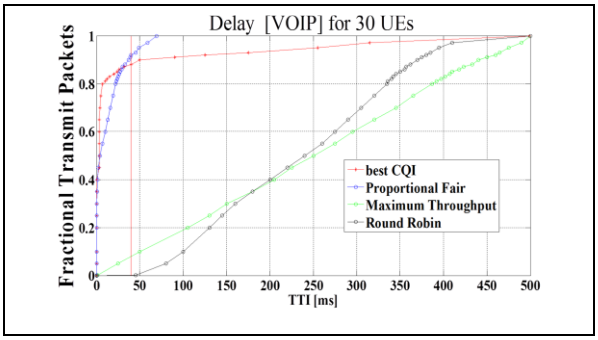

Figure 5. VoIP Delay for four schedulers for (30 UEs)

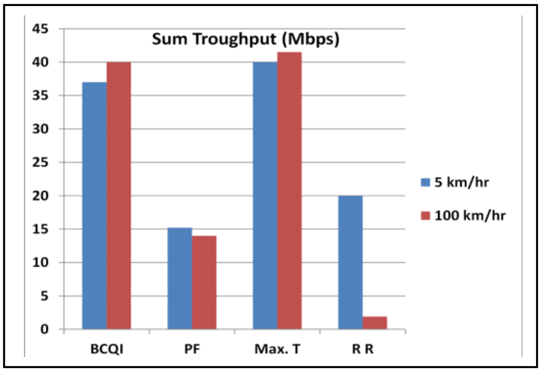

Figure 6. Sum of the Throughput for four schedulers for 20_UEs for 5 and 100kmh^{-1}

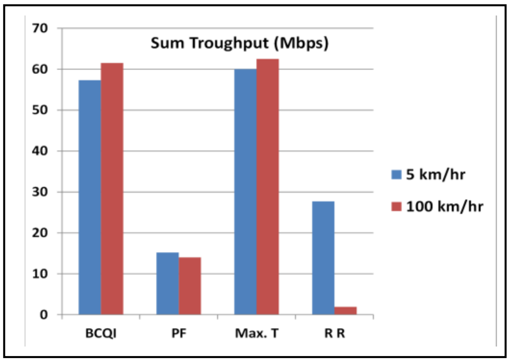

Figure 7. Sum of the Throughput for schedulers for 20_UEs for 5 and 100kmh^{-1}

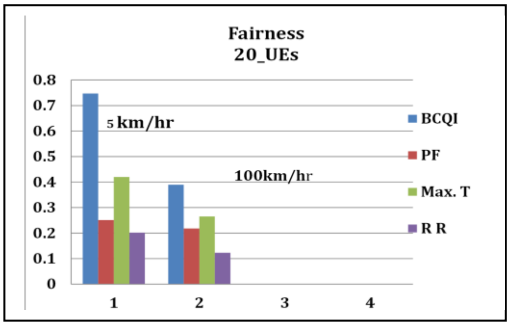

Figure 8. Fairness of the schedulers for 20_UEs of speeds(5 and 100) kmh-1

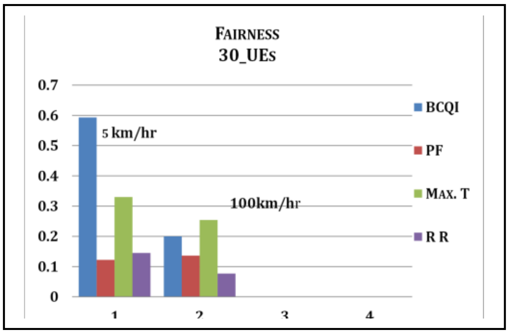

Figure 9. Fairness of the schedulers for 30UEs of speeds (5 and 100 kmh-1)

Table III: THE COMPARISON RESULTS BETWEEN SCHEDULER TYPES

Scheduler	VoIP	Game	Video	Fraction transmitted packets at 40 TTI
PF 20UEs	260	64	460	0.875
PF 30UEs	113	360	460	0.85
BCQI 20 UEs	415	426	470	0.84
BCQI 30UEs	358	195	7	0.84
Max.20UEs	500	499	498	0.075
Max. 30UEs	500	500	500	0.005
RR 20UEs	496	500	478	0.004
RR 30UEs	498	500	488	0.00

CONCLUSION

In this paper, a comparative performance is conducted among different scheduling algorithms in the uplink of LTE-A system under high speed users' mobility which is not addressed so far by researchers. The Proportional Fair (PF), Best Channel Quality Indicator (BCQI), Maximum throughput (Max T) and Round Robin (RR) schedulers are simulated using Vienna uplink- simulator. Performance for scheduling in the uplink was evaluated and compared in terms of throughput and delay for real-time users under heavy mobility. The simulation results show that Proportional Fair and Best CQI schedulers are the best in performance delivering packets with lower delay. In term of the sum throughput the Max T and BCQI shows the best results at a speed of 100km/hr. Finally in term of fairness the BCQI scheduler shows the best results. As a future work further different transmission parameters such as the instant data rate, handover criteria, modulation scheme, beam forming and error coding scheme and other parameters related to uplink transmission can be selected and tested under the condition of high mobility.

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