



Performance analysis of prioritization in LTE networks with the Vienna LTE system level simulator

**Master degree of
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Abstract

This study was performed with two main goals in mind. The first goal was to understand the prioritisation capabilities in Long Term Evolution (LTE) networks and how it is done. The second goal was to understand the simulation of LTE networks (Vienna LTE simulator) and to add on the system level simulator an algorithm that will lead us to have priority access for some users following their QoS Class Identifier (QCI) and finally analyse the results.

Key words: LTE, prioritization, Vienna LTE simulator, QCI.

Table of contents

Priority access and simulation in Long Term Evolution (LTE)



	... 1
Introduction	1
1. Introduction	1
1.2. Goal and objectives of the thesis	1
1.3 Thesis structure.....	1
Prioritisation capabilities in LTE networks	3
2.1. Overview of LTE network:	3
2.2. Public Safety Network, Commercial Networks and Preemption mechanism	6
2.3. Public Safety LTE Priority and Quality of Service (QoS)	9
2.3.1. Overview of ARP (Allocation and Retention Priority)	10
2.3.2. Overview of QCI (QoS Class Identifier)	11
2.3.3. LTE Prioritization Gates.....	12
2.4. Fully automated LTE system and non-fully automated LTE system	13
2.5. Conclusion.....	14
Simulation of LTE networks	15
3.1. Vienna LTE simulator	15
3.1.1. LTE link level simulator.....	15
3.1.2. LTE system level simulator.....	16
3.2. Types of scheduler	18
3.3 Fractional Frequency Reuse (FFR).....	20
3.4 Transmission modes	21
3.5. Femtocells	25
3.6. SNR to CQI mapping.....	25
3.7 Plotting results	27

3.8. Conclusion.....	29
Performance assessment of prioritization capabilities.....	30
4.1. Prioritization mechanism	30
4.1.1 Proportional Fair (PF) scheduling:.....	30
4.2 Validation of the simulator	32
4.2.1 Validation of the instantaneous throughput and the accumulated throughput and see how there are connected.....	32
4.2.2 Testing the dynamic of the system.	38
4.3 QCI-aware Proportional Fair (PF) scheduling.....	42
4.3.1 Simulation results:	43
4.4. Conclusion:.....	49
Conclusion and Future Work	50
References:	51

List of Figures

Figure 1: The main components of the LTE network and let us see their relationship [3]	4
Figure 2: Dedicated public safety network with a shared commercial network [4].....	7
Figure 3: Public safety users and commercial user in the shared commercial RAN [4]	8
Figure 4: Slow arrival of public safety users in shared commercial network [4]	9
Figure 5: Fast arrival of public safety users in shared commercial network [4]	9
Figure 6: LTE prioritization gates [5]	12
Figure 7: Elements of link level simulator. [11]	16
Figure 8: Schematic block diagram of the LTE system level simulator [6].....	17
Figure 9: Scheduler comparison [7]	19
Figure 10: Fractional Frequency Reuse applied in the LTE system level simulator [7].....	21
Figure 11: SISO and TxD transmission mode [7]	23
Figure 12: Throughput comparison for CLSM NxN [7].....	24
Figure 13: All antenna configurations [7]	24
Figure 14-A: SNR to CQI mapping [7]	26
Figure 14-B: CQI BLER curve [7]	26
Figure 15: eNodeB and UE position [7].....	27
Figure 16: throughput and mixed result [7].....	27
Figure 17: Raccum and Rinst for user number one in cell number one at TTI=10	33
Figure 18: Raccum and Rinst for user number one in cell number one at TTI=20	34
Figure 18 a : Value of Rinst at TTI equal to 15	34
Figure 18 b :Value of Raccum at TTI equal to 14	34
Figure 18 c :Value of Raccum at TTI equal to 15.....	34
Figure 19: Raccum of user number one in cell number 13 at TTI=500.....	36
Figure 20: Raccum and Rinst of user one in cell number one at TTI=30.	37
Figure 21: Raccum and Rinst for user number two in cell number one at TTI=30	38
Figure 22: Rinst for the ten users in cell number one at TTI=10.....	39
Figure 23: Rinst for the ten users in cell number one at TTI=30.....	39
Figure 24: Rinst for the ten users in cell number one at TTI=50.....	41
Figure 25: Raccum for the ten users in cell number one at TTI=20	41
Figure 26: Raccum for the ten users in cell number one at TTI=50.....	42
Figure 27: Raccum for the ten users in cell number one with alpha equal to 1 and 0.5	44
Figure 28: Raccum for the ten users in cell number one with alpha equal to 1 and 0.8	45
Figure 29: Raccum for the 20 users in cell number one with alpha equal to 1 and 0.8	45
Figure 30: Raccum for the 20 users in cell number one with alpha equal to 1 and 0.6	46
Figure 31: Mean throughput of the two kinds of users with alpha fix equal to 1 and 0.6	47
Figure 32: Mean throughput of users in cell number one at TTI=50.....	48
Figure 33: Mean throughput of the two kinds of users.....	49

List of Tables

Table 1: QCI values and their QoS [3]	11
Table 2: Different transmission modes [9]	21

List of Acronyms

3GPP	Third Generation Partnership Project
16-QAM	16 Quadrature Amplitude Modulation
4-QAM	4 Quadrature Amplitude Modulation
64-QAM	64 Quadrature Amplitude Modulation
AMC	Adaptive Modulation and Coding
AMC	Adaptive Modulation and Coding
ARP	Allocation and Retention Priority
BICM	Bit Interleaved Coded Modulation
BLER	Block Error Ratio
CLSM	Closed Loop Spatial Multiplexing
DL-SCH	Downlink Shared Channel
ECDF	Empirical Cumulative Distribution Function
EPC	Evolved Packet Core
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FFR	Fractional Frequency Reuse
FR	Full Reuse
GBR	Guaranteed Bit Rate bearers
ICI	Inter Cell Interference
IP	Internet Protocol
LL	Link Level
LTE	Long Term Evolution
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
Non-GBR	Non-Guaranteed Bit Rate bearers
OFDMA	Orthogonal Frequency-Division Multiple Access
OLSM	Open Loop Spatial Multiplexing
PCRF	Policy and Charging Rules Function
PDN-GW	Packet Data Network Gateway

PF	Proportional Fair scheduling
PLMN	Public Land Mobile Network
PMI	Precoding Matrix Indicator
PR	Partial Reuse
PSTN	Public Switched Telephone Network
QCI	Quality Class Identifier
QCI	Quality of Service Class Identifier
QoS	Quality of Service
RAN	Radio Access Network
RB	Resource Block
RI	Rank Indicator
S-GW	Serving Gateway
SIM/USIM	Subscriber Identity Module/Universal Subscriber Identity Module
SINR	Signal to Interface and Noise Ratio
SL	System Level
SNR	Signal to Noise Ratio
TFT	Traffic Flow Template
TTI	Transmission Time Interval
TxD	Transmission Diversity
UE	User Equipment
UMTS	Universal Mobile Telecommunication Systems
X2	interface between eNB's

Chapter 1

Introduction

1. Introduction

In November 2004, 3GPP began a project to define the long-term evolution (LTE) of Universal Mobile Telecommunications System (UMTS) cellular technology to have higher performance and wider application.

In addition mobile broadband is growing fast; some studies say that by 2016 there are expected to be close to 5 billion mobile broadband subscriptions worldwide, and since the majority of these will be served by LTE networks so LTE is continuously being developed to make sure that future requirements and scenarios are being met and prepared for in the best way. For example some researches are done in order to provide the public safety users priority access to the commercial users in the same network. In the following report we will change the rule of the PF schedulers, since the role of the scheduler is to assign resource block to the users, to provide and guarantee the prioritization between the users following their safety role in public.

1.2. Goal and objectives of the thesis

Like we said before the first goal was to understand the prioritization capabilities in Long Term Evolution (LTE) networks and how it is done. The second goal was to understand the simulation of LTE networks (Vienna LTE simulator) and to add on this simulator a QCI number for users in addition to add a new mechanism on the PF scheduler which will lead to the prioritization between the users and finally getting some plots to analyses how the new mechanism affects the LTE simulator.

1.3 Thesis structure

This thesis is organized as follows:

- Chapter2: In this chapter in section 2.1 we will take a quick view of LTE networks. Section 2.2 discusses the public safety network and commercial network, how public

safety users can roam to the commercial network in case of congestion in his dedicated network and finally what are the four possibilities in the shared commercial RAN when public safety users and commercial users exist and how the preemption mechanism work. Section 2.3 discusses the public safety LTE priority and the quality of service which is supported by Quality of Service Class Identifier (QCI) (2.3.1) and the Allocation and Retention Priority (ARP) (2.3.1) in addition LTE prioritization gate (2.3.3). Finally in section 2.4 we will explain what are the differences between a fully automated system and a non-fully automated system and when they should be used.

- Chapter3: This chapter is organized as follow: In section 3.1 discusses the Vienna LTE simulator that support the link and level simulation. In section 3.2 till 3.7 talk about how to use the LTE system level simulator and discuss some figures and some structures. Finally this chapter is followed by a conclusion in section 3.8.
- Chapter4: In this chapter section 4.1 discusses the Proportional Fair scheduling. In addition, section 4.2 discusses the validation of the simulator. Moreover in section 4.3 shows the alpha that have been added to have priority access and we will discuss some plots that we got. Finally this chapter is followed by a conclusion in section 4.4.

Chapter 2

Prioritisation capabilities in LTE networks

2.1. Overview of LTE network:

LTE refers to Long Term Evolution, where it is divided into two main parts: the radio access network which is called E-UTRAN (Evolved UMTS Terrestrial Radio Access Network) and the packet core network which is called EPC (Evolved Packet Core).

The E-UTRAN has two essential components: the User Equipment (UE) and the eNodeB which is the base station. Moreover UE is any device used directly by an end user to communicate with the base station. However eNodeB grips or controls all radio access functions in addition each eNodeB is connected to the evolved packet core by means of the S1 interface, so like that it allows for user equipment to communicate with the radio access network (EPC). Not to mention that eNodeB may be interconnected with each other's by means of the X2 interface and the main goal of this interface is to minimize packet loss due to user mobility so briefly X2 interface supports enhanced mobility, inter-cell interference management and SON functionalities. Note the eNodeB functionalities are: radio resource management (radio bearer control, radio admission control, connection mobility control and scheduling in both uplink and downlink), measurement and measurement reporting configuration for mobility and scheduling, AS security, IP header compression and encryption of user data stream, routing of user plane data towards serving gateway, Scheduling and transmission of paging messages and finally scheduling and transmission of broadcast information. [2] [3]

The EPC is composed of several components: The Mobility Management Entity (MME), the Serving Gateway (S-GW), the Packet Data Network Gateway (PDN-GW) and the Policy and Charging Rules Function (PCRF). The MME is in charge of all control plane functionalities linked to subscriber and session management. Briefly MME controls mobility, UE identity and diverse features of security. The S-GW is the termination point of the packet data interface towards E-UTRAN. The main functionalities of S-GW are: local mobility anchor when terminals move through eNodeB in E-UTRAN and this mean that the packet are routed through E-UTRAN mobility and mobility with other technologies, Packet routing and forwarding, QCI granularity.

The PDN-GW allows connection between the core network and the external packet data network. The main functionalities of PDN-GW are: Uplink and Down Link service level charging, UE IP addresses allocation, DL rate enforcement based on APN-AMBR and credit control for online charging. Briefly PDN-GW supports policy enforcement feature in addition to packet filtering and finally evolved charging support. The responsibility of PCRF is to initiate QoS if a user needs better QoS in addition PCRF detects service flows and enforces the charging policy. [1] [2] [3]

In addition it is important to mention that EPC would not have a circuit switched domain anymore and that the EPC use packet switched architecture.

To clarify what we have said before, below figure 1 includes the main components of the LTE network and let us to see their relationship.

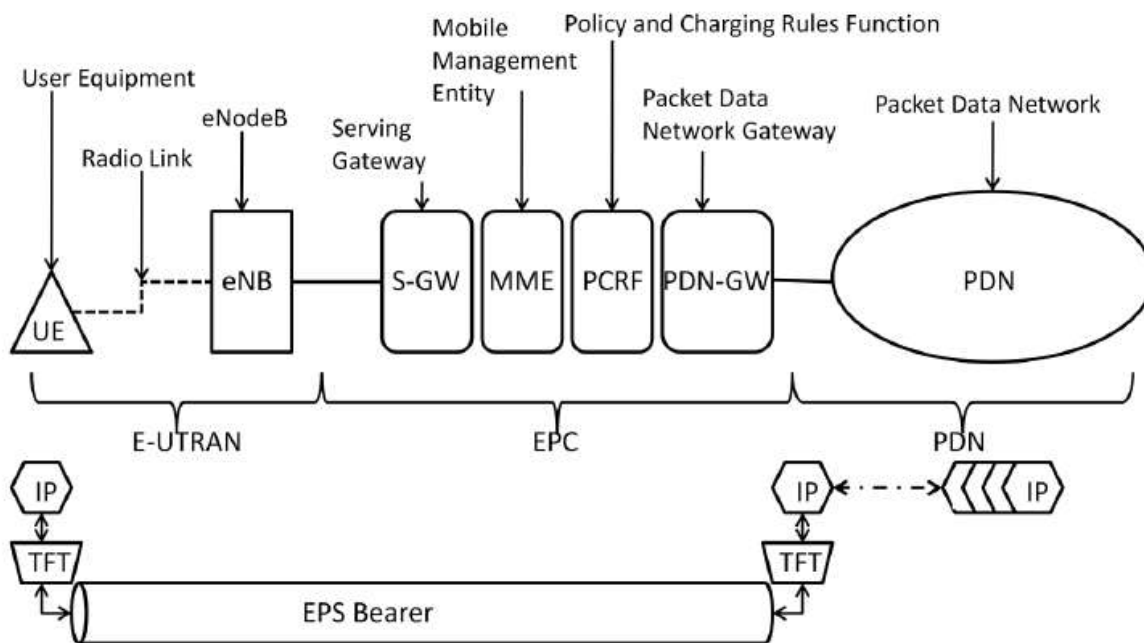


Figure 1: The main components of the LTE network and let us see their relationship [3]

Let us now talk about EPS Bearers, EPS bearers are a connection oriented transmission network which requires the establishment of a virtual connection between two end points (in LTE between the user equipment and the PDN-GW). Note that there are two types of EPS bearer:

The default bearer where each user's equipment has at least one and it is initiated when he is connected to the network and last till the user equipment disconnects from the network. The dedicated bearers are initiated at any time and each user's equipment can have different one, this dedicated bearer is used where the QoS requirement for some traffic is different than the one given by the default bearers. [3]

Moreover dedicated bearers are divided into two types:

1. GBR (guaranteed bit rate) bearers
2. Non-GBR (non-guaranteed bit rate) bearers

In GBR bearers there are no packet drops in case of congestion since the system insures that a minimum bit rate will be given to the GBR bearer. However in non-GBR bearers we may have packets loss in case of congestion since there are no guarantees that the amount bit rate needed will be given to the non-GBR bearers. Not to mention that GBR bearers are used when it is better to block a service to not have a problem in case it is accepted, for example in case of a real time voice call it is better to block this call if the system can insure a minimum bit rate than accept it because if the system accept it and can't insure a minimum bit rate to maintain it all time this will lead to an incomprehensible voice. Nevertheless non-GBR bearers are used in other applications for example e-mail or web-browsing. Note that the importance of an application doesn't depend on the type of bearers (GBR bearers or non-GBR bearers). [3]

Finally note that the bearer mechanisms (GBR or non-GBR) allow us to differentiate between the applications traffics and put in the same bearer the traffics that have similar QoS. So when an EPS bearers are established a single user equipment can have multiple bearers related to him because the traffics that have similar QoS are grouped together and send it in an EPS bearers, and it's the role of Traffic Flow Template (TFT) to identify which IP packets should be assigned to which bearers by using IP header information.

2.2. Public Safety Network, Commercial Networks and Preemption mechanism

To support the public safety users they should be able to roam or to access to commercial wireless broadband networks in case where their own networks are fully loaded or in case of congestion and this roaming to the commercial wireless broadband networks will lead to many advantages for example increasing the total capacity, the total coverage, the cell site diversity and finally increasing resiliency.

However the key point of that is to give a priority access to public safety users by providing them preferential treatment than commercial users when public safety users are roaming in the commercial LTE networks, since the public safety users have a critical mission to do as protecting the public and keeping them safe.

Figure 2 below will show us the architecture of a dedicated public safety network with a shared commercial network and how they are connected to each other. Moreover from this figure we can deduce that the public safety traffic are manage first in the public safety RAN however during congestion the public safety users roam into the shared commercial RAN but in case where the commercial RAN is also congested we should here provide several features for controlling and initiating the QoS mechanisms to give priority access to public safety users such as QCI (Quality Class Identifier) or ARP (Allocation and Retention Priority) which will be discussed later. Note that a commercial user can only be connected to the commercial RAN and their traffic will be handled over the commercial EPC. [4]

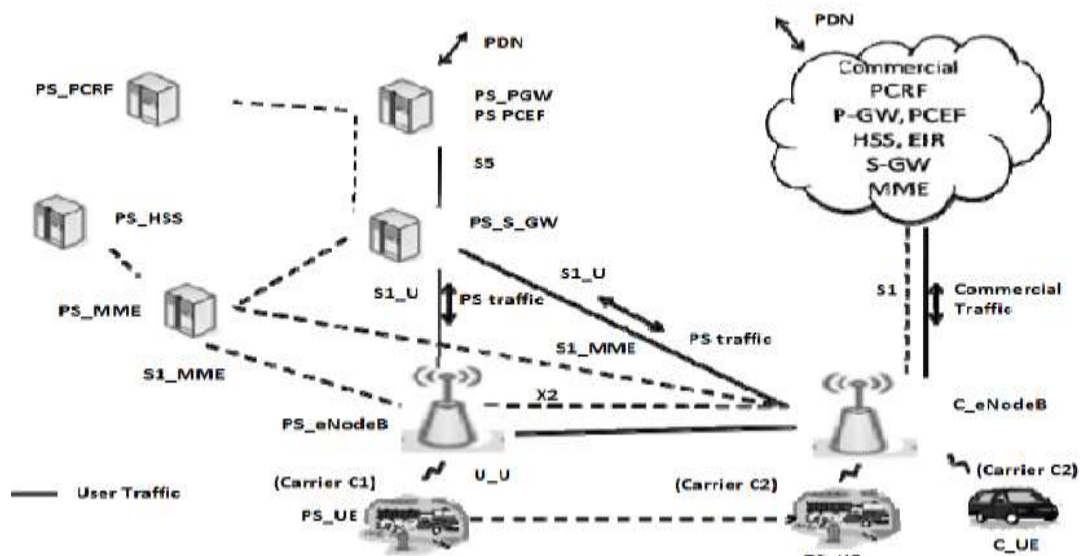


Figure 2: Dedicated public safety network with a shared commercial network [4]

In addition when public safety users roam into a commercial network we will have four possibilities in the shared commercial RAN shown in figure 3 below. Figure 3(a) reveal to us where there are extra capacity not used for the both public safety users and commercial users in the shared commercial RAN. In Figure 3(b) the commercial users is allowed to use the extra free capacity for the public safety users since the commercial users spent all their capacity and there are free space in the public safety users but the maximum range to which the commercial users can enter is shown in figure 3(c) but in this case if a public safety users want to be manage in the commercial network since his dedicated network is in congestion this public safety user will be given a higher priority access and a commercial user will be rejected from the shared commercial RAN and give his place to the public safety user (preemption mechanism). Finally Figure 3(d) show the case where both the public safety and the commercial users occupy the total capacity allocated to them. In addition in this case when a new public safety user arrives he will be kept in the congested public safety RAN and here the priority treatment will be applied. Moreover in case where the dedicated public safety network doesn't suffer any more from congestion than a chosen public safety users will be sending it back to the dedicated public safety network to be manage their. [4]

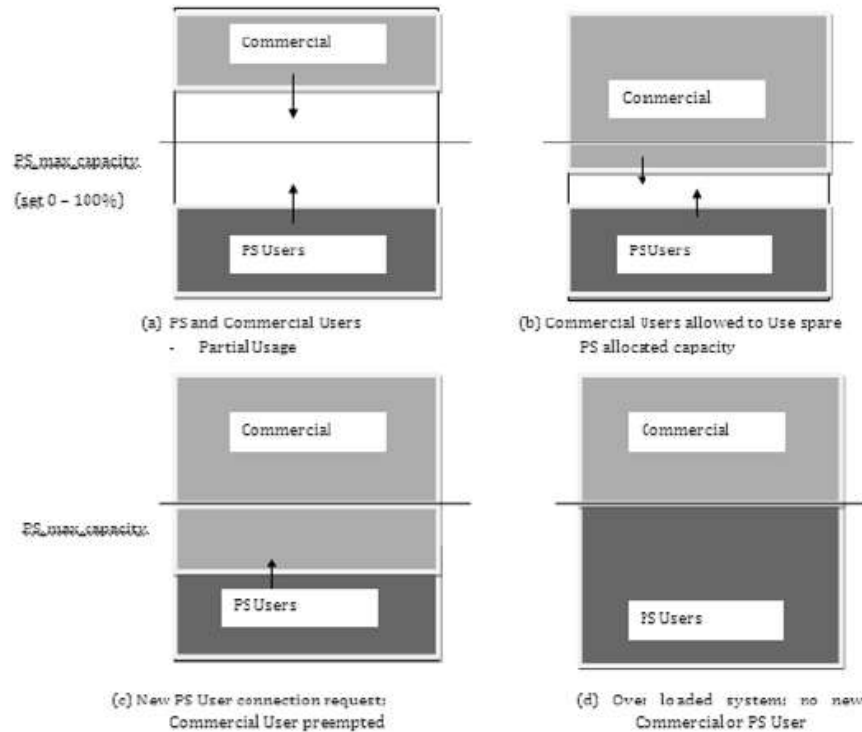


Figure 3: Public safety users and commercial user in the shared commercial RAN [4]

To more clarify the preemption mechanism let us see the below figure 4 where a Matlab based simulation is done to show the preemption mechanism when we have priority access for public safety users in a shared commercial network. In this figure we can see that the commercial users arrive and they use the free space dedicated for the public safety users because they arrive faster and the public safety users are not using all their given capacity (figure 12b). However when public safety users arrive (their dedicated public safety network is in congestion) some commercial users are preempted and the public safety users can use their allocated space because they are given a higher priority access (figure 4).

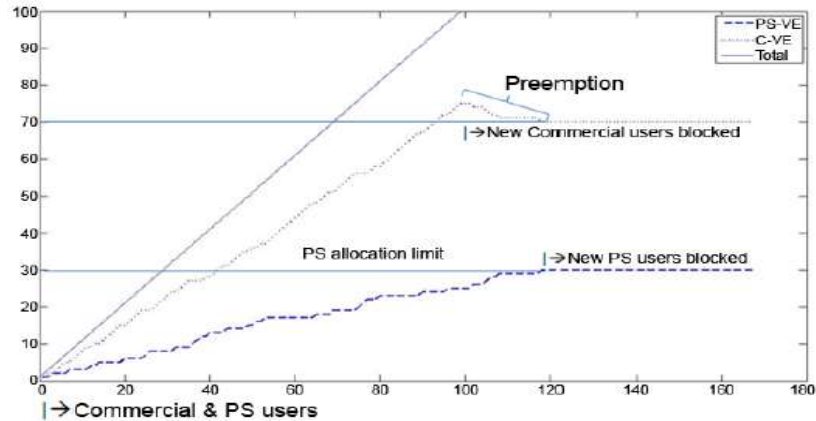


Figure 4: Slow arrival of public safety users in shared commercial network [4]

In contrast if the public safety users arrive at a faster rate before commercial users no preemption will occur in this case since the public safety users have preferential treatment. This can be shown in figure 5.

Briefly, note that in these two cases the dedicated public safety RAN is on congestion and the public safety users are routed to the commercial network where they will be allocated to the commercial RAN and they are given a higher priority access.

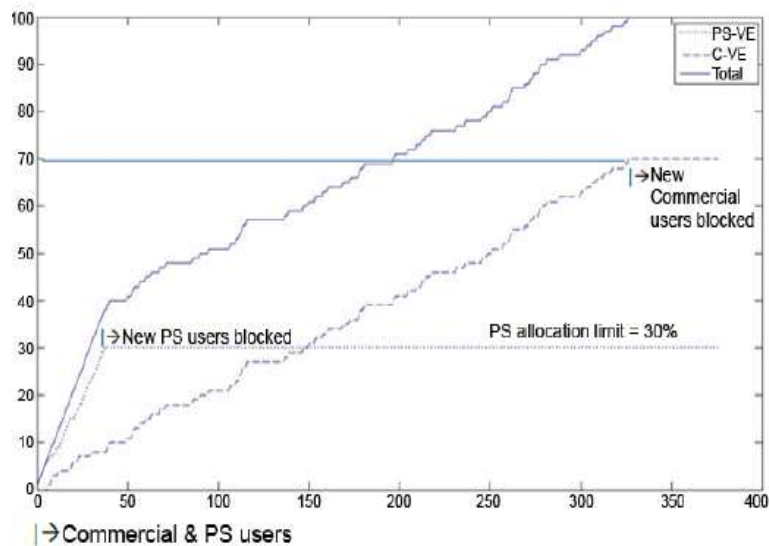


Figure 5: Fast arrival of public safety users in shared commercial network [4]

2.3. Public Safety LTE Priority and Quality of Service (QoS)

In order to support QoS (Quality of Service) demands each EPS bearer (GBR or non-GBR) explained in section 2.1 contains a number of parameters which will give it preferential

treatment from other bearers. These parameters are the QoS Class Identifier (QCI) and the Allocation and Retention Priority (ARP). Briefly to support QoS demands QCI and ARP are needed.

2.3.1. Overview of ARP (Allocation and Retention Priority)

The ARP parameters hold three components: a single scalar and two separate flag values. The single scalar value holds data related to the priority level of a bearer, however the two flags are assigned to the preemption (dropping or interrupting) capability which means whether or not a bearer is allowed to preempt other bearers which hold a lower priority level, or assigned to the preemption vulnerability of the bearer which means whether or not a bearer is at risk to be dropped even with a higher ARP priority level. So the ARP priority level is used to make sure that the bearers with a higher priority level are given preferential treatment than bearers with a lower priority level in case of congestion. Note that the ARP parameters don't play a role in the packet forwarding process.

Briefly ARP mechanisms allow two processes; the first process is that the lower priority level can be preempted by a higher one and the second process where the lower priority users that ask for request can be congested if resources are being used for higher priority users. For example during congestion the base station (eNodeB) can discard the bearer which transport the video component without influencing the bearer which transport the voice in a case of video telephony application since the two components are transported into two different EPS bearer with different ARP parameters (the voice bearer has a higher ARP priority level than the video bearer).

Not to mention that is possible to increase the number of ARP priority levels from 16 to 64 levels by using the two spare bits in the octet which are in the present not used.

2.3.2. Overview of QCI (QoS Class Identifier)

Like we mention before ARP doesn't play a role in the packet forwarding process, so the nodes in the network use QCI to recognize how to treat the packets for each bearer. Briefly, the QCI parameter will let the node know how to handle the packets for each bearer or to arrange the resources between the packets following their importance, so QCI is related to the node in the network.

QCI parameter is described by a simple scalar value. So it specifies when traffic should be sent to or received from the mobile user equipment by considering the packet latency and the packet loss rate in both downlink and uplink. Briefly the QCI mechanism makes sure that the packet received at each node in the network follow to explicit QoS characteristics (packet latency or packet delay budget and packet loss rate) and this will lead to prioritization.

In the table 1 below we can see the QCI values that have been specified and this table include QCI priority level, packet delay, packet error loss rate, and some examples for each QCI value.

Resource Type	QCI	Priority	Packet Delay Budget ¹²	Packet Error Loss Rate ¹³	Example Services
GBR	1	2	100 ms	10 ⁻²	Conversational Voice
	2	4	150 ms	10 ⁻³	Conversational Video (Live Streaming)
	3	3	50 ms	10 ⁻³	Real Time Gaming
	4	5	300 ms	10 ⁻⁶	Non-Conversational Video (Buffered Streaming)
Non-GBR	5	1	100 ms	10 ⁻⁶	IMS Signalling
	6	6	300 ms	10 ⁻⁶	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
	7	7	100 ms	10 ⁻³	Voice, Video (Live Streaming), Interactive Gaming
	8	8	300 ms	10 ⁻⁶	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
	9	9	300 ms	10 ⁻⁶	QCI typically used for the default bearer of a UE/PDN

Table 1: QCI values and their QoS [3]

Not to mention that nowadays only 9 out of 256 values are used for QCI so the rest value are kept for future use which let us to say that LTE could support hundreds of QCI levels.

2.3.3. LTE Prioritization Gates

To have a better idea about the priority and QoS we can take a look at figure 6 which will summarize the LTE prioritization gates where each user's equipment should precede the three gates or pass shown in the figure below before he can use wireless resources.

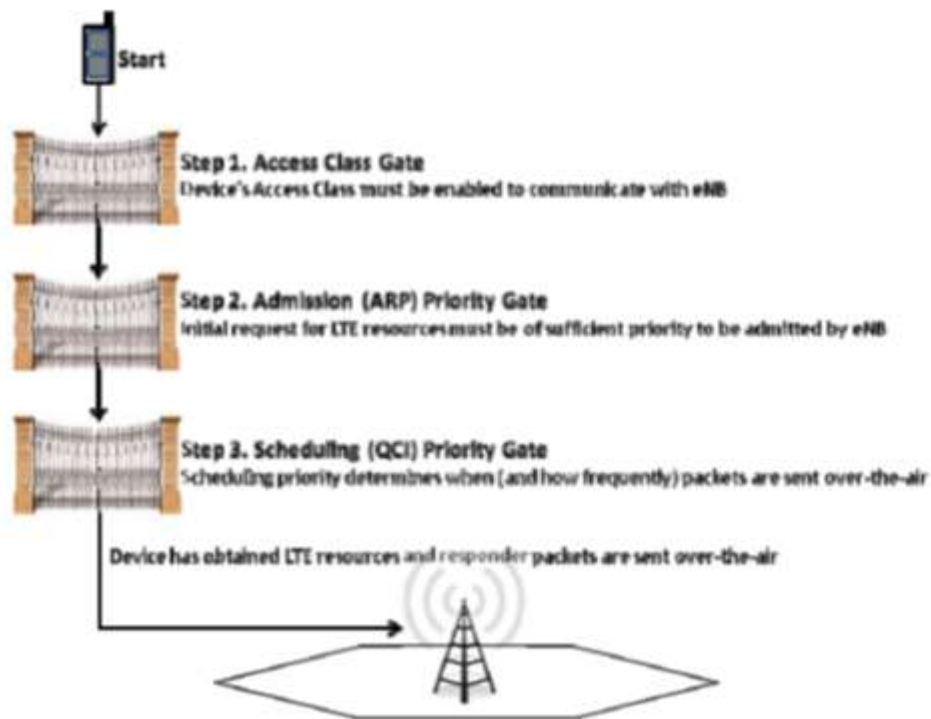


Figure 6: LTE prioritization gates [5]

When user equipment wants to send and receive data from an LTE network he has three gates to use wireless resources which are given by the network. First gate as shown in figure 6 is an access class gate, this gate decides if user equipment is authorized to interact (to be in contact) with a specific eNodeB. The second gate is the admission (ARP) priority gate where eNodeB decides that user equipment should be authorized to allocate system resources. Note that this gate is the allocation and retention priority (ARP) explained before (2.3.1). The third gate is scheduling (QCI) priority gate where the bandwidth given to specific user equipment is divided,

allocated and controlled or maintained the rate or speed by the system (QCI table1). Note that this gate is the QoS Class Identifier (QCI) explained before (2.3.2).

Note that in case of congestion LTE gives a standard capability call ACB (access class barring) to block UEs or slow down UEs from entering the system and not to mention that this happen before admission priority gate (gate 2). So the role of ACB is to block or slow down UEs in case of congestion and is not used in normal day to day operation so it is used for specific situations (when a large number of responders at a given location).

Briefly, the access class value from 0 to 9 is used for commercial users so these values should not be given to public safety users. However access class 11 is for PLMN (Public Land Mobile Network) use, access class 12 is for security services, access class 13 is for public utilities (e.g. Water or gas suppliers), access class 14 is used for emergency services and finally access class 15 is used for PLMN staff. In addition the access class number is registered in the users equipment's SIM/USIM. Note that Public Land Mobile Network (PLMN) is any wireless communication system used by terrestrial users and it is usually connected to the fixed system (PSTN).

2.4. Fully automated LTE system and non-fully automated LTE system

In an automated LTE system the QCI (QoS Class Identifier) and the ARP (Allocation and Retention Priority) are given by the system following some policies and decision rules based on the system can knows the value of a priority and can detect the value without any human interaction, and this value are given following an agreement between the commercial operators and public safety. However an automated LTE system in some cases can't give the right preferential treatment to any users so to handle these cases a non-fully automated LTE system could be added, note that this system requires human intervention. For example an automated LTE system can give a police officer a priority access while his making a voice call without knowing if his pursuing a suspect or his doing a normal voice call while allowing human intervention (non-fully automated LTE system) we can make a better decisions about prioritization and resource allocation in the previous example this mean that we can know if

the police officer is doing a normal voice call or by some mechanism he can indicate if this session is important because his pursuing a suspect. [3]

In conclusion human intervention in priority decisions can accommodate additional functionality then an automated system provide.

2.5. Conclusion

Finally in order to supply a nationwide broadband access to public safety users during emergencies it is essential that the public safety user can roam to a shared commercial network and receive preferential treatment (QCI) as if they are in the home dedicated public safety network. Not to mention that the public safety users should roam in the commercial network without affecting the commercial users by balancing the capacity usage in the shared commercial RAN, briefly by restricting the public safety user to a defined pre-allocated limit and allowing the commercial user to use the free capacity if the public safety users are not using all their allocated capacity.

Chapter 3

Simulation of LTE networks

3.1. Vienna LTE simulator

Vienna LTE simulators are an open-source simulation that supports the link and system level simulations of the Universal Mobile Telecommunications System (UMTS) Long-Term Evolution (LTE). The main role of vienna LTE simulator is to test and optimize algorithms and procedure and this is done in both link level (LL) simulator and the system level (SL) simulator since both of them are supported by the vienna LTE simulator. Note that the two simulators are accessible for free for non-commercial academic use license, which helps academic research and allows a closer teamwork between different universities and research facilities. [6]

Now let us discuss the difference between the two simulators and where each one is used and then focusing on the system level simulator, since the LTE system level simulator the performance of a whole network is analyzed, and the models over which this simulator is built.

3.1.1. LTE link level simulator

Link level simulations allow for the inspection of channel estimation, tracking and prediction algorithms, synchronization algorithms, Multiple-Input Multiple-Output (MIMO) gains, Adaptive Modulation and Coding (AMC) and feedback techniques. In addition, it can be divided into three main blocks: Transmitter (one eNodeB), Downlink channel model, and receivers (which are the users equipment) as we can see in figure 7.

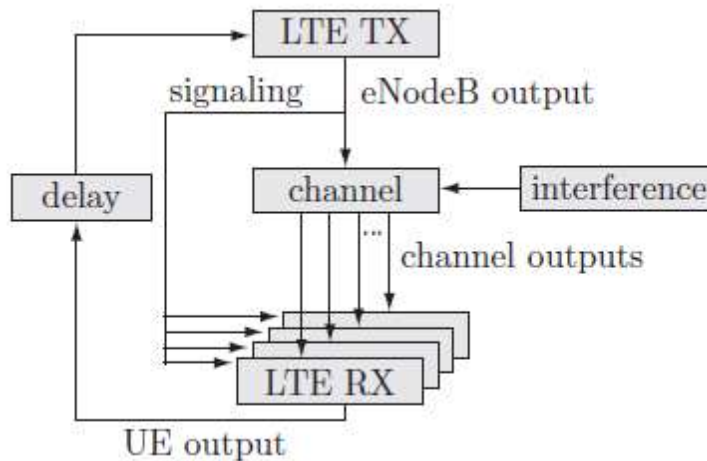


Figure 7: Elements of link level simulator. [11]

Note that in the downlink channel model only the Downlink Shared Channel (DL-SCH) is transmitted where the possible modulation for this channel are 4-QAM, 16-QAM and 64-QAM.[11]

3.1.2. LTE system level simulator

System level simulations focus more on network related issues for example resource allocation and scheduling, multi-user handling, mobility management, admission control, interference management and network planning optimization.

Note that because of the vast amount of data processing that is needed for executing the radio links between all terminals and base station it is impossible to perform the physical layer simulations in this case describe before, so to perform system level simulation the physical layer should be abstracted by reduced models without losing the main characteristics and with high efficiency and low complication. [6]

Figure 8 below describes the schematic block diagram of the LTE system level simulator which is divided into two parts.

First part is the link measurement model where the link quality is evaluated by using SINR (Signal to Interference and Noise Ratio) as metric and it is required or used to give us link adaptation and resource allocation. Note that link adaptation refers to a set of techniques where for example modulation and coding rate parameters are changed to better match the

condition on the radio link. Briefly LTE uses Adaptive Modulation and Coding (AMC) as the link adaptation technique to adapt transmission parameters, modulation scheme and code rate dynamically to the channel. For example, to adapt the modulation scheme if the SINR is high a higher order modulation scheme with a higher spectral efficiency is used (64-QAM) however if the SINR is low a lower order modulation scheme should be used like QPSK (better performance in transmission errors, but has a lower spectral efficiency). In addition, to adapt the code rate we use a higher code rate when the better the channel quality is, and this leads to a higher data rate. [12]

Second part is the link performance model which predicts the block error ratio (BLER) is defined as the ratio of the number of error blocks received to the total number of blocks sent) of the link at the receiver given a certain resource allocation, modulation and coding scheme (based on the link measurement model). Moreover the simulator output gives us the throughput, the error rates and the error distribution.

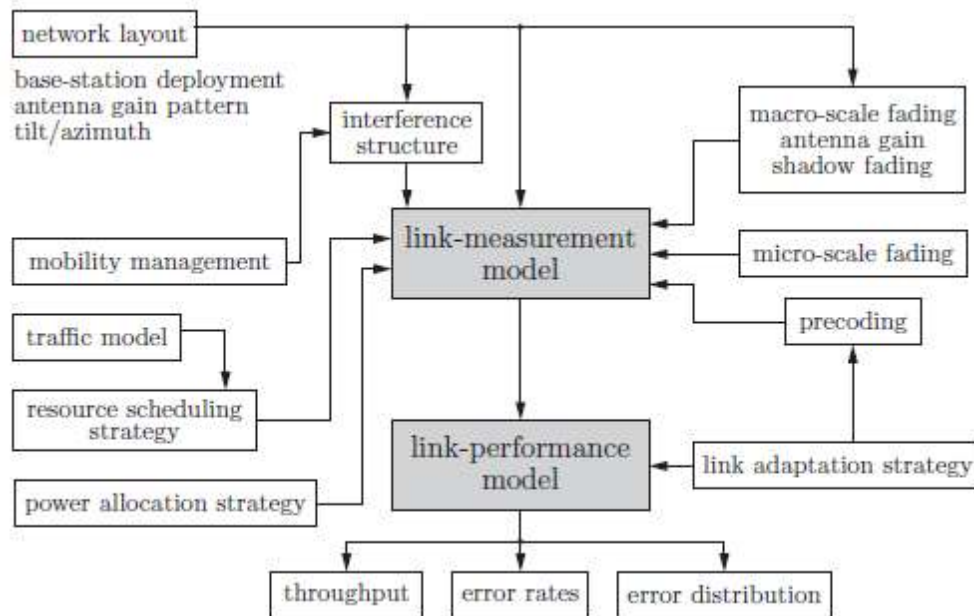


Figure 8: Schematic block diagram of the LTE system level simulator [6]

In other hand the LTE system Level Simulator allows for the following settings to be changed: [10]

1. Number of frames to simulate
2. Transmit and receive antenna numbers (LTE_config.nTX, LTE_config.nRx)
3. Network layout (section 3.5)
4. Transmit mode (LTE_config.tx_mode[2] explained in section 3.4)
5. Scheduling algorithm (LTE_config.scheduler)
6. Channel model (macroscopic path loss, Shadow fading and micro scale fading) (LTE_config.channel_mode.type)

Note that

- The macroscopic path loss is used to join the propagation path loss and the antenna gain between an eNodeB and user equipment.
- The shadow fading is generated by the obstacles and geographical characteristics in the propagation path between the user equipment and the eNodeB.
- Finally macroscopic path loss and shadow fading are position dependent and time invariant however small-scale (or micro scale) fading is a time dependent process which is the attenuation affecting a signal over certain propagation media.

From now on we will divide this chapter following the figure 2. Resource Scheduling Strategy defines how resource are distributed in a cell and how resource are assigned to user and it is referred to section 3.2 (types of scheduler) and to section 3.3 (FFR). However network layout defines the base station deployment and antenna gain pattern and it is related to section 3.4 transmission mode as well as femtocells section 3.5. In addition the Block Error Ratio is calculated from the link performance model so it will be related to section 3.6. Finally the plotting result in section 3.7 will be referred to the simulator output traces.

3.2. Types of scheduler

These types of schedulers are actually supported in the simulator, namely "Round Robin", "best CQI" and "Proportional Fair". The selection of the scheduler algorithm is done through the LTE_config.scheduler file. The Round Robin algorithm assigns the physical resources equally to all user equipments so this scheduler doesn't take the instant channel conditions into account. Accordingly it offers fairness among the users in a radio resource assignment but reduce the system throughput performance. The best CQI scheduling algorithm assigns resource blocks to

the user with the best radio link condition. Note that a higher CQI value means better channel condition and CQI refer to channel quality indicator which is a summary of the channel condition under the current transmission. Moreover, the base station in the downlink transmits reference signal to user equipment and these reference signals are used by user equipments for the measurement of the CQI and then user equipments send channel quality indicator (CQI) to the base station in order to perform scheduling. It is important to mention that in this scheduling terminal located far from the base station are rare to be scheduled. Finally the proportional fair scheduler operates between the best CQI scheduling and round robin scheduling. Proportional fair exploits user diversity by selecting the user with the best condition to transmit during different time slots so this scheduler show an acceptable throughput level while providing some fairness between users. In this figure 9 below we can see the scheduler comparison in terms of mean, edge and peak user equipment throughput the fairness is shown in the legend.

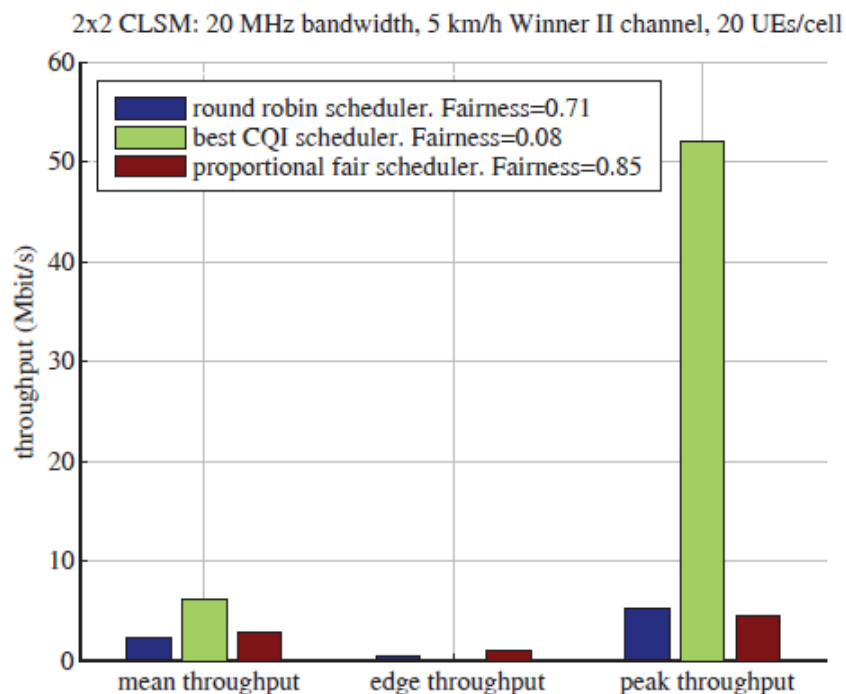


Figure 9: Scheduler comparison [7]

Note that the mean throughput refers to cell average, edge throughput refers to users located at the cell edge which indicate the cell borders and peak throughput stands for the maximum

achievable throughput in optimal condition. Like we see in the figure best CQI scheduler works on the mean throughput and has achieved its higher throughput at the peak throughput however on the edge throughput this scheduler turn to be zero because terminals are located far from the base station and they are unlikely to be scheduled like we said before. Furthermore since round robin ignores the channel quality information it usually results in lower user and overall network throughput levels. We can notice that best CQI scheduling can increase the cell capacity at the price of the fairness between user equipments. Finally by using a proportional fair scheduler we can notice that we are increasing the system throughput compared to a round robin scheduler by serving user in a fair manner.

3.3 Fractional Frequency Reuse (FFR)

It is important to mention that FFR is implemented in the LTE system level simulator as a new kind of scheduler called FFR scheduler and allows to identify a scheduler for the FR (Full Reuse) and PR (Partial reuse) parts independently. For example the activation of the FFR scheduler is done through the `LTE_config.FFR_active` and now we should identify a scheduler for the FR and PR parts as e.g. round robin or proportional fair scheduler, and this is done through the `LTE_config.scheduler_params.FR_scheduler.scheduler [7]` for the FR parts and should be equal to the type of the scheduler we need to assign to it as well as for the PR parts it is done through the `LTE_config.scheduler_params.PR_scheduler.scheduler [7]`.

Not to mention that FFR refers to fractional frequency reuse where different parts of available spectrum are allocated to different users depending on their location in the cell. To clarify more we can see figure 10 where the users closer to cell center are scheduled in frequency band with frequency reuse one however users close to cell borders (edge) are scheduled in other parts of the available spectrum with partial reuse such that the signals are orthogonal to the neighbor users. Briefly this technique consist of splitting the bandwidth into two parts: FR (full reuse) and PR (partial reuse) for the cell edge users and is used to reduce ICI (inter cell interference) caused by OFDMA system.

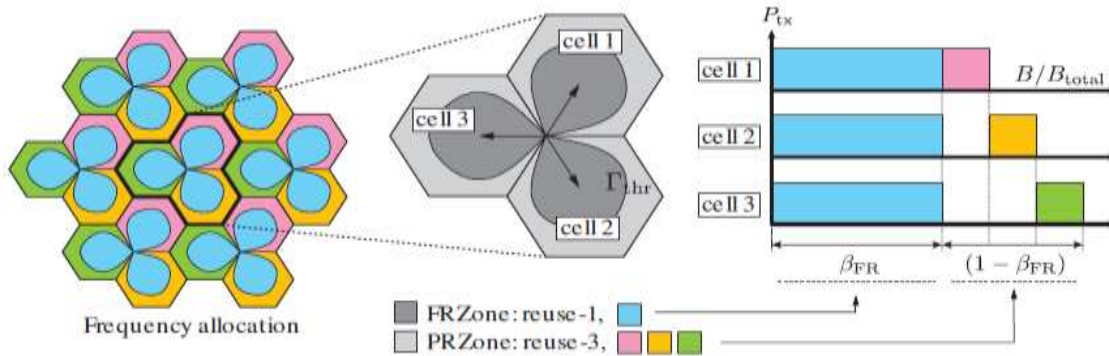


Figure 10: Fractional Frequency Reuse applied in the LTE system level simulator [7]

Note that we can get the FFR simulation (figure 4) through the Launcher_FFR_performance_simulations which is scripted in the reproducibility/FFR folder [7].

3.4 Transmission modes

As shown in Table 2 LTE Release 8 supports seven different transmission modes. These modes are designed to take the best advantage of different channel and multipath conditions and eNodeB antenna configurations, as well as differences in UE capabilities and mobility.

Transmission Mode	Downlink Transmission Scheme
Mode 1	Single Antenna Port (SISO or SIMO)
Mode 2	Transmit Diversity
Mode 3	Open-Loop Spatial Multiplexing
Mode 4	Closed-Loop Spatial Multiplexing
Mode 5	Multi-User MIMO
Mode 6	Closed-Loop Rank-1 Spatial Multiplexing
Mode 7	Single Antenna Port Beamforming
Mode 8	Dual-Layer Beamforming [†]

Table 2: Different transmission modes [9]

In the simulation parameters in Matlab we can know the transmission mode used by using this code LTE_config.tx_mode.

There are five different modes:

1. Single antenna
2. Transmission Diversity (TxD)
3. Open Loop Spatial Multiplexing (OLSM)

4. Closed Loop Spatial Multiplexing (CLSM)
5. Multiuser MIMO (this one is not yet implemented)

Where TxD is used to reduce the effects of fading, which is the attenuation affecting a signal over certain propagation media, by transmitting the same information from two different antennas. However spatial multiplexing is a transmission technique in MIMO (multiple inputs and multiple outputs where we use multiple antennas at both the transmitter and receiver side to send multiple parallel signals and by doing that we are improving communication performance) wireless communication used in LTE downlink which transmit independent encoded data from each of the multiple transmit antennas. Like we saw before that Spatial Multiplexing is divided into two modes the first one is the Open Loop Spatial Multiplexing (OLSM) where user equipments reports the rank indicator (RI) and the channel quality indicator (CQI). The second Closed Loop Spatial Multiplexing where the user equipments reports the RI, CQI and the precoding matrix indicator (PMI).

Note that the CQI is an indicator which let us to know how good or bad the communication channel quality is and its depend at which value the user equipments reports the network will transmit data with large or small transport blocks. Briefly CQI is a summary of the channel condition under the current transmission. RI is the best number of streams a user would like to receive for example RI equal to one UE can't separate two transport blocks so it use transmission diversity, for RI equal to two user equipment is able to separate two transport blocks so eNodeB can use MIMO transmission techniques and finally PMI is used only in CLSM where user equipments indicates to eNodeB how to map the data on the two antennas to optimize reception with selected codebook index. Briefly PMI determines the best precoding matrix for the current channel conditions. Finally it's important to mention that spatial multiplexing requires multipath to work and provide extra gain as compared to TxD.

The figure 11 below show the difference in throughput respect to signal to noise ratio (SNR) in two different modes which are SISO where we have one transmitting and one receiving antenna and TxD where we transmit information from two different antennas. We notice that by using TxD transmission mode for system and link level the throughput will be higher than

using SISO transmission mode till SNR equal to 26 dB because when SNR will be equal to 20 dB the throughput (using TxD transmission mode) will be stable and like that by using SISO transmission mode it will be better than TxD above 26 dB.

Note that SNR stands for signal to noise ratio which is a measure that compares the level of a desired signal to the level of noise. Moreover a ratio higher than 0 dB indicates more signal than noise.

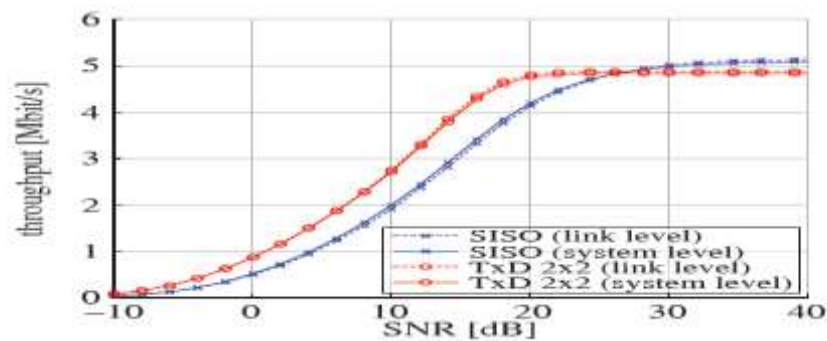


Figure 11: SISO and TxD transmission mode [7]

Figure 12 below show the difference by using CLSM 2x2, CLSM 4x2 and CLSM 4x4. By using CLSM 2x2 we double the capacity and throughput however by using CLSM 4x4 we quadruple the capacity and throughput. In addition NxN stand for the number of antennas used to transmit signals from the base station and the number of antennas to receive signals from mobile terminal or user equipments for example 2x2 configuration is two antennas to transmit signal from the base station and two other antennas to receive signals. We can deduce from the figure that by using CLSM 4x4 we have more throughput than using CLSM 2x2 because we double the capacity and throughput.

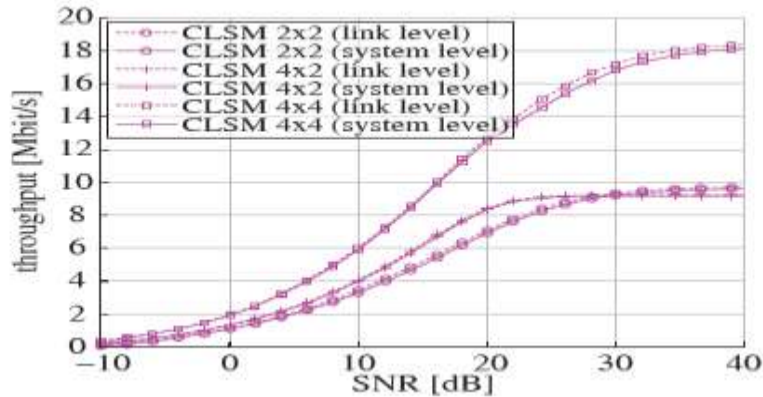


Figure 12: Throughput comparison for CLSM NxN [7]

Figure 13 below shows all antenna configurations and their different throughput respect to SNR. From the graph we can deduce that the lowest throughput is when we use a SISO mode after we have TxD mode. However by using spatial multiplexing CLSM 4x4 we will have the highest throughput till SNR will be equal to 40 dB and it will be equal to OLSM 4x4 above SNR equal to 40 dB. Note that in spatial multiplexing modes require high scattering of multipath signals and high SNR so data will be decoded well. Briefly LTE will produce the highest gain in throughput when multipath and user equipment abilities give the opportunity for spatial multiplexing mode and when the user equipment is able to give the data needed to the eNodeB to match the current channel condition.

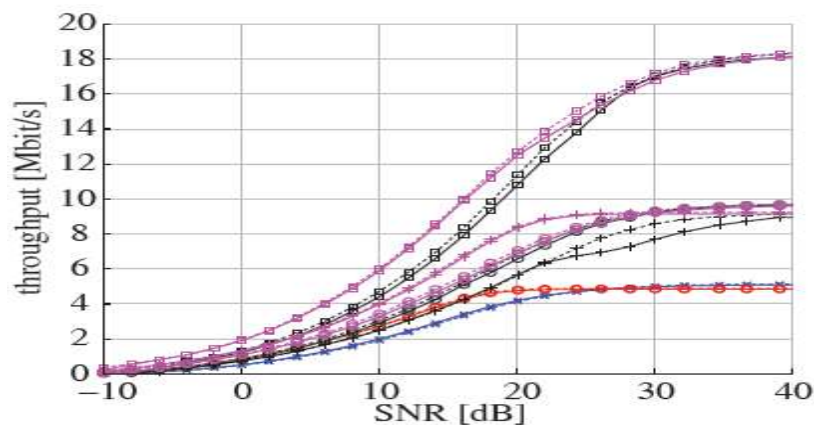


Figure 13: All antenna configurations [7]

3.5. Femtocells

Finally let us talk about femtocells since the LTE system level simulator permits for an additional layer of a node to be added over the standard eNodeB grid. So in Matlab by using this function `LTE_config.femtocells` function we are adding a layer called femtocells or small cells. In addition by adding this layer we can specify the spatial distribution of femtocells for example it can be homogeneously spread or we can know what is the transmit power of each of the femtocells in watts and which path loss model are used.

Not to mention that due to the increasing indoor phone calls and data transfers and because of the lack macrocell coverage so the femtocells will be a good solution in the near future. Where femtocell is a wireless access point act as a repeater so it increases cellular reception for example of data inside a home or office building. In addition this device communicates with the mobile phone and changes voice calls into voice over IP packets which will be transmitted to the operator's servers. In contrast macrocell provide radio coverage served by a high tower (base station) which should be installed on a ground or on a rooftop so it will be installed with a clear view. [9]

3.6. SNR to CQI mapping

BLER which stand for Block Error Ratio curve data files can be provided to the simulator from LTE link-level simulator.mat results file and this file contain two vectors (SNR value and BLER value) of equal length. Moreover the CQI table are used to generate the SNR to CQI mapping which is shown in figure 14 (a & b). The 15 CQI BLER are shown in figure 14 (b) and from their 10% BLER points we can get the CQI mapping (figure 14 a). [7]

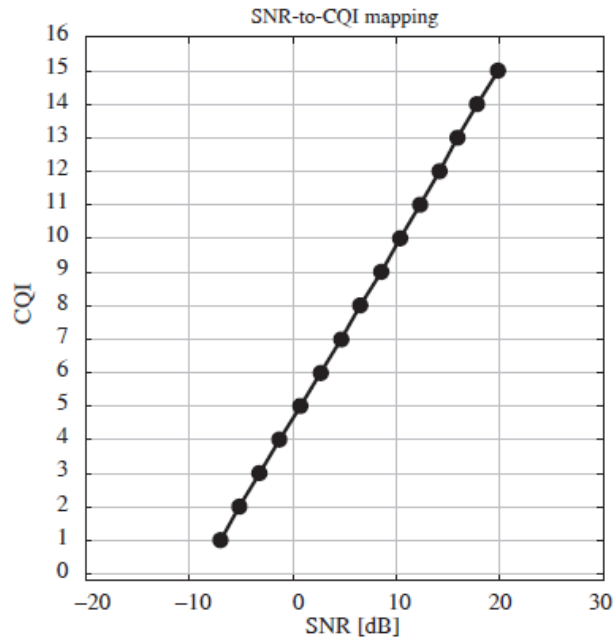


Figure 14-A: SNR to CQI mapping [7]

Like we said before figure 14 (a) shows the CQI mapping gotten from 10 % BLER points (from figure 8 b). This figure shows that when SNR will be more than zero dB the CQI number will increase and we have CQI equal to 15 when SNR will be equal to 20 dB. Where CQI is a summary of the channel condition under the current transmission and SNR is the measure that relates the level of wanted data to the level of unwanted ones so when SNR increase we should have higher CQI number. Briefly higher the CQI number (send it by user equipment to the base station) the network will transmit data with larger transport block size and vice versa.

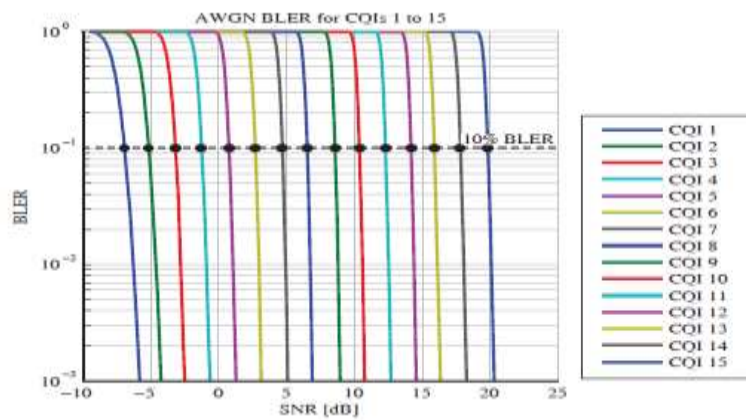


Figure 14-B: CQI BLER curves [7]

3.7 Plotting results

Let us now talk about the plotting results which is generated by using LTE_sim_main_examples on Matlab. When we run this function two graphs will appear the first one is eNodeB and UE position (figure 15) and the second graph (figure 16) is throughput and combined or mixed results.

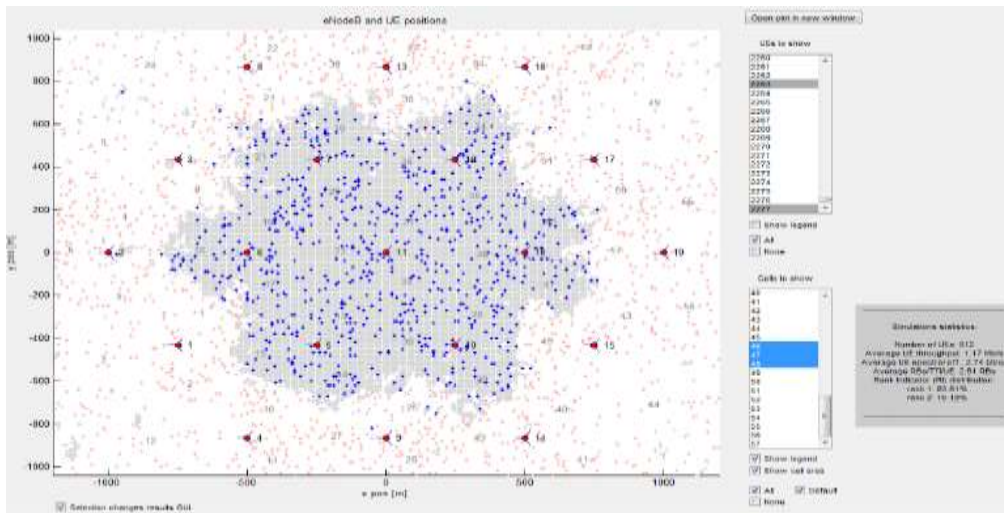


Figure 15: eNodeB and UE position [7]

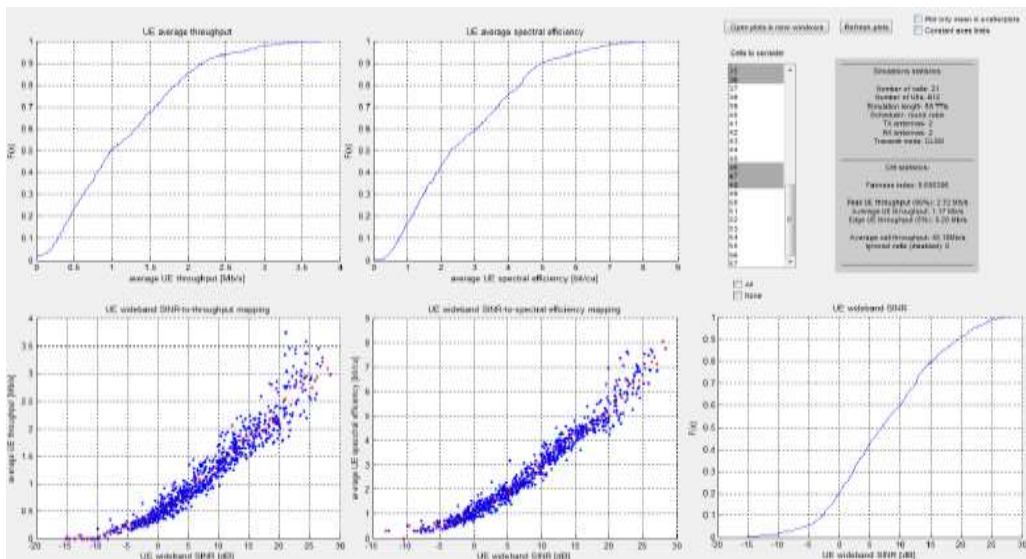


Figure 16: throughput and mixed result [7]

Figure nine display the location of all user equipments as well as eNodeBs and from this graph we can know get many information related to user equipments and eNobeB. For example in the graph we select the cell number 46, 47 and 48 directly we can see the user equipments related or connected to these cells are displayed in red and the other user equipments are hided. Note that if we make use of Fractional Frequency Reuse (FFR) scheduler the users which use full reuse scheduler are revealed as dots conversely the users which use partial reuse scheduler are revealed as crosses. In addition, we have a grey box on the right which help us to know some information like number of user equipments, average user equipments throughput, average user equipments spectral efficiency moreover if we are using round robin scheduler so we will have equally assigns physical resources to all user equipments therefore the throughput and spectral efficiency will be approximately equal not to mention that spectral efficiency refers to the information amount that can be spread over a given bandwidth , average resource blocks per user equipments and TTI and finally rank indicator distribution. [7]

Furthermore figure ten displays five graphs and one grey box. Let us first see the grey box which helps us to know the number of eNodeB from where the results are taken and the number of user equipment related to these eNodeBs, the length of the transmission in TTI, the scheduler being used, the number of transmission and receiver antennas in addition the transmit mode, the fairness index (get it from the user equipment average throughput value), the 95% peak user equipment throughput, the average user equipment throughput, the 5% edge user equipment throughput and finally the average cell throughput. [7]

Secondly the five graphs are:

1. Empirical Cumulative Distribution Function (ECDF) of user equipment average throughput
2. Empirical Cumulative Distribution Function (ECDF) of user equipment average spectral efficiency
3. Empirical Cumulative Distribution Function (ECDF) of user equipment wideband signal to interface plus noise ratio (SINR)
4. A scatter plot showing average UE spectral efficiency over UE wideband SINR

5. A scatter plot showing the wideband SINR over the spectral efficiency.

Not to mention that SINR is a measure of the signal quality which determine the relation between radio frequency conditions and the throughput, UE use SINR to compute the CQI and then report this value to the network.

3.8. Conclusion

In conclusion in this part we highlighted on the models over which the simulator is built and we evaluate the performance of LTE using system lever simulator, For example by describing the core part of the system level simulator and the comparison of the scheduler types the user throughput, the CQI, SNR and many others. In my opinion LTE system level simulator will play a good role in making mobile communication better and better through analyzing the output result and finding solutions for the problems which occur and since it is a non-commercial academic use where every person interested in this field can develop some algorithm to fix the problem.

Chapter 4

Performance assessment of prioritization capabilities

4.1. Prioritization mechanism

The prioritization mechanism is designed as an extension of the PF scheduling. In particular, the PF algorithm has been modified to account for the priority level embedded in the QCI value. The resulting scheduler is named QCI-aware PF scheduler. Next subsection describes both algorithms.

4.1.1 Proportional Fair (PF) scheduling:

The proportional Fair (PF) scheduling algorithm is based on maximizing the scheduling metric. In more details for any resource block in any TTI this scheduler schedules only the user with the maximum performance metric (max PM).

In mathematics it can be shown as follows:

$$k_{i,j}(\tau) = \arg \max_k \left\{ \frac{R_{k,j,i}(\tau)}{\tilde{R}_{k,i}(\tau)} \right\} \quad (\text{Eq.1})$$

Where:

- K is the selected user in the i^{th} CC at the j^{th} RB in time τ
- R is the estimated throughput of the user k in the i^{th} CC at the j^{th} RB in time τ which will be in our case later the instantaneous throughput (R_{inst}).
- \tilde{r} is the average throughput in the past of the user k in the i^{th} CC in the time τ which will be in our case later the accumulative throughput (R_{accum}).

Note that τ refers to TTI, j refers to the number of RB and finally CC refers to Component Carrier.

In the PF scheduler the metric used by the programmer is calculated as follow:

$$\text{Metric} = (C \times 12 \times 7) / R^{\text{alphatemp}} \quad (\text{in log scale}) \quad (\text{Eq.2})$$

Where $\text{alphatemp}=1$; R represent the accumulated throughput in bit/s; however C represent the BICS (Bit Interleaved Coded Modulation) efficiency which is here in bits/channel use, because of that we multiply it by 12×7 (12 represent the subcarrier and 7 the symbols) to get the instantaneous throughput for a specific user. Not to mention that the “obj.d” and obj.k” used to calculate C (BICS efficiency) in “LTEScheduler” are the coefficients from the linear fit in order to avoid nonlinearity and this linear fit has to be applied depend on the actual value of CQI for each user[13].

In addition, in the simulator we have a total number of users divided into 57 cells where each cell contains a fix number of users. Moreover, the simulator contains 19 eNodeBs and each three cells are attached to one eNodeB.

From that we can understand how the simulator pass the users in each TTI, for that lets focus in the first TTI (TTI=1) since for the others TTIs in the simulator repeat the same method for the same users. So for the first TTI we have 57 cells, in the first cell we have the number of users that we fixed and for each one of these users have an average throughput (Raccum) and an instantaneous throughput (Rinst), moreover these numbers of users have 100 resource blocks available since the bandwidth is equal to 20 MHZ in each TTI.

After finding the maximum value in the metric calculated as showed before, the users that should be allocated resource block to them are putted in an array called RBs, which include zero and one where one represents the user that should be allocated a resource block and these users are putted in a list called UE_id_list to allocate to them resource block. Note that to avoid allocating many users to one resource block because maybe they have the same value that has been calculated following equation 2, the programmer use a function $\text{ind} = \text{randi}(\text{length}(\text{RB_idx}))$ so by doing that the programmer is allocating a resource block for only one user.

4.2 Validation of the simulator

To validate the simulator we will see first the relation between the instantaneous throughput and the accumulated throughput and how is computed in section 4.1.2.1, and then we will see how the dynamic of the simulator works in section 4.1.2.2.

4.2.1 Validation of the instantaneous throughput and the accumulated throughput and see how there are connected.

First before starting with the validation of the instantaneous and the accumulated throughput let us see now under which scenario the PF scheduler has been addressed:

- Antenna configuration:
 - Number of Tx Antenna: 2
 - Number of Rx Antenna: 2
 - Transmission mode = Closed Loop Spatial Multiplexing (CLSM)
- Number of eNodeBs: 19
- Total number of users: 570 users only 210 users are active since the simulator computes only users from cells numbers: 1, 13, 14, 15, 16, 17, 18, 19, 20, 21, 28, 29, 30, 31, 32, 33, 34, 35, 36, 46 and 48. Note that here in each cell we have ten users.
- Spatial distribution of terminals: Each three cells are connected to one eNodeB
- Traffic model: Full Buffer
- Bandwidth= 20 MHz (Number of RBs= 100 each TTI)
- Simulation time T_{SIM} (TTI) = 10, 20, 30, 50 and 500
- Average window size of 20 TTI for the accumulative throughput

Secondly, to simplify our calculation we run the simulator at TTI=10 for the first time where we have cell number one active containing ten users and connected to eNodeB number one. In this case figure 17 displays the accumulated throughput (R_{accum}) and the instantaneous throughput (R_{inst}) for user number one in the cell number one.

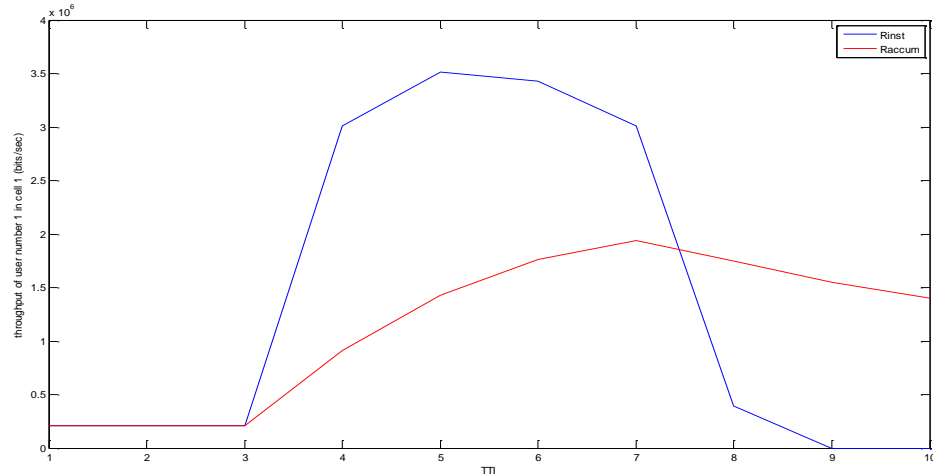


Figure 17: Raccum and Rinst for user number one in cell number one at TTI=10

Here the X axis represents the number of TTI and Y axis represents the throughput in bits/s conversely the blue line represents the Rinst (instantaneous throughput) of the user number one in cell number one at each TTI and the red line represent the Raccum (accumulated throughput) of the user number one in cell number one at each TTI.

In addition Rinst and Raccum here are related following this function:

- $R_{accum}(n) = (1 - \alpha) \cdot R_{accum}(n-1) + (\alpha) \cdot R_{inst}$

Where $R_{accum}(n)$ represents the accumulative throughput at a specific TTI , $R_{accum}(n-1)$ represents the previous accumulative throughput at TTI-1, finally Rinst represents the instantaneous throughput of this user at a specific TTI.

Furthermore it is important to mention that alpha from TTI = 1 till TTI = 10 is computed as $1/TTI$ number, for example in TTI equal to two alpha is equal to $1/2$, for TTI equal to five alpha is equal to $1/5$. However for TTI above ten always alpha will be equal to $1/10$, for example for TTI equal to sixteen alpha will be equal to 0.1.

Now let's take some examples to know how we can compute Raccum is calculated:

For the TTI= 1, alpha is equal 1 so $R_{accum} = (\alpha)R_{inst} = R_{inst} = 208000$ bits/s

For TTI=2, alpha is equal 0.5 so $R_{accum} = (0.5) R_{accum} \text{ (of TTI=1)} + (0.5) R_{inst} = (0.5) (208000) + (0.5) (208000) = 208000 \text{ bit/s}$

For TTI= 5, alpha is equal 0.2 so $R_{accum} = (1-0.2) R_{accum} \text{ (of TTI=4)} + (0.2) R_{inst} = (0.8) (908000) + (0.2) (3512000) = 1428800 \text{ bit/s}$

Moreover if we run the simulator at TTI=20 (Figure 18) to check if the alpha is stable now, and equal to 0.1 above TTI=10. So finally by calculating the Raccum at a different TTI above ten we found that alpha is equal to 0.1.

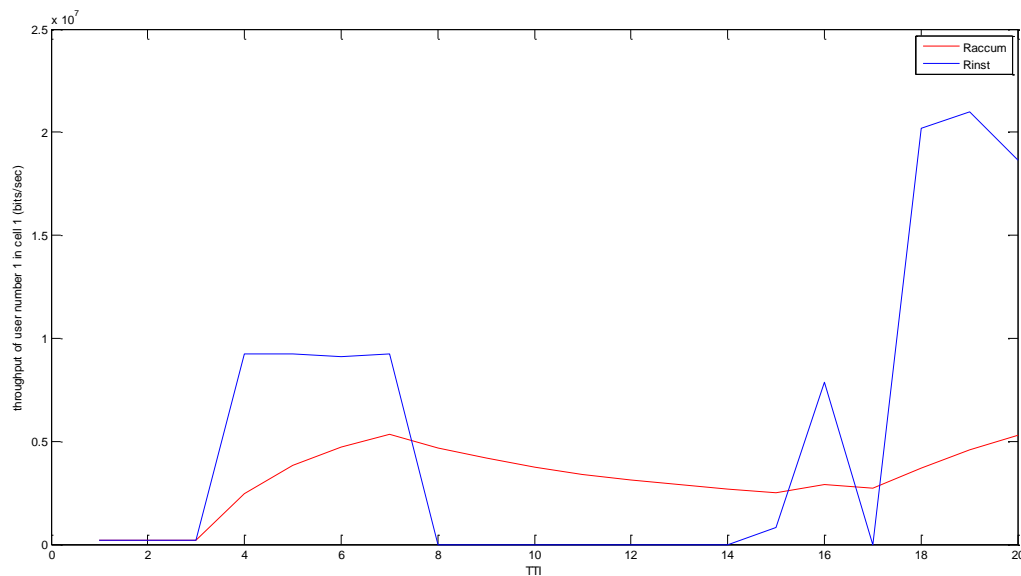


Figure 18: Raccum and Rinst for user number one in cell number one at TTI=20

For example in the Figure 18, for TTI=15, alpha is equal 0.1 so $R_{accum} \text{ (of this user at TTI=15)} = (1-0.1) R_{accum} \text{ (of TTI=14)} + (0.1) R_{inst} = (0.9) (2682000) + (0.1) (824000) = 2496000 \text{ bit/s}$ and by comparing this result to the graph we will find that it's the case. Note that these values that we got are showed in figure 18 (a), figure 18(b) and figure 18(b).

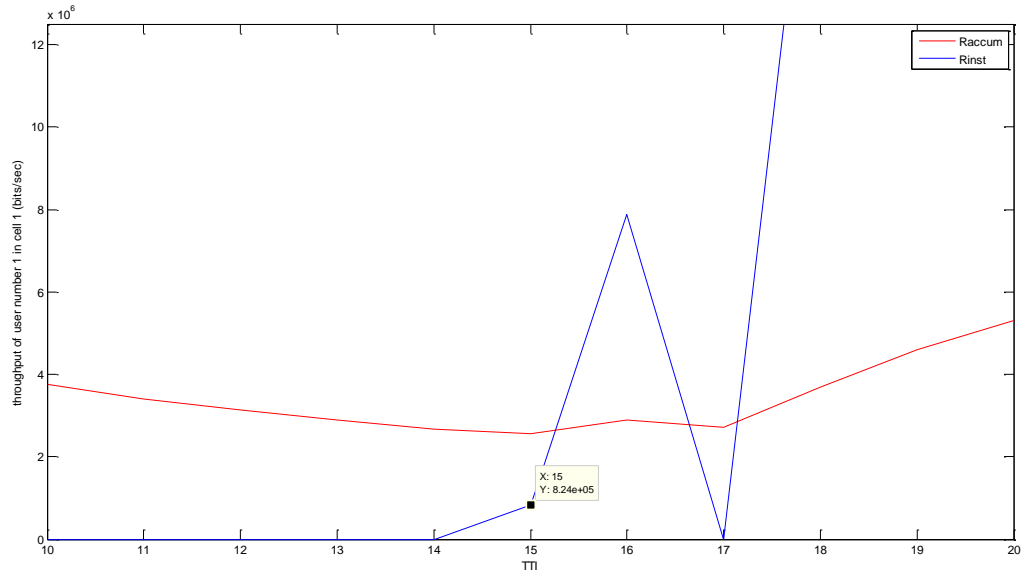


Figure 18 a : Value of Rinst at TTI equal to 15

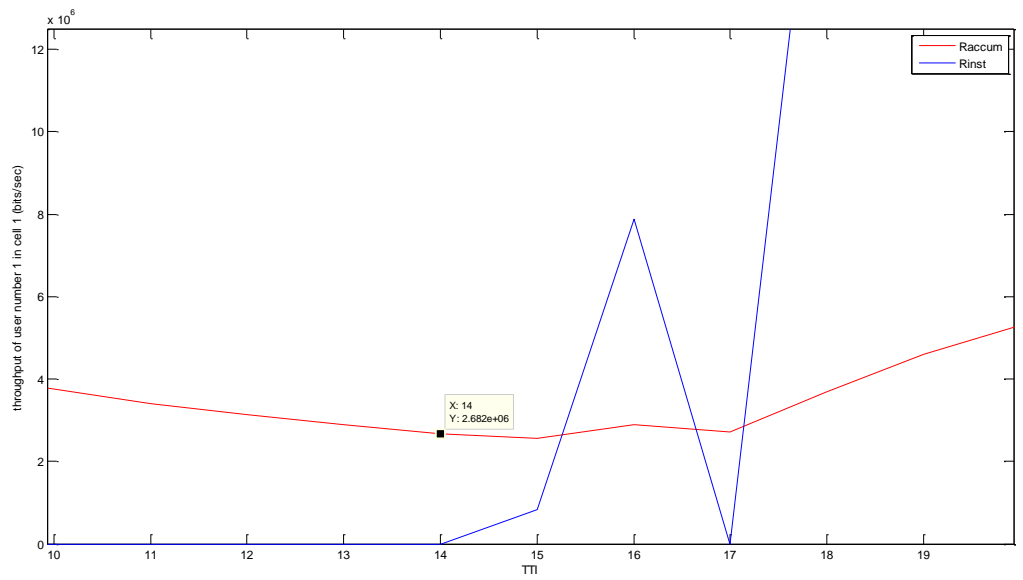


Figure 18 b: Value of Raccum at TTI equal to 14

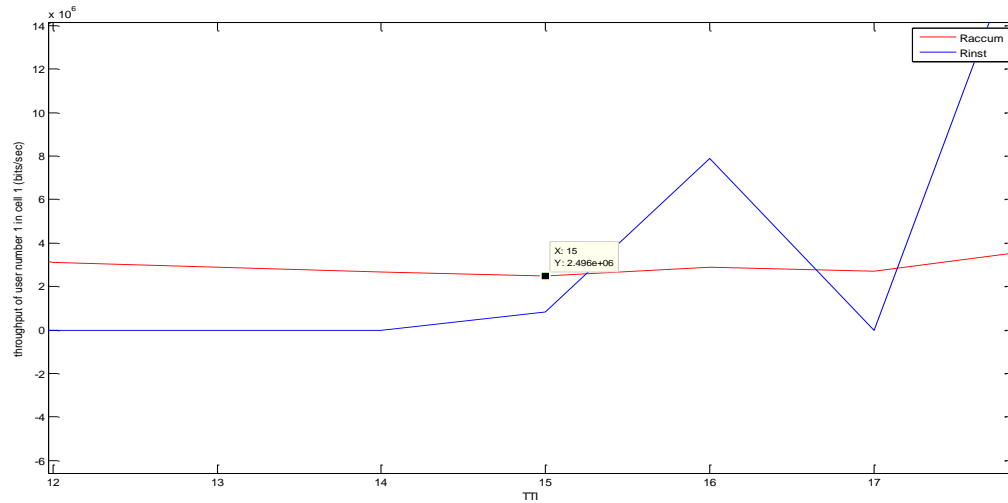


Figure 18 c : Value of Raccum at TTI equal to 15

Finally, to check if Raccum is stable at a certain TTI we run the simulator for TTI=500 and as we can notice from Figure 19 that the Raccum is not stabilized even for that TTI. Not to mention that this graph present the accumulated throughput of user number one in cell number thirteen connected to eNodeB number five.

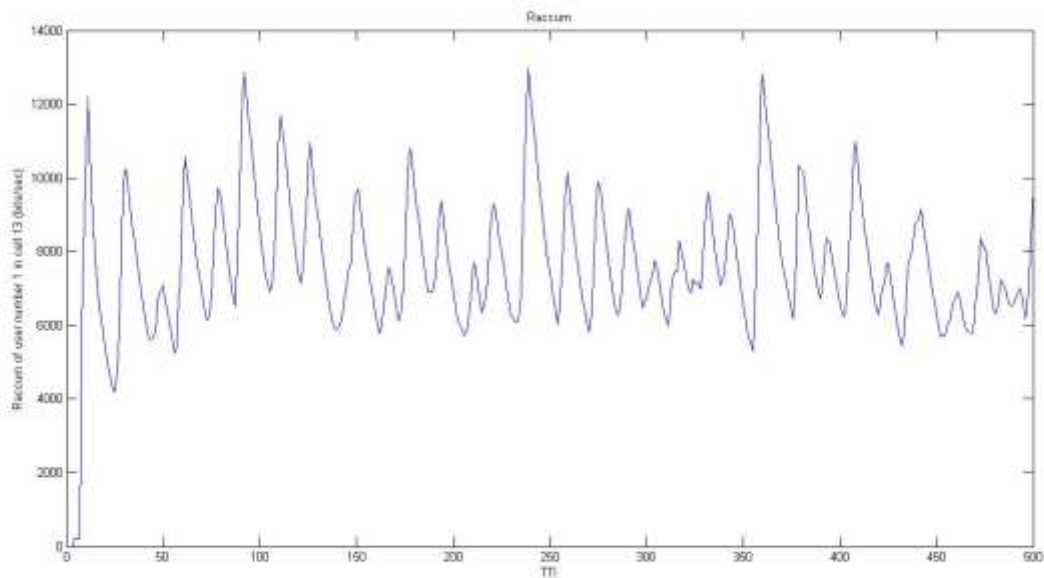


Figure 19: Raccum of user number one in cell number 13 at TTI=500

Since Raccum is not stabilized after running the simulator at a higher TTI we can conclude that the accumulated throughput is affected by the instantaneous throughput like we can see in figure 20 (Raccum of user one and Rinst of user one in cell number 1 at TTI=30) when Rinst is equal to zero Raccum will decrease since Raccum and Rinst are related in the equation describe before, so because of that we the accumulated throughput is not stabilize at a specific TTI.

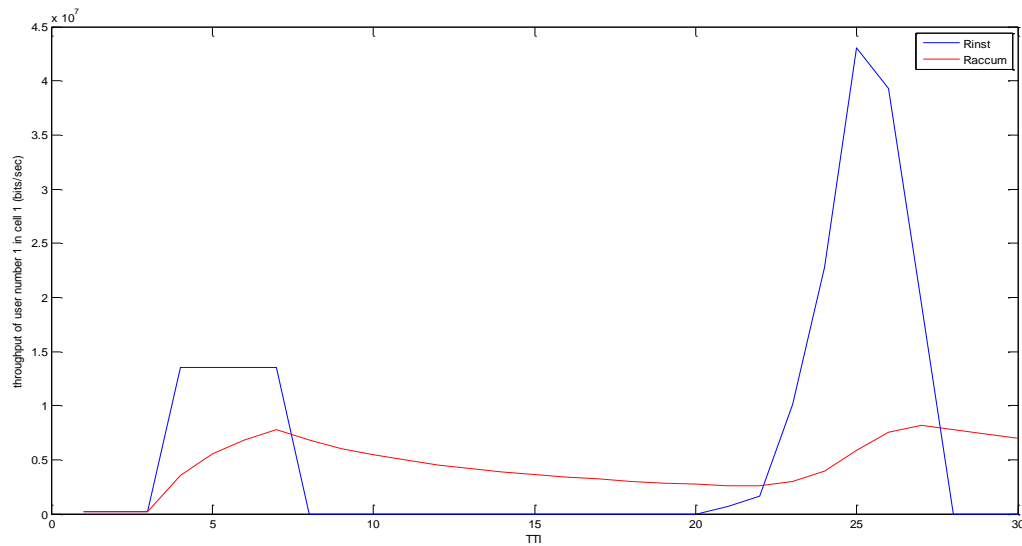


Figure 20: Raccum and Rinst of user one in cell number one at TTI=30.

To make sure the conclusion that we made before about the stability of the accumulated throughput, we plotted the accumulated throughput and the instantaneous throughput for the user number two in cell number one at TTI equal to 30 and as we can see in figure 21 we got the same conclusion as before.

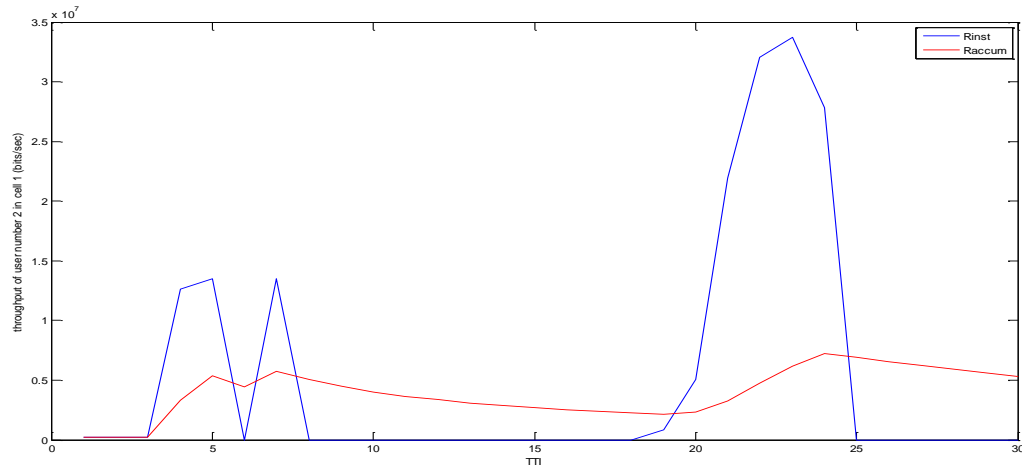


Figure 21: Raccum and Rinst for user number two in cell number one at TTI=30

4.2.2 Testing the dynamic of the system.

To test the dynamic of the system first we check the instantaneous throughput and then we will check the accumulated throughput.

First to see how the instantaneous throughput is manage in the system, we run the simulator at TTI equal to ten for the first time where we plot the instantaneous throughput for the ten users in cell number one which is connected to eNodeB number 1 as show in figure 22 .

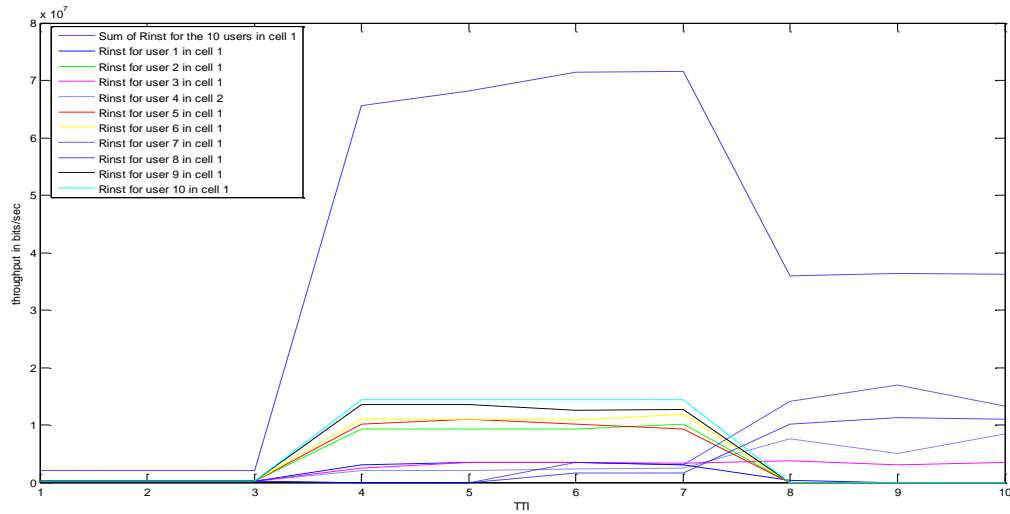


Figure 22: Rinst for the ten users in cell number one at TTI=10

So like we can notice from TTI equal to zero till TTI equal to ten the system is in a warning period however like we will see later in Figure 24 that the simulator above TTI equal to ten will be in a steady state.

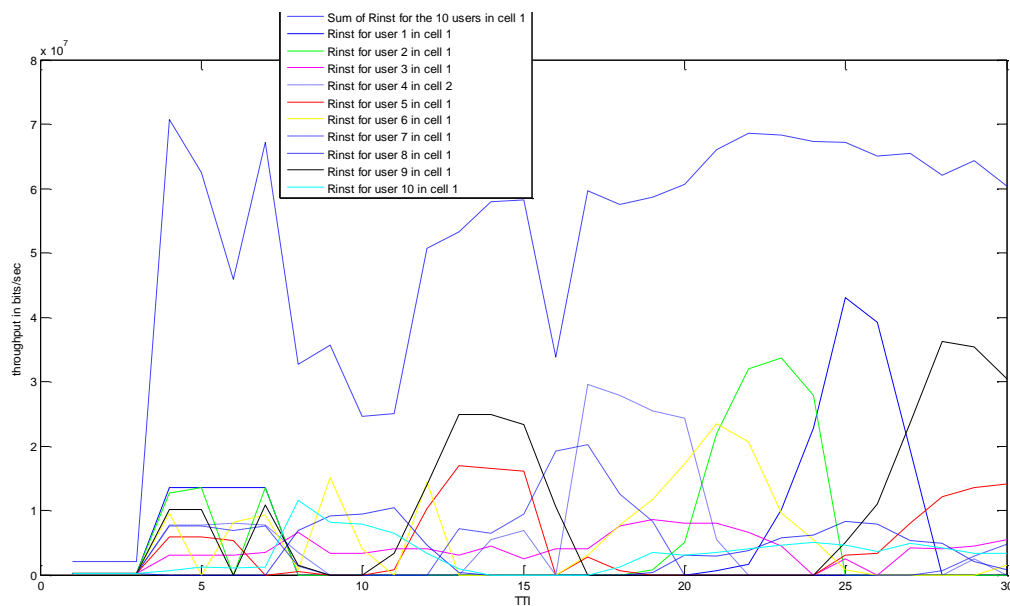


Figure 23: Rinst for the ten users in cell number one at TTI=30

Now the Rinst for the ten users in cell number one at TTI equal to 30 is showed in figure 23. First as we can see in the legend each line color presents the Rinst for a specific user for

example the red line presents the instantaneous throughput (Rinst) for user number 5, however the blue dashed line presents the summation of Rinst in each TTI.

As we can realize from figure 23 for TTI equal to 0 till 10 we can't have a clear view about how the system distribute the capacity for the 10 users, so we are sure now that the system below TTI equal to ten the system is in a warning period. However for TTI equal to 10 and above we can see clearly now how Rinst is distributed among the 10 users. It is between 5 and 7 TTI (5 or 7 ms) a specific user has a higher Rinst than the others users. So finally we can say that the dynamic of this process work as following, between 5 and 7 TTI a specific user will have a higher Rinst than the other users, then while the Rinst of this specific user will start to decrease, at this moment Rinst of another user will start to increase till he gets a higher Rinst between all the other users. For example as we can see in the graph user number one (present it in blue line) when his Rinst start to increase the Rinst of user number two (present it in green line) start to decrease. Not to mention that at 25 TTI user number one will have a higher Rinst then the others users.

Note that when the summation of Rinst for the 10 users decrease all the Rinst at this specific TTI will be small and this case that we are talking about is present it in TTI equal to 8 till 11.

To make sure about the conclusion that we just made it about how the dynamic of this process work, we run the simulator at TTI equal to fifty as show figure 24 and as we can see in the following figure we got the same conclusion that we got it before.

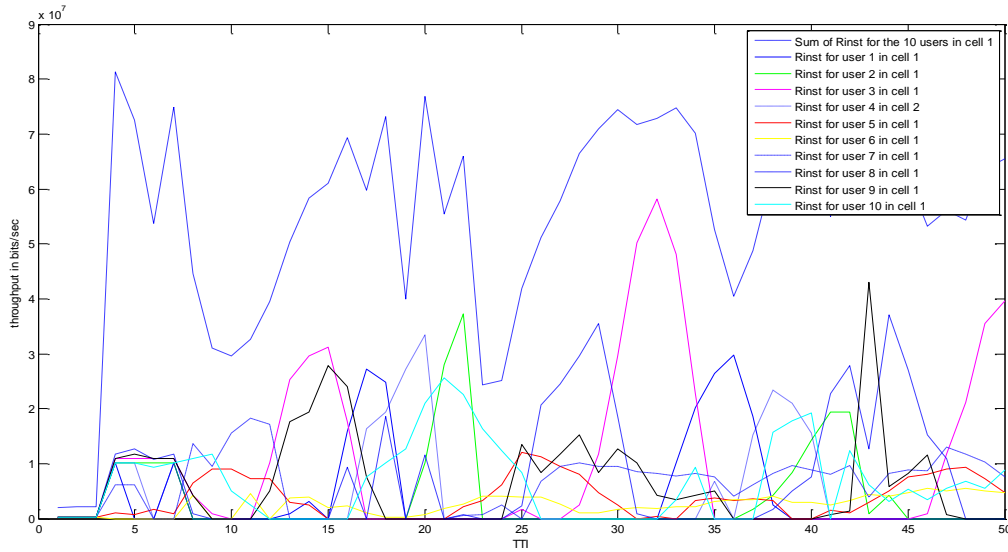


Figure 24: Rinst for the ten users in cell number one at TTI=50

Secondly to see how the accumulated throughput is manage in the system, and at which TTI the accumulated throughputs will be fairly distributed among the ten users we run the simulator at TTI equal to twenty and in figure 25 we show the accumulated throughput for the ten users in cell number one.

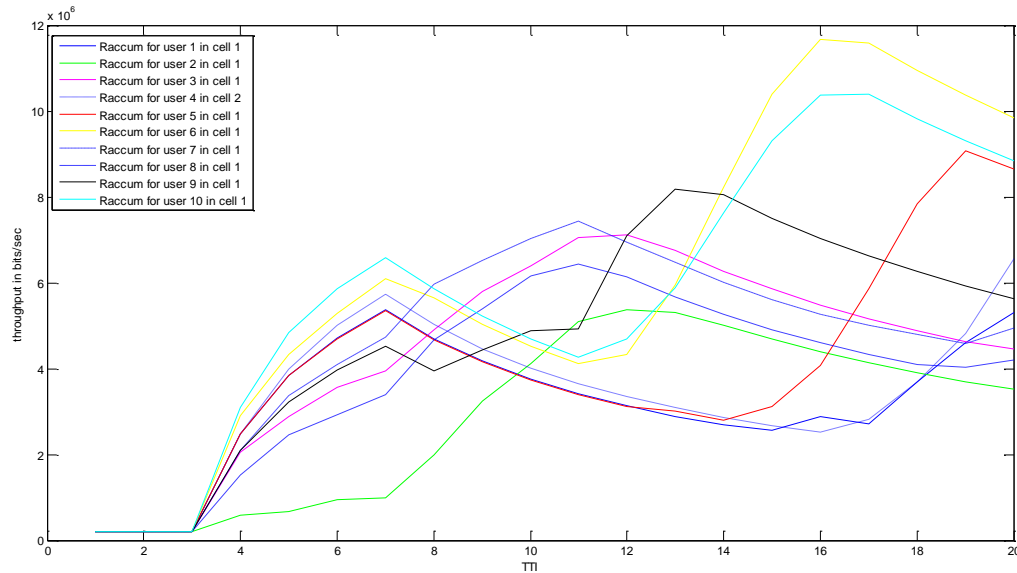


Figure 25: Raccum for the ten users in cell number one at TTI=20

Like we can see from figure 25 the accumulated throughput at TTI equal to twenty is not yet fairly distributed among the ten users. However if we run the simulator at TTI equal to fifty as we can get from Figure 26 the accumulated throughputs at TTI equal to fifty they are more fairly distributed between the ten users, so we decided to fix TTI at 50.

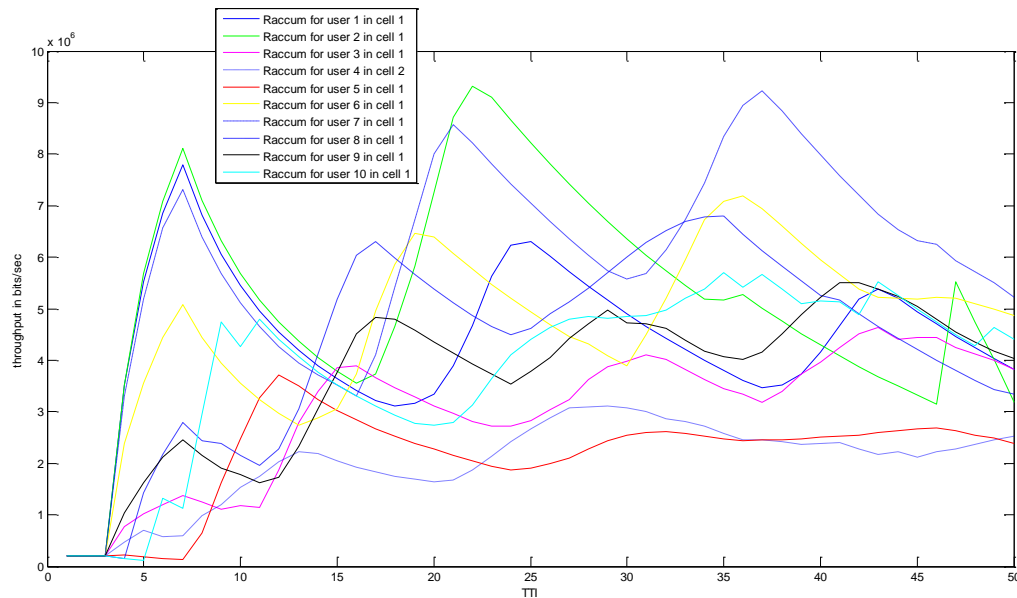


Figure 26: Raccum for the ten users in cell number one at TTI=50

4.3 QCI-aware Proportional Fair (PF) scheduling.

So far we explained how the proportional fair scheduler is working without adding priority access to it. By adding the QoS Class Identifier (QCI) to each user we need now to take into consideration the QCI number of each user.

So the new mechanism that we added is to introduce in the metric calculated in the PF scheduler (Eq.2) an alpha for the users so like that we can differentiate now between users following their QCI numbers, so the new formula will be as following:

$$\text{Metric} = (C \times 12 \times 7 \times \alpha) / R^{\text{alphatemp}} \quad (\text{Eq.3})$$

4.3.1 Simulation results:

The performance analysis of QCI-aware PF scheduler has been addressed under the following scenario settings:

- Antenna configuration:
 - Number of Tx Antenna: 2
 - Number of Rx Antenna: 2
 - Transmission mode = Closed Loop Spatial Multiplexing (CLSM)
- Number of eNodeBs: 19
- Total number of users: First if we have 10 users per cell we will have 570 users in total, only 210 users are active since the simulator computes only users from cells numbers: 1, 13, 14, 15, 16, 17, 18, 19, 20, 21, 28, 29, 30, 31, 32, 33, 34, 35, 36, 46 and 48. However if we modify the simulator to have sixteen users per cell the total number of users will be 912 users. Finally if we decide to have twenty users per cell the total number of users will be 1140 users. Not to mention that in the simulation results I will focus only in the users in cell number one.
- Spatial distribution of terminals: Each three cells are connected to one eNodeB.
- QCI configuration: two QCI values (Being the users with QCI_1 higher priority), however we will focus in the following case where the percentage of terminals with QCI_1 and QCI_2 Beta=50% so like that half the users will have QCI_1 and the other half users will have a QCI_2 .
- Traffic model: Full Buffer.
- Bandwidth= 20 MHz (Number of RBs= 100 each TTI)
- Simulation time $T_{SIM} = 50$ TTI
- Average window size of 20 TTI for the accumulative throughput

From now on we will focus our study on the accumulated throughput to understand what will happen with the accumulated throughputs of the users when these users will receive different QCI numbers.

Now to see which alpha numbers (introduced in Eq.3) we should pick for the users that have QCI_1 and for the users that have QCI_2 , first we gave to user number one in cell number one an alpha equal to one and for the others nine users (in the same cell) we gave them an alpha equal to 0.5, so like that I am giving a priority access to user number one over the nine users that we have in cell number one. So we are assuming here that user number one has a QCI_1 , however user two till ten have QCI_2 .

Figure 27 illustrates the accumulative throughput for each user in cell number one and as we can deduce the accumulated throughput of user number one in cell number one has the highest value from the other nine users but the gap between them is very high at TTI equal to fifty. This gap between user number one and the other nine users will be equal to times nine.

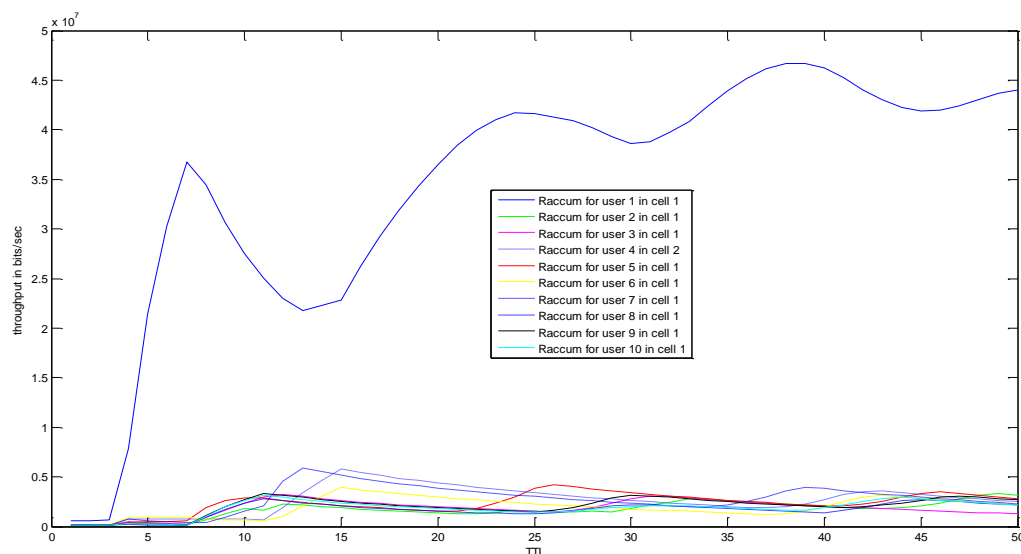


Figure 27: Raccum for the ten users in cell number one with alpha equal to 1 and 0.5

Because the gap that we got in this scenario at these two values of alpha is very high, and if we run the simulator with an alpha equal to one and 0.8, first user in cell number one has an alpha equal to one and for the others nine users have an alpha equal to 0.8, the gap between the accumulated throughput at TTI equal to fifty between user number one and the others nine users will be less than before and more reasonable as we can see in Figure 28. This gap will be

equal to times three. Not that like we said before at TTI below ten the system is in a warning period so at TTI above ten the system will be in a steady state.

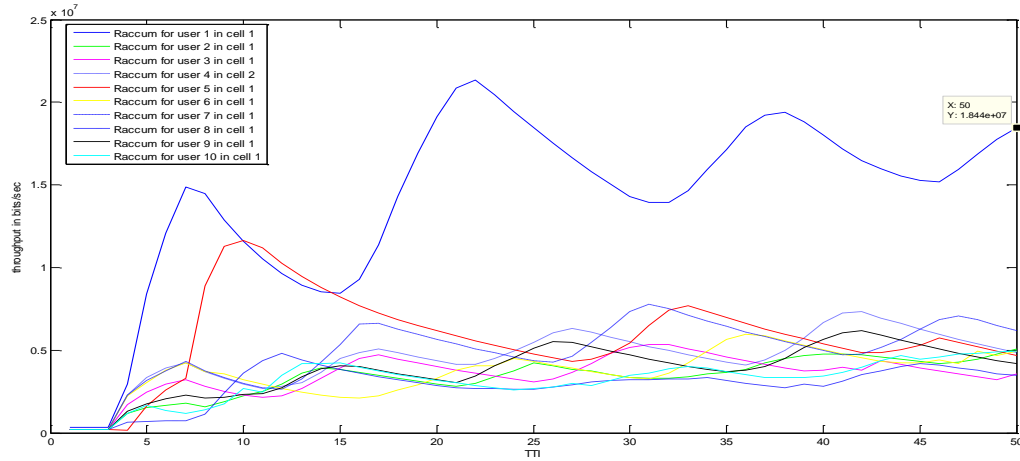


Figure 28: Raccum for the ten users in cell number one with alpha equal to 1 and 0.8

However if we have twenty users per cell and if we took alpha equal to 0.8 the accumulated throughputs of the users at TTI equal to 50 will overlap for the both kind of users (users that have QCI_1 and QCI_2) as showed in figure 29. Note that the blue line presents the users that have priority (QCI_1), however the red line present the users with lowest priority (QCI_2).

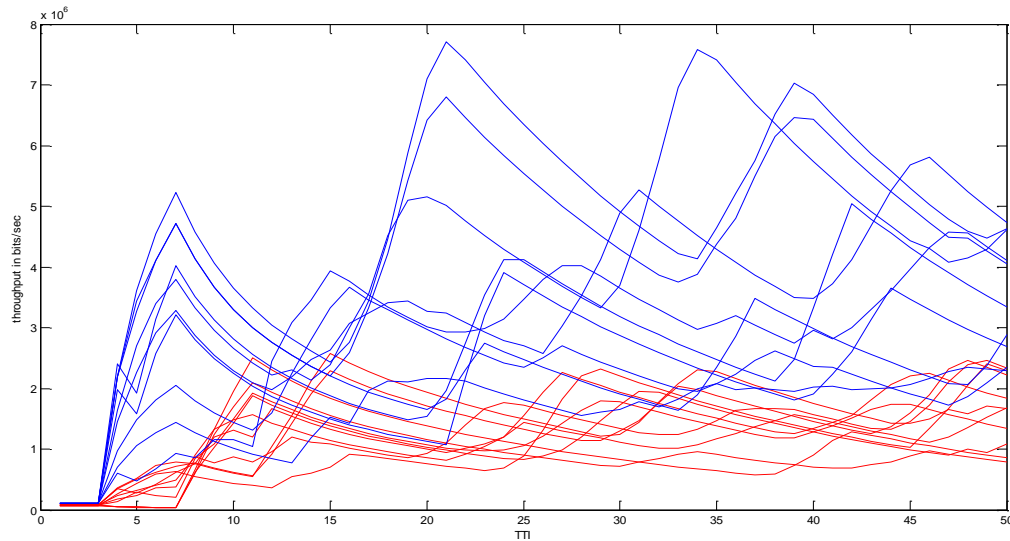


Figure 29: Raccum for the 20 users in cell number one with alpha equal to 1 and 0.8

In contrast in the same scenario but with alpha equal to 1 for QCI_1 and equal to 0.6 for a QCI_2 as we can notice from figure 30 the accumulated throughputs of the users at TTI equal to 50 don't overlap for the both kind of users. So from that we can conclude that alpha will depend on the number of users per cell. Note that the blue line presents the users that have priority (QCI_1), however the red line present the users with lowest priority (QCI_2).

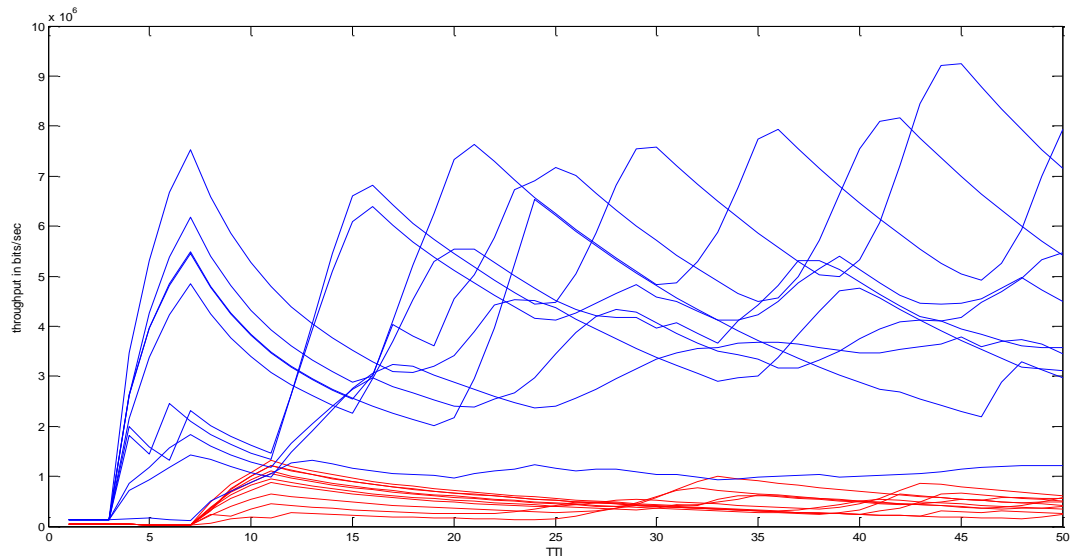


Figure 30: Raccum for the 20 users in cell number one with alpha equal to 1 and 0.6

Hence from now on the alpha for the users will be equal to 1 for QCI_1 and equal to 0.6 for a QCI_2 .

Figure 31 shows the behavior of the mean throughputs (at TTI=50) depending on the number of users per cell, with modification (here alpha is introduce to the simulator as we saw previously in Eq.3 with the same value that we fixed). Not to mention that the X axis present the number of users in the cell number one, and the Y axis present the mean throughput of the users. In addition here for the first time we run the simulator with ten users per cell and then with sixteen users per cell, in addition Beta is equal to 50% so for example for the first time five users will have a QCI_1 and the others five users will have a QCI_2 .

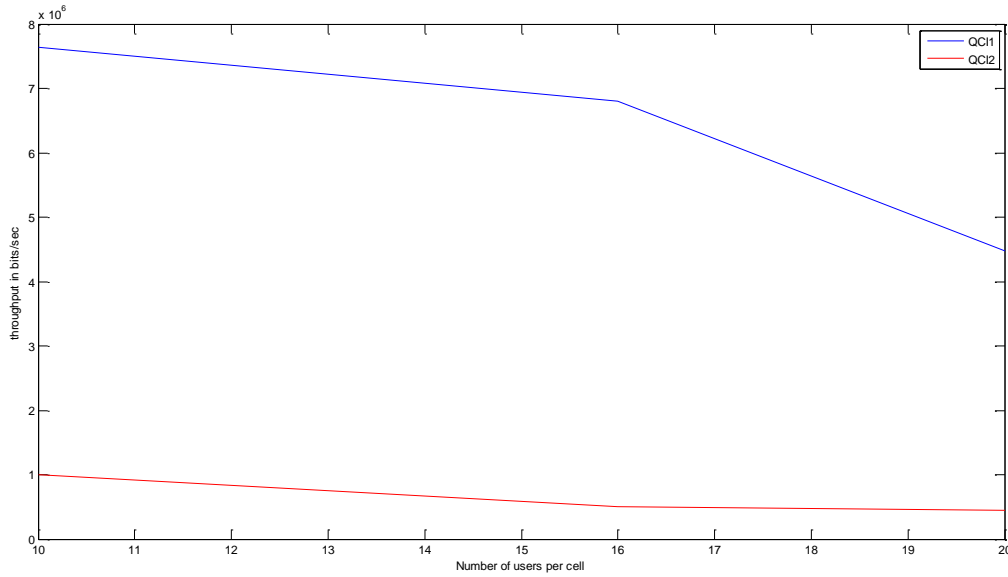


Figure 31: Mean throughput of the two kinds of users with alpha fix equal to 1 and 0.6

As we can notice by introducing an alpha to the simulator we just got two values for the average user throughputs in each case, for example in case where we have ten user per cell the five users that have QCI_1 equal to one will have a mean throughput equal to 7640000 bit/s which is highest then the mean throughput of the others five users (which has a QCI_2 equal to six) which is equal to 1002000 bit/s. The gap between the two kinds of users where we have 10 users per cell is 7.62 times, however the gap between the two kinds of users where we have 16 users per cell is 13.6, finally the gap between the two kinds of users where we have 20 users per cell is 10.18 times.

However figure 32 shows the behavior of the mean throughputs of the users where prioritization is not enforced (alpha equals one for both QCIs) in eq.3. Not to mention that here also we fix the number of users per cell as follow: ten users, sixteen users per cell and finally twenty users per cell, at $TTI=50$.

As we can notice there is no distinction between the average user throughputs of the users which are in the same cell.

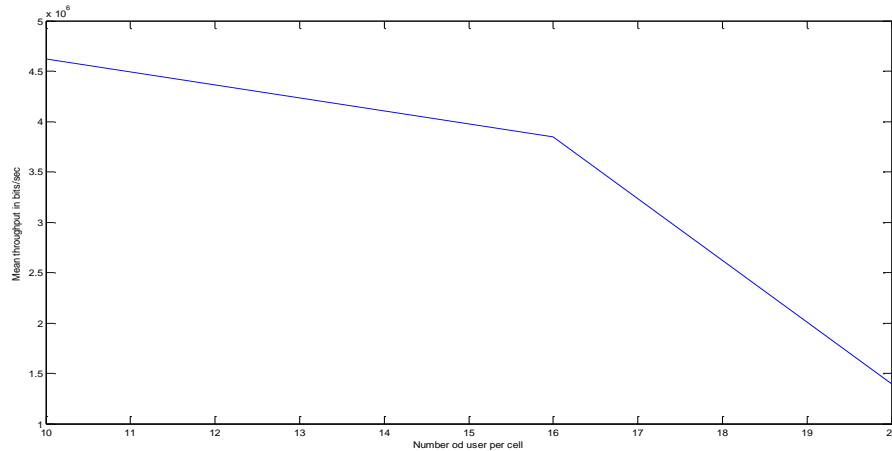


Figure 32: Mean throughput of users in cell number one at TTI=50

Nevertheless since in figure 31 the gap between the two kind of users (with alpha equal to 1 and 0.6) are for the first both case 10 users per cell and 16 users per cell is consecutively equal to 7.6 times and 13.6 times, however for 20 users per cell is equal to 10.18 times. If we run the simulator where alpha equal to 1 for QCI_1 then equal to 0.8 for a QCI_2 , for the both case where we have ten users per cell and for 16 users per cell and we leave alpha equal to 1 for QCI_1 and equal to 0.6 for a QCI_2 in the scenario where we have 20 users per cell, we will find that the gap will decrease for the both first two scenario (10 users per cell and 20 users per cell) as show in figure 33 and it will be times 2.5 for 10 users per cell but equal to 2.38 times in the scenario where we have 16 users per cell. Note that the gap will be equal to 10.18 times in the scenario where we have 20 users per cell as before since we left the alpha numbers as before(1 for QCI_1 and 0.6 for a QCI_2).

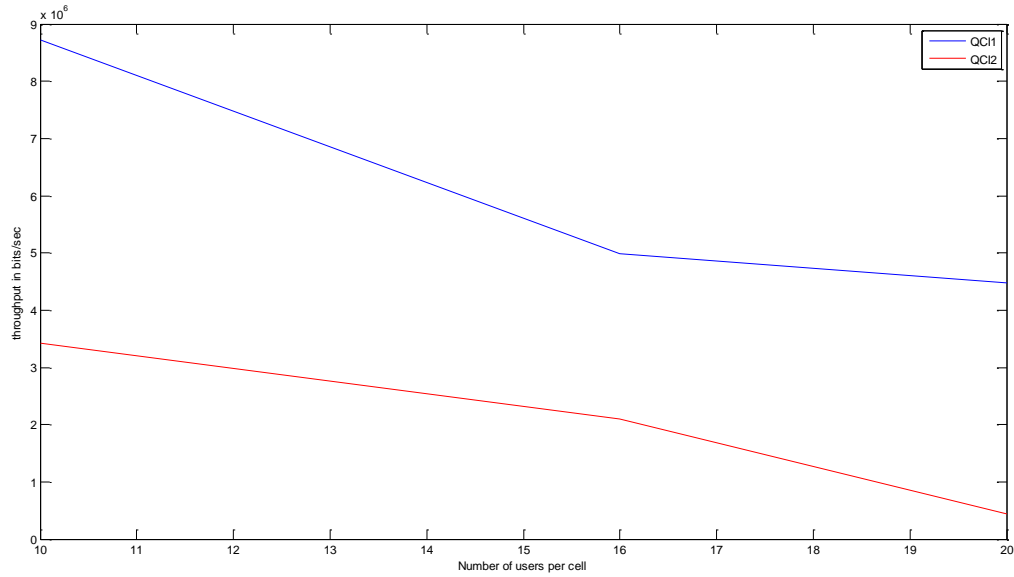


Figure 33: Mean throughput of the two kinds of users

4.4. Conclusion:

In conclusion, by introducing an alpha to the equation (eq.3) we just separate users following their QCI numbers and as we saw the users with highest priority will get highest throughputs then the other users with lower priority access. In addition we saw that value of alpha depends on the number of users per cell.

Chapter 5

Conclusion and Future Work

In this thesis, in order to implement the prioritization to some users following their QCI numbers in the Vienna LTE simulator more specific in the System Level simulator since the performance of a whole network is analyzed, first we explained the prioritization capabilities in LTE networks and then we see the Vienna LTE simulators which is used to test and optimize algorithms and procedure.

Since we just modify the PropSunFair scheduler it will be better to work the prioritization capabilities in all the scheduler available in the LTE system since the scheduler allocates resource blocks to the users and each scheduler works in different manner than the other one, in addition it is better to work in more complex scenarios for example higher number of users, higher number of cells and eNodeB's, or finally to see the packet delay related to each users when QoS is introduced.

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