KAUNAS UNIVERSITY OF TECHNOLOGY

ELECTRICAL AND ELECTRONICS ENGINEERING FACULTY

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QOE/QOS CROSS LAYER RESOURCE MANAGEMENT IN LTE NETWORKS

Master's Degree Final Project

Supervisor

Assoc. prof. dr. Lina Narbutaite

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Smart Telecommunication Technology (code 621H64001)

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" QOE/QOS Cross Layer Resource Management in LTE Networks "

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Dinesh Manogaran. QOE/QOS Cross Layer Resource Management in LTE Networks. *Telecommunications engineering Master's* Final Project / supervisor assoc. prof. dr. Name Surname; Faculty of electrical and electronics engineering, Kaunas University of Technology.

Research field and area

Keywords: *LTE, QOS, QOE, Packet Scheduling, Resource.*

Kaunas, 2016. 46 p.

SUMMARY

Today, mobile Internet has become an indispensable part of people's life. Nowaday LTE is one of the most developed wireless broadband systems worldwide. The traditional methods to evaluation of network performance are based on system Quality of Service (QoS), and main parameters are throughput, delay and loss. Bur analyse of cross layer resource allocation mostly based on Quality of Experience (QoE) for multiple applications. The evaluating packet scheduling performance in LTE downlink key performance indicators are system throughput and fairness. To achieve this thesis aim these scheduling algorithms are choose: the Best CQI (BCQ) Round Robin (RR) and Proportional Fair. Suggested model for investigation effect different packet scheduling for cross layer recourse management was done in this thesis . The performance evaluation of each of these algorithms is performed using the created block LTE Downlink Link simulator in Matlab. This block was integrated into simulator "Vienna LTE system". The established relationship model between QoS and QoE is presented and investigated in this thesis too.

Content

Introduction

Over recent decades Quality of Service (QoS) has been used as the principal descriptor for specifying the performance quality. The concept of QoE refers to the amount of end user experience of the delivered service. But nowadays both parameters have strong relationship: QoE needs the support from QoS and QoS performance can impact QoE satisfaction.

The LTE specification was published as part of Release 8. The downlink physical resource is the grid of time-frequency resource consisting of multiple resource blocks that are divided in multiple resource elements. The throughput of users (UE) depends on the different factor like scheduling algorithms, distance from eNodeB, multipath environment, multiple antenna techniques and UE speed. A scheduler is main element in the base station and it assigns the time and frequency resources to different users in the cell. The scheduler design must take different factors: service type, application QoS demands, throughput fairness among same user types etc. The LTE system needs to use various end-to-end QoS/QoE management control model in order to satify the QoS/QoE requirements. Another important key is the adoption of advanced radio resource management procedure, which has been used in order to increase the system performance. There are many scheduling algorithms and every one of them has different influence on the LTE resource distribution for user. Packet scheduling plays a fundamental role in this because it is responsible for choosing fine time and frequency resolution and also how to manage the radio resources among different stations taking all the conditions into account. Packet scheduling is playing a vital role in QoS and QoE also.

Therefore, the ***aim of this thesis*** is to investigate the effect of different packet scheduling for cross layer resource management in LTE network and create the relationship model between QoS and QoE

In order to reach this aim, these ***tasks*** should be solved:

- to analyse of LTE network, service, QoS parameters ;
- to analyse existing relationship models between QoE and with QoS;
- to analyse packet scheduling p algorithms for resource management and create the cross layer model for evaluation their effect for resource management;
- Using suggested model to investigate different packet scheduling and create the relationship model between QoS and QoE.

Different methods are used during the research:

- scientific literature review;
- simulation study;

- result analysis with conclusion.

The thesis is organized as follows:

- chapter 1: analysis of scientific literature is provided in order to highlight various aspects of packet scheduling and resource management for overview of the QoS and QoE.
- chapter 2 presents the LTE network structure, service and QoS parameters;
- chapter 3 shortly presents various models for evaluation relationship between QoS and QoE .
- chapter 4 is the analysis and comparison of different packet scheduling algorithms. The performance of Round Robin (RR), Best CQI, proportional fair (PF) scheduling algorithms influence for cross layer recourse management is analysed in this thesis;
- chapter 5 presents the suggested model for investigation effect different packet scheduling for cross layer recourse management . The performance evaluation of each of these algorithms is performed using the created block LTE Downlink Link simulator in Matlab. This block was integrated into simulator “Vienna LTE system”. The established relationship model between QoS and QoE is presented and investigated too;
- chapter 6 presents the overall conclusion of the work.

1 Research literature analysis

Quality of Service (QoS) has become an important issue for the service provider as well as for the users. The ITU-T recommendation G.1010 defines the parameters and how they affect user perception with regards to RT and packet loss. Other recommendation ITU-T G.1030 provides the result in reference to subjective responses from different type of users for RT while they are having access to web browsing sessions. Analysing this recommendation it can be seen, that many parameters affect the end user perception of service quality. There are many different sources for a general definition of Quality of experience (QoE), but generally QoE is a subjective measurement of the quality experienced by a user when he uses different services. User's QoE depends on the QoS of network. Any change in the QoS influences the QoE. The analysis of literatures helps to understand the current state of the QoS and QoE and which methods are using for solving this problem. QoE emerged as one of a popular topic among researchers during recent years.

Several studies proposed the models for the estimation of QoE. The investigations presented in other papers propose models for web browsing QoE estimation and analyse the impact video streaming QoE.

The authors [5] describe the basic mechanisms of providing QOS and its implementation over the long-term evolution (LTE) mobile network. The document [6] is focused on the fundamentals of LTE and its security architecture. Threats to LTE networks are identified and described potential mitigations to these. The authors [7] propose a novel architecture for providing quality of experience (QoE) awareness to mobile operator networks. They analysed possible architecture for QoE-driven resource control for long-term evolution (LTE) and LTE-advanced networks, including a selection of Key performance indicators (KPI) to be monitored in different network elements. All the information related to QoS or QoE are managed in a centralized point that collects performance indicators from different network elements and take potential actions to improve the QoE in proposed architecture. They present the main KPI parameters which must be measured at each protocol layer. Three different services: Web browsing, Video YouTube, VoIP were analysed and using proposed model were evaluated MOS (figure 1.1).

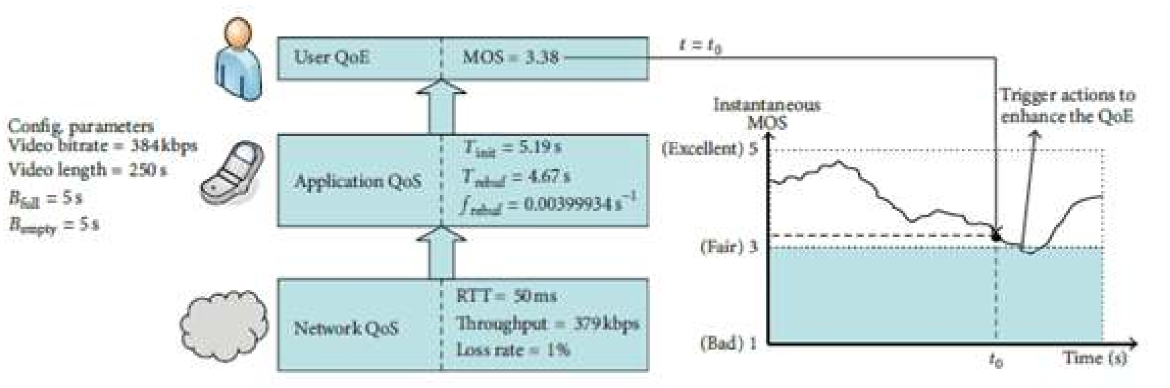


Figure1.1. MOS evaluation for YouTube service [7]

Authors [11] present holistic QoE model by bringing all disparate pieces of the communication ecosystem together to understand total QoE. This model provides a taxonomy of the relevant variables and their interactions in order to aid practitioners in thinking more broadly about QoE.

Some authors analyse the correlation models which attempt to map Quality of Service (QoS) to Quality of Experience (QoE) [8]. They show, that there are many QoE/QoS correlation models, Most of them are only partial approaches to the QoE prediction issue. Some of them are too specific for a particular kind of application, as well as they have quite different computational and operational requirements. Many solutions were proposed to evaluate QoE from various viewpoints.

Several methodologies using subjective and objective evaluation voice, audio signals multimedia services have been standardized in ITU recommendations. The summation recommendations of QoE using subjective evaluation methods are shown in Figure 1.2.

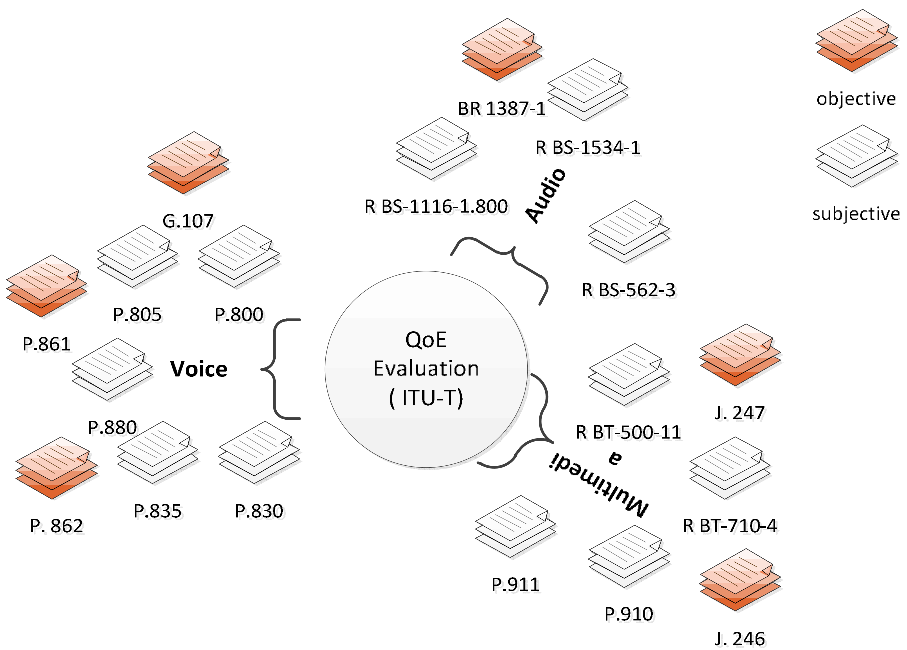


Figure1.2. ITU's standards on QoE

Other works are focused on specific models to evaluate QoE using real tests over different radio technologies. Authors [12] describe an Android application that carries out measurements of objective QoS indicators associated to YouTube service; these performance indicators are then mapped onto subjective QoE (MOS). The

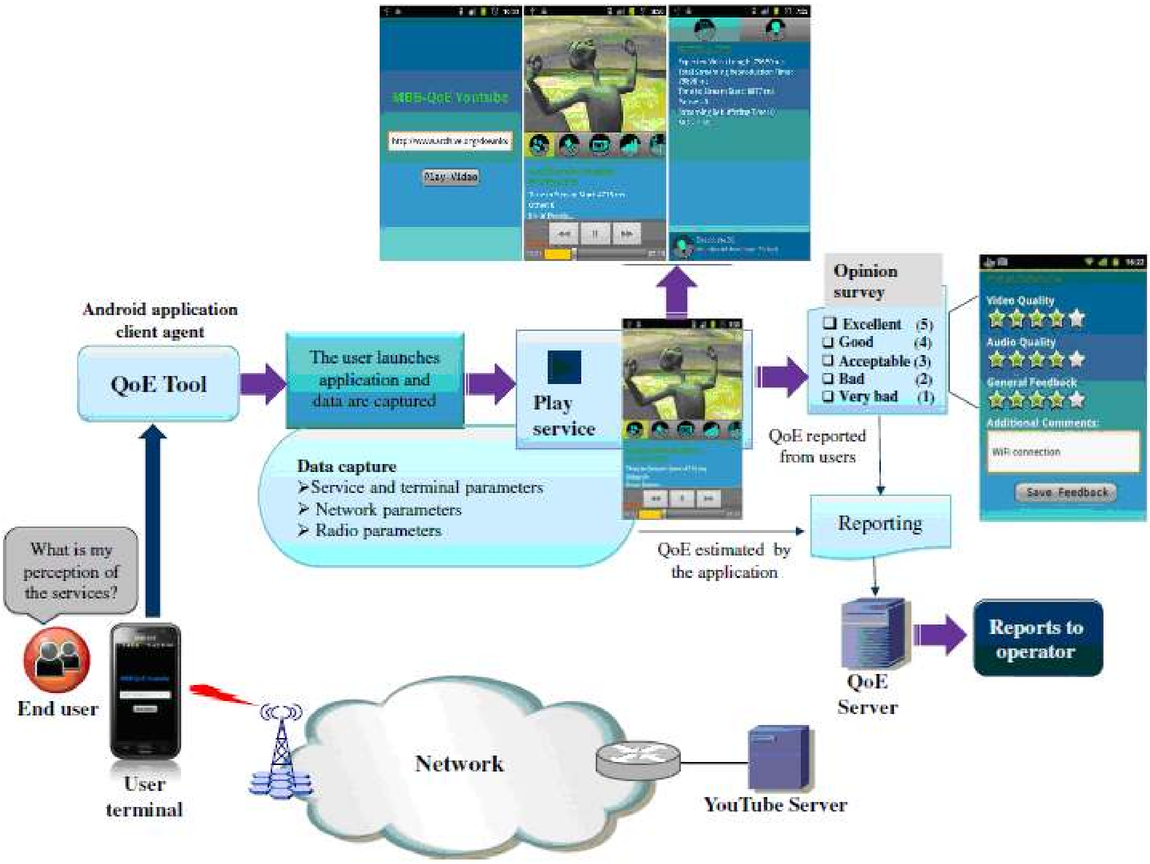


Figure1.3. QoE framework and snapshot of Android

Packet scheduling for wireless communications has been an active research area in recent years, because there has been rapidly increasing demands on data services. The problem of allocating resources to multiple users on the downlink of a LTE system is discussed in paper [19]. The maximum throughput multiuser scheduler model is proposed and its performance is evaluated in this article. The proposed sub-optimal multiuser scheduler consists of two stages. The scheduler determines the set:

$$Q^{t}_{i\max}(K_i) = \{q_{i\max}(x_{i,k}(t)) \mid k \in K_i\}. \tag{1.1}$$

The users are then ranked according to their priority index values:

$$\delta = \begin{cases} f\left(Q^{(t)}_{i\max}(K_i)/\overline{R_i}(t)\right) & PF \\ f\left(Q^{(t)}_{i\max}(K_i)\right) & Max-rate \end{cases}. \tag{1.2}$$

The research results show that the correlation among sub-carriers and the amount of information feedback play important roles in determining the system throughput. The sequential PF scheduler has a slightly lower throughput than the sequential Max-rate scheduler but a higher fairness index.

The investigation of the performance of packet scheduling in downlink LTE systems using Round Robin strategy in time domain and time and frequency domain are described in the [21]. Two types of non-real time services are considered in the analysis performed, with and without priority. A new radio resource scheduling algorithm for downlink LTE-Advanced networks by introducing a linear balance factor which is used to strike the balance between system throughput and fairness are presented in [22]. The comparison of the proposed EPE Cross with other algorithms is carried out regarding average system throughput and fairness. The results have shown that the EPF algorithm can essentially balance between LTE UE and LTE-Advanced UE to outperform the fairness between different categories UE. In [23] paper, authors consider the effect of scheduling algorithm with throughput performance. They apply proportional fair (PF) scheduler, round robin and best CQI for LTE in order to find best scheduler which provides high-quality cell throughput and improved fairness. In [26] authors investigate the aggregated system capacity as well as the breakdown of this capacity for different ACM modes in each HARQ scheme. This investigation was done by using maximum weighted capacity (MWC) resource allocation at the PHY layer in conjunction with a novel packet error rate (PER)- based scheduling at the medium access control (MAC) layer.

2 LTE network, service, QoS parameters

2.1 LTE network structure

Cellular mobile networks have been evolving for many years. LTE stands for Long Term Evolution and it came into existence because of high data rate and better services and increased throughput. The specifications for LTE are produced by the Third Generation Partnership Project (3GPP). The LTE specification was published as part of Release 8 in December 2008, and the first implementation of the standard was deployed in 2009. The LTE downlink transmission scheme is based on Orthogonal Frequency Division Multiplexing (OFDM) and spectrum is divided into multiple carriers which called subcarriers. Data symbols are modulated and transmitted using modulation schemes: QPSK, 16QAM and 64 QAM. LTE use multiple bands of spectrum. This technology is working on 800MHz and 1800MHz. The major components of the LTE system architecture are:

- User Equipment (UE);
- Radio Access Network (RAN);
- Evolved Packet Core (EPC).

The figure 2.1 shows the basic LTE network structure.

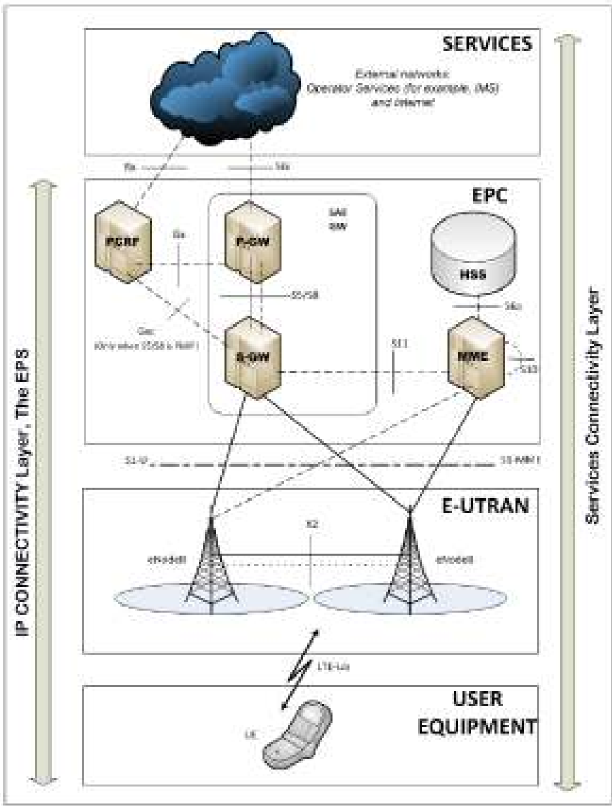


Figure 2.1 LTE network structure [2]

The EPS provides the IP based connectivity services, with all services offered at the top of the IP layer. The E-UTRAN corresponds to the access part of the network, handling all radio communications between the UE and the EPC. Different services are carried over the radio interface to the evolved base station, eNodeB connects with radio user equipment (UE) on one side and with the core network (EPC) on the other side. EPC is connected to the external IP networks [5]. LTE standards refer to a mobile device as the User Equipment (UE), which refers the terminal with the mobile operating system and LTE radio. The Radio Access Network (RAN) has evolved over time into the E-UTRAN. UEs connect to the E-UTRAN to send data to the core network. LTE uses a concept of named interfaces to easily identify the communication link between two endpoints. EPC is the routing and computing brain of the LTE network. For communication over the air between the UE and the eNodeB the protocols are used. This protocol suite is referred to as the air interface protocol stack, which is generally divided into three layers. Logically, these protocols set the foundation for all TCP/IP traffic operating above it. These protocols are [6]:

- Layer 3 - Radio Resource Control (RRC);
- Layer 2 - Packet Data Convergence Protocol (PDCP);
- Layer 2 - Radio Link Control (RLC);
- Layer 2 - Medium Access Control (MAC);
- Layer 1 - Physical Access (PHY).

Each protocol within the air interface cellular stack performs a series of functions and operates on one of two logical planes: the user plane or the control plane.

LTE network use OFDM for DL and UL transmission. And LTE network use 3 different modulations, which depend upon the channel quality estimation. If the channel quality is good, higher order modulation like 16-QAM or 64-QAM is used. To improve data rate and spectral efficiency the MIMO technology is used in this network. The common key of LTE is shown on the table 2.1 [13]

Table 2.1 Common key of LTE

LTE release 8		
Access scheme	DL	OFDMA
	UL	SC-FDMA
Scalable BW [MHz]	1.4/3/5/10/20	
Modulation	QPSK/16QAM/64QAM	
Duplexing	FDD/TDD	
Spatial multiplexing	Single layer for UL Up to 4 layers for DL MU-MIMO support	

2.2 LTE services and QoS parameters

According to the 3GPP specification for UMTS and LTE QoS concept and architecture in [3], four different classes of service are defined based on their QoS requirements. These classes are classification into [4]:

- Conversational;
- Streaming;
- Interactive;
- Background.

Conversational traffic includes telephony services, voice over IP (VoIP) and conferencing tools. These services are mostly characterised and performance reliant on the transfer time (delay) and time relation (variation) between the information entities of the stream. Streaming services are audio-video streaming in mobile TV applications. This service has a strong dependence on the time relation between both ends of the stream. Interactive services web browsing and social networking, where one end-user requests data from a remote equipment, characterised by the request response pattern from the end-user and a transparent content transfer (with low bit error rate). Background services Email, SMS, MMS and Cloud applications, consist of end-users sending and receiving data files to a background, where they are stored and can be later accessed. Hence, they are more or less delivery time insensitive and require transparent payload transfer as well.

The QoS concept in LTE brings out a central element which is named bearer. A bearer identifies packet flows that receive a common QoS treatment between the terminal and the gateway (Fig.2.2.)

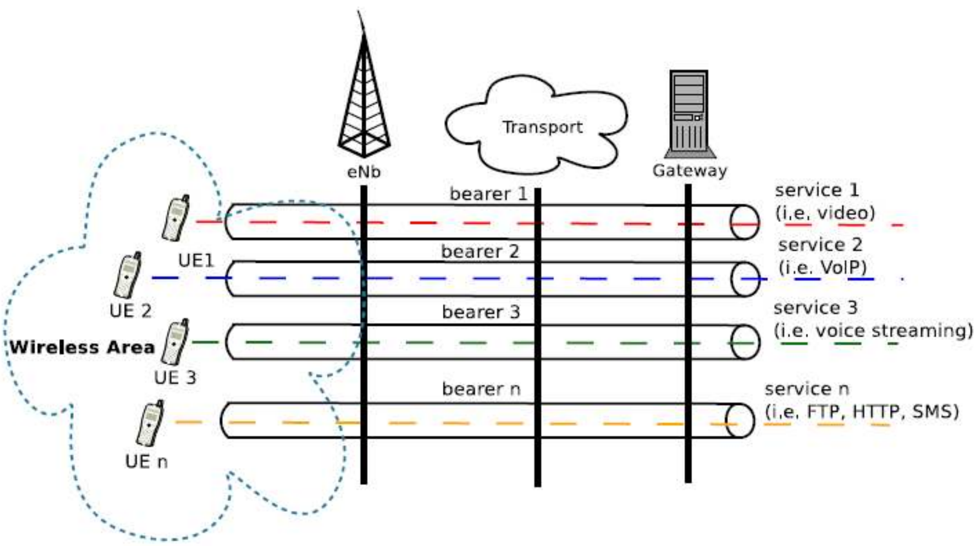


Figure 2.2 LTE bearer concepts [10]

According the traffic type the classification is presented in the figure 2.3.

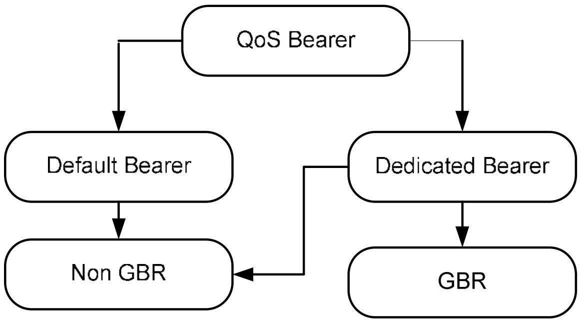


Figure 2.3 LTE QoS bearer [4]

Default bearer doesn't support any guaranteed bit rate service, it only offer best effort service. Dedicate bearer acts as a dedicate tunnel to give suitable treatment to specific services (i.e. video). Minimum guaranteed bit rate (GBR) bearers are mainly used for real time voice calling applications. Non-GBR bearer doesn't guarantee any particular bit rate service. This bearer is mainly used for applications web browsing and FTP transfer. Dedicated bearer offers GBR and Non-GBR services. The summary of services and QoS parameters target values are presented in the table 2.2.

Table 2.2. Summary of services and QoS parameters target values [4]

QCI	Bearer Type	Priority	Packet Delay [ms]	Packet Loss Rate	Example service
1	GBR	2	100	10^{-2}	VoIP call
2		4	150	10^{-3}	Video call
3		3	50	10^{-6}	Online Gaming (Real Time)
4		5	300	10^{-3}	Video streaming
5	Non-GBR	1	100	10^{-6}	IMS Signaling
6		6	300	10^{-3}	Video, TCP based services (email, ftp, etc.)
7		7	100	10^{-6}	Voice, Video, Interactive gaming
8		8	300	10^{-6}	Video, TCP based services (email, ftp, etc.)
9		9		10^{-6}	

LTE QoS concept is based on two principles:

- Network initiated QoS control;
- Class based.

In the first, only network can make the decision to establish or modify a bearer. It specifies a set of signalling procedures for managing bearers and for controlling their associated QoS. [9]. The second - each bearer is assigned a scalar QoS Class Identifier (QCI). The QCI specifies the user plane packet forward treatment associated with bearer.

Adaptive link modulation is employed to better utilize the current channel quality. All this features depends upon the Channel Quality Indicator (CQI). The CQI index is between 1 and

15. The ratio of CQI dependent from which modulation is use. The relationship between CQI and modulation is presented in the table 2.3

Table 2.3 Relationship between CQI and modulation in LTE

Modulation	CQI	Modulation	CQI
QPSK	1	16QAM	9
QPSK	2	64QAM	10
QPSK	3	64QAM	11
QPSK	4	64QAM	12
QPSK	5	64QAM	13
QPSK	6	64QAM	14
16QAM	7	64QAM	15
16QAM	8		

The EPS bearer QoS is controlled using the following LTE QoS parameters in the LTE network (figure2.4):

- Resource Type: GBR or Non-GBR;
- QoS Parameters;
  - ✓QCI;
  - ✓ARP;
  - ✓GBR;
  - ✓MBR;
  - ✓APN-AMBR;
  - ✓UE-AMBR;

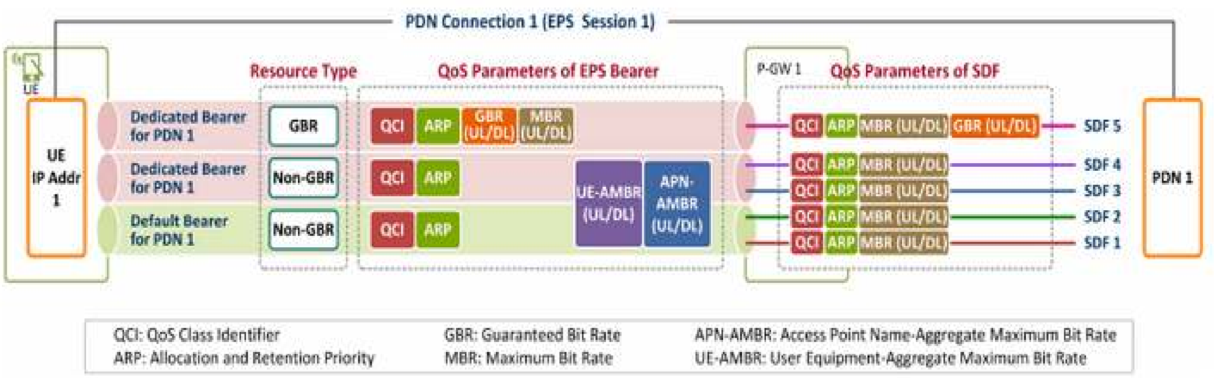


Figure 2.4 LTE QoS parameters [14]

The services , which are classified using QoE and QoS classes are presented in table 2.4 [16]

Table 2.4 LTE services

User experience class	Service class	Example services
Conversational	Basic conversation	Voice telephony (including VoIP), Emergency calling (call to public safety points), Push-to-talk (quick exchange of information).
	Rich conversation	Video conference, High-quality video telephony, Remote collaboration, e-Education (e.g. video call to teacher), Consultation (e.g. video interaction with doctor), Mobile commerce.
	low delay Conversation	Interactive gaming, Consultation, Priority service.
Interactive	Interactive high delay	e-Education (e.g. data search), Consultation (e.g. data search), Internet browsing, Mobile commerce (buying/selling through wireless handheld devices), Location-based services (to enable users to find other people, vehicles, resources, services or machines).
	Interactive low delay	Emergency calling, e-mail (Internet Message Access Protocol, IMAP server access), Remote collaboration (e.g. desktop sharing), Push alerting (e.g. notification of hazardous situation), Messaging (instant messaging), Mobile broadcasting/multicasting (mobile interactive personalised TV), Interactive gaming.
Streaming	Streaming live	Emergency calling, Push alerting, e-Education (e.g. remote lecture), Consultation (e.g. remote monitoring), Machine-to-machine (e.g. observation), Mobile broadcasting/multicasting, Multimedia.
	Streaming non-live	Mobile broadcasting/multicasting, e-Education (e.g. education movies), Multimedia, Mobile commerce, Remote collaboration.
Background	Background	Messaging, Video messaging, Public alerting, e-mail (transfer Receiver /Transmitter, e.g. Post Office Protocol, POP), Machine-to-machine, File transfer/download, e-Education (file upload/download), Consultation (file upload/download), Internet browsing, Location-based service.

3 QoE relationship with QoS

Many times ago QoS was the basic concept to show the performance of applications. However, now it was necessary to use a metric to provide a better understanding of a user's experience. Nowadays, QoE is evaluated as the satisfaction levels of users for the service quality. However, the essence of QoE is the combination of multiple effects from many factors. Hence, the QoE should be considered from multiple aspects. QoE describe how satisfied by subscribers to the provided service quality. The poor QoE will cause dissatisfied subscribers. The QoE is very subjective in nature and it is important for the operator to devise a strategy for it. QoS is the ability of the network to provide a service with an assured service level. QoS is measured of throughput, packet loss, delay, jitter, SNR and etc. Comparing QoS and QoE, QoS is concentrated of network characterization of the service quality, QoE is a user characterization of service quality. QoE depends on human and technical factors. QoS depends on network parameters. QoE refers the perception of the user about the quality of a particular service. These expressed by the human feelings : good, excellent, poor. Any change in the QoS could be reflected on the QoE. In some case good QoS does not mean good QoE. Thus combination of QoS and QoE is necessary for a good user experience. The part quality of service (QoS) and quality of experience (QoE) is shown in the figure 3.1 [15] and the end to end QoE model in the figure 3.2.

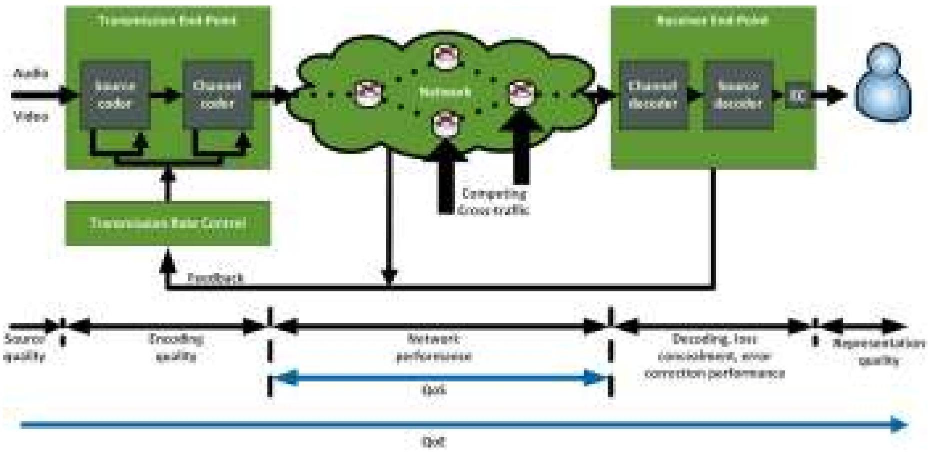


Figure 3.1 Part of QoE and QoS

The technical or nontechnical factors are affected of QoE. QoE metric is Mean Opinion Score (MOS), which quantifies the perception quality of different user-based applications. The MOS is a numeric value between 1 and 5. 5 are the highest quality and 1 is the lowest quality. QoE can be evaluated use subjective or objective testing. Subjective testing is based on user perceptions and objective is based on instrumental calculations. Subjective QoE factors represent quantitative and qualitative aspects of human needs and requirements.

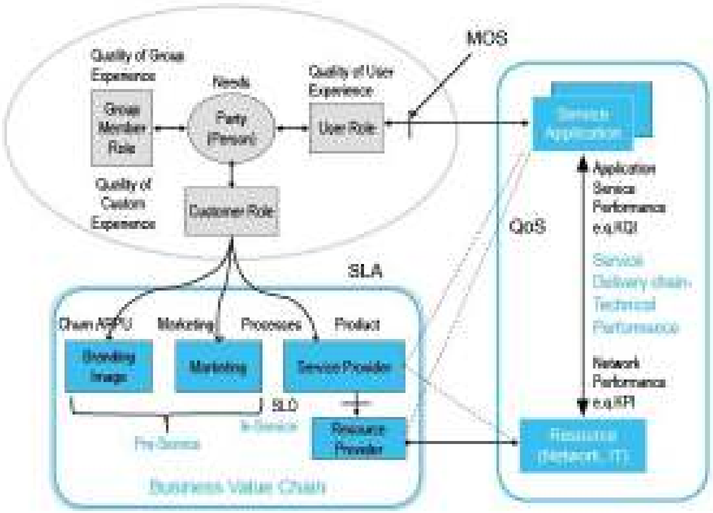


Figure 3.2 End to end QoE model.

End-to-end QoE assessment system (Figure 3.3) that consists of indices for customer, service and network [15]. The top layer is customer experience indicator (CEI). This provides an objective measurement of customer experience. This indicator is used to describe customer service experience. The second layer is key quality indicator (KQI). This indicates the performance of products and services. The KQI can be calculated using different KPIs. The construction of objective assessment models requires a set of metrics or Key Performance Indicators (KPIs), which can be modelled against the user subjective feedback. The third layer is network-based KPI. This represents a certain part of end-to-end service data. KPIs are based on alarm, performance, and network configuration data; analysis data from active/passive probing and packet capturing, and billing data. QoS is represented by KQI and is what end-users experience directly. KPI represents the performance of sources (network equipment) and is invisible to users.

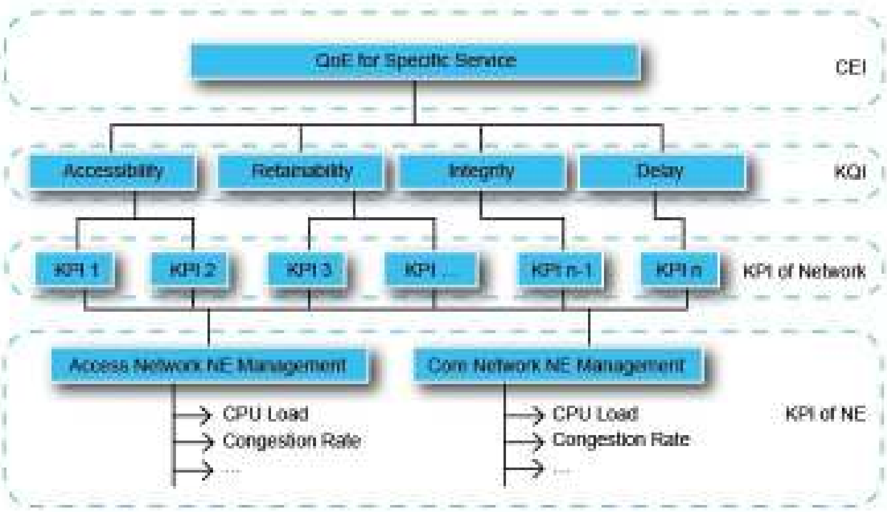


Figure 3.3 End-to-end QoE assessment system.

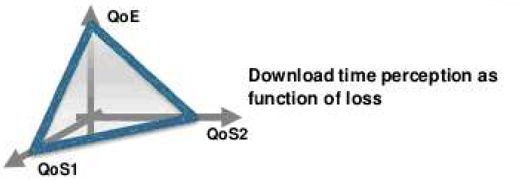
QoS and QoE are interdependent but the relationship between them the most case is not linear. QoE as a function QoS is given by

$$QoE = f\{QoS_1, QoS_2, ..., QoS_n\}. \quad (3.1)$$

The relationship between QoE and QoS can be expressed using different dependencies [8]:

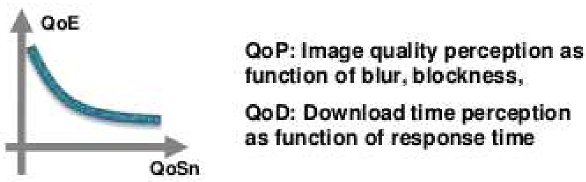
- Linear

  $QoE = a1 + a2 * f\{QoS\}$, a1 ,a2, a3..an - parameters, obtained by applying a linear fit between the QoS KPI values.



- Exponential

  $QoE = a1 * \exp(a2 * f\{QoS\}) + a3 * \exp(a4 * f\{QoS\})$

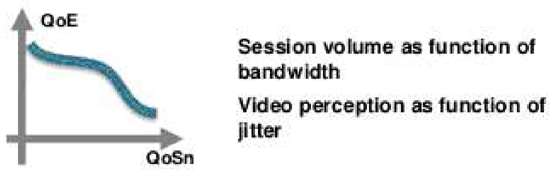


- Logarithmic

  $QoE = a1 - a2 * \log(f\{QoS\})$

- Power functions

  $QoE = a1 * f\{QoS\}^{a2} + a3$



The foundation of a subjective evaluation of QoE is known as the MOS. Commonly a five level scale MOS is based, which corresponds to the following qualitative opinions: excellent, good, fair, poor, and bad (fig 3.4).

MOS	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible
3	Fair	Annoying
2	Poor	Very annoying
1	Bad	Impossible to communicate

Figure3.4 MOS scale

The one of objective evaluation of use opinion sometime is use R-factor (ITU-T G.107). R-factor is defined by equation 3.2

$$R = R_0 - I_s - I_D - I_e + A \,, \qquad (3.2)$$

where: R - Transmission rating factor; R_0 - a basic ratio of signal to noise; I_s - simultaneous impairment factor; I_D - delay impairment factor; I_e - equipment impairment factor; A - advantage factor for expectation.

Table 3.1 is from the ITU-T G.107 recommendation that shows how the R value and user satisfaction MOS are related and the relationship between R values and MOS is displayed in in figure 3.5.

Table 3.1 R value and MOS (ITU-T G.107)

R value ≤	MOS ≤	Good or Better (%) ≤	Poor or Worse (%) ≥	User Satisfaction
90	4.34	97	Nearly 0	Very satisfied
80	4.03	89	Nearly 0	Satisfied
70	3.60	73	6	Some users dissatisfied
60	3.10	50	17	Many users dissatisfied
50	2.58	27	38	Nearly all users dissatisfied

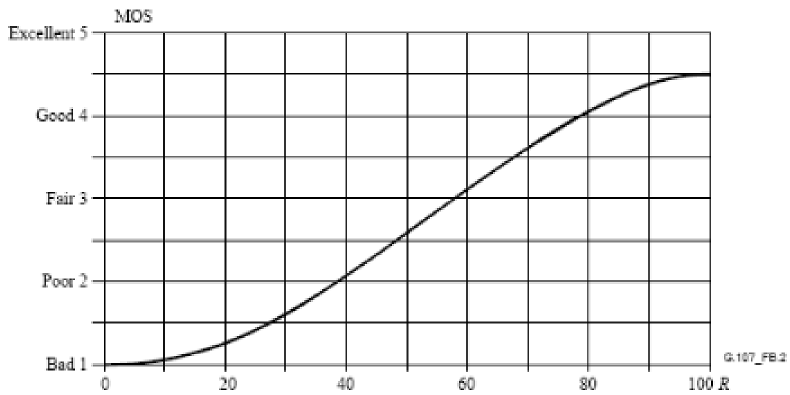


Figure 3.5 Relationship between R values and MOS

Often QoE suggested is not a non-linear function of QoS. One of possibility of correlation between QoE and QoS is describers by authors [17]. Using the QoS information measured at a network-level, a QoS/QoE correlation model for objective QoE was proposed using equations (3.3) and (3.4).

$$QoE = f\{delay, erros, rate, jitter \ldots.\}, \quad (3.3)$$

$$QoE = QoE\{QOS\} = H\left\{\frac{(e^{QoS-a} + e^{-QoS+a})}{e^{QoS-a} + e^{-QoS+a} + b} + 1\right\}. \quad (3.4)$$

Another QoE model, which is QoS based, is name as Experience-aware Adaption [18]. Flow related aspects are the main components of the QoE (3.5):

$$QoE = f(QoL\{QoS, QoF(QoS)\}), \quad (3.5)$$

where: *QoL* - a clear set of goals for learning; *QoF* - a clear set of goals for interaction, skills, and challenges; *QoS* - a clear set of goals for quality of service.

4 Packet scheduling algorithms for resource management

Scheduling is a process of allocating the physical radio resources among user. The aim of scheduling scheme is to maximize the overall system throughput while keeping fairness, delay and packet loss rate. The main model for packet scheduling algorithm is given in figure 4.1

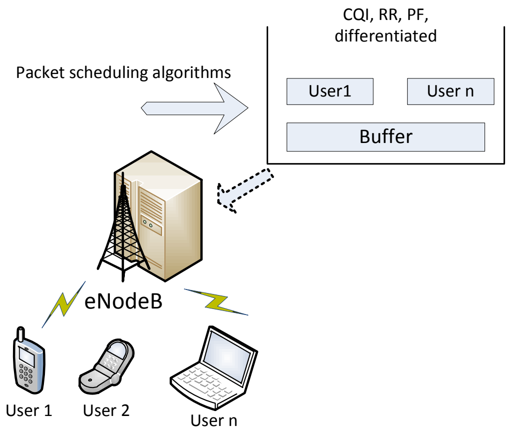


Figure 4.1 Model for packet scheduling algorithm

Users packet arriving into an eNodeB and stored in the buffer, these packets are time stamped and based on queued for transmission. The evaluating packet scheduling performance in LTE downlink key performance indicators are system throughput and fairness. To achieve this thesis aim these scheduling algorithms are choose: the Best CQI (BCQ) Round Robin (RR) and Proportional Fair. For resource management, LTE use link adaptation, HARQ, Power Control, and CQI reporting. They are placed at physical and MAC layers, and strongly interact with each other to improve the usage of available radio resources.

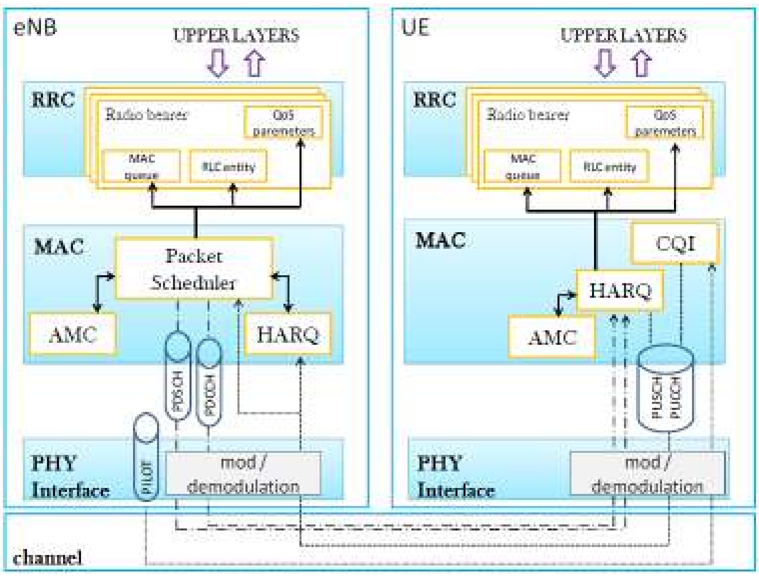


Figure 4.2 Interaction of the main functions of data exchange in the LTE [20]

There is only one node between the user and the core network known as eNodeB which is used to operate all radio resource management functions in the LTE radio network architecture. LTE contain some algorithms for example Hybrid ARQ (HARQ), link Adaptation (LA) and Channel Quality Indication (CQI). HARQ is utilizing for fast retransmissions of the packets which are in correct. It is use to keep the radio interface delay minimum also. UE is use to measures the received channel quality and news the channel dependent CQI reports in uplink [23]. LA select different modulation and coding schemes (MCS) based on CQI reports to maximize the spectral efficiency.

Usually resource allocation is based on a metric calculation. These metrics are used to define a transmission priority of each user on a specific resource block and is calculated by taking information of each flow and other useful information that helps in resource allocation decision. These parameters are [22]:

- Channel Quality: CQI feedback received from the users could help to allocate resources to those users who are experiencing better channel conditions;
- Status of the Queue: Status of the queue helps to minimize the packet delay experienced by the flow;
- Resource allocation history i.e. past performance can be used to improve fairness. Users having lower past throughput will have higher metric;
- QoS requirements of the flow that are received form the CQI can be used to make better scheduling decision.

4.1 Best CQI scheduling

LTE use 15 different CQI values depending which value UE reports, network transmit data with different transport blocks size. Best CQI scheduling can increase the cell capacity at the expense of the fairness. Users located far from the base station are unlikely to be scheduled in this scheduling strategy. This scheduling algorithm is used for strategy to assign resource blocks to the user with the best radio link conditions. The resource blocks assigned by the Best CQI to the user will have the highest CQI on that resource blocks. The user equipment must feedback the CQI to the BS to perform the Best CQI. In order to perform scheduling, terminals send (CQI) to the base station (BS). Basically in the downlink, the BS transmits reference signal to terminals. These reference signals are used by UE for the calculation of the CQI. A higher CQI value means better channel condition and it transmits the data with larger transport block size and vice versa. At first time CQI is sent to the eNodeB by the terminals. The eNodeB transmits reference signal to terminals. These reference signals are used by UE for the measurements of the CQI. If network sends a large transport block even though UE reports low CQI, it is highly probable that UE failed to decode it. After that UE send Negative Acknowledge (NACK) to network. When network received this signal, it used retransmission function which in turn causes waste of radio resources. The cell throughput can be increased by Best CQI scheduling scheme but at the expense of the fairness [21]. The disadvantage of this scheduling scheme, terminals located far from the eNodeB are unlikely to be scheduled.

4.2 Round Robin scheduling

Round robin (RR) method is used to allocate the radio resources to users, the first user will be served with the whole frequency spectrum for a specific period of time and then serve the next serve for another time period. he scheduler provides resources cyclically to the users without considering channel conditions into account. It’s a simple procedure giving the best fairness. But it would propose poor performance in terms of cell throughput. RR meets the fairness by providing an equal share of packet transmission time to each user. The terminals are assigned the resource blocks in turn (one after another) without considering CQI in round robin scheduling. Thus the terminals are equally scheduled. However, throughput performance degrades significantly as the algorithm does not rely on the reported instantaneous downlink SNR values when determining the number of bits to be transmitted.

4.3 Proportional Fair scheduling

A Proportional Fair scheduling algorithm (PF) provides balance between fairness and the overall system throughput. It tries to maximize total throughput while at the same time it provides all users at least a minimal level of service. The eNodeB obtains the feedback of the instantaneous channel quality condition (CQI)for each UE_k in time slot t in terms of a requested data rate $R_{k,n,}$ (t). After that it keeps track of the moving average throughput C(t) of each UE on every physical resource block (PRB)

PF was originally developed to maintain non real time service in code division multiple access high data rate system. The scheduler can affect PF scheduling by allocating more resources to a user, comparatively with better channel quality. This is done by giving each data flow a scheduling priority that is inversely proportional to its anticipated resource consumption. This gives high cell throughput as well as fairness satisfactorily.

5 QoE/QoS cross-layer resource management model

5.1 System model

Our analysed system model structure consist three parts (fig.5.1). The main part of research is access network, which is divided into two subsystems: user equipment and access node. An access node is the network element responsible for interconnecting between the user equipment (UE) and servers or service providers, in order to provide an end-to-end connection.

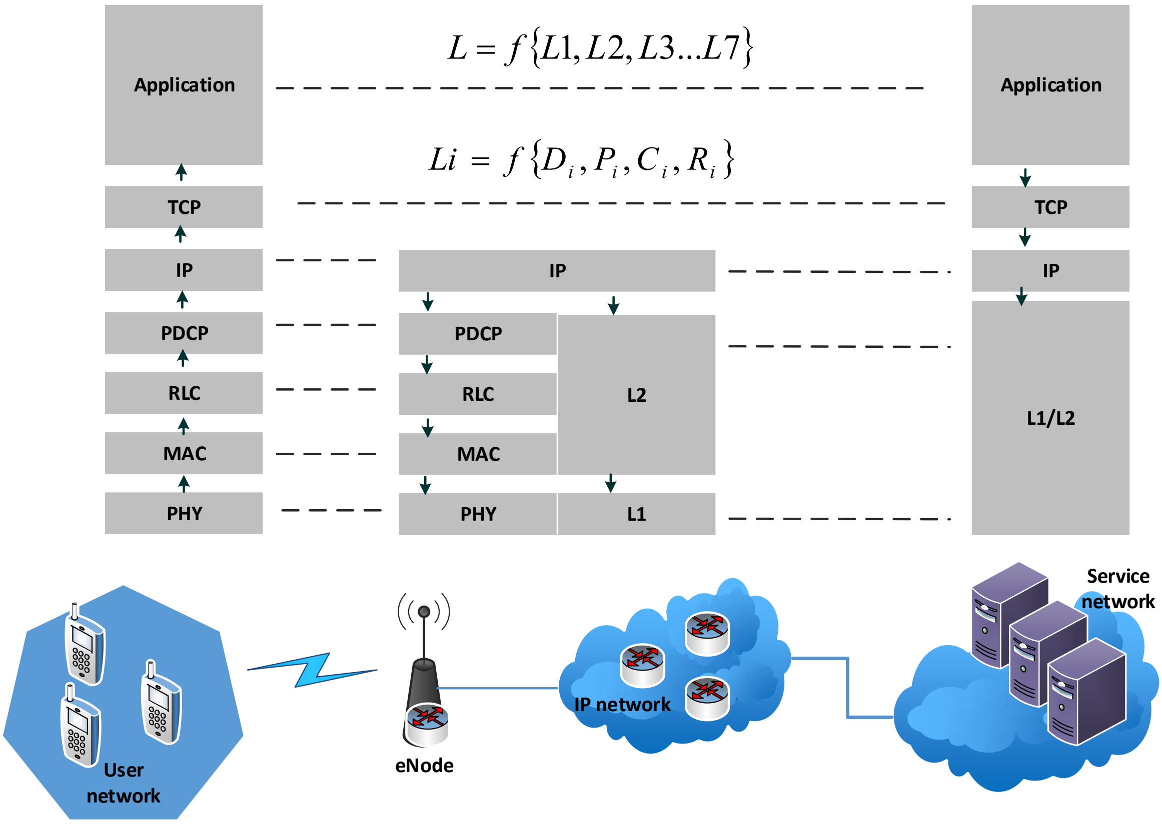


Fig. 5.1 The structure of analysed LTE end to end system model

The main parameters, which influence to end- to- end QoS /QoE and which will be analysed are:

- Delay (D);
- Probability of loss (P);
- Data rate (R).

Each layer different influence for service QoS and use QoE. PHY layer define the data rate and redundancy according to the instantaneous quality of the channel. At link layer (L2) resources are assigned to users following a specific user multiplexing algorithm. In IP network average queuing delays, throughput and loss rates in the routers have been analysed. The factors are used for packet scheduling process is shown in the figure 5.2.

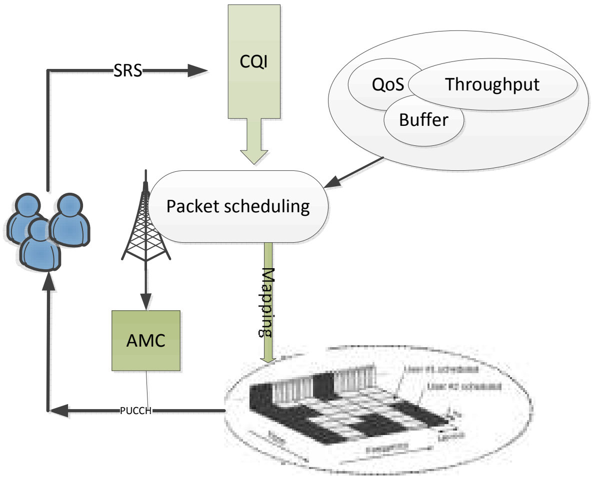


Fig. 5.2 Factors are used for scheduler process

Each UE sends the sounding Reference Signal (SRS), with which the CQI is computed and sent to the eNodeB. When the eNodeB received the CQI information for the allocation decisions it compute the RB mapping. The AMC module selects the best MCS that should be used for the data transmission by scheduled users. AMC is used to select proper Modulation and Coding Scheme (MCS) according to the information provided by the CQI reporting. Main purpose of AMC is to maximize throughput with given Block Error Rate (BLER). Therefore, users having higher SINR will achieve high bit rate while users with low SINR who are experiencing bad channel conditions will get lower throughput. The information about these users, the allocated RB, and the selected MCS are sent to the UE via Physical Uplink Control Channel (PUCCH). Each UE reads the PUCCH and, in case it has been scheduled, accesses to the proper PUSCH payload. Downlink transmission over PDSCH is usually allowed at certain time according to the decision taken by scheduling scheme. The parts of packet scheduler process is shown in figure 5.3 and user connection to BS in figure 5.4

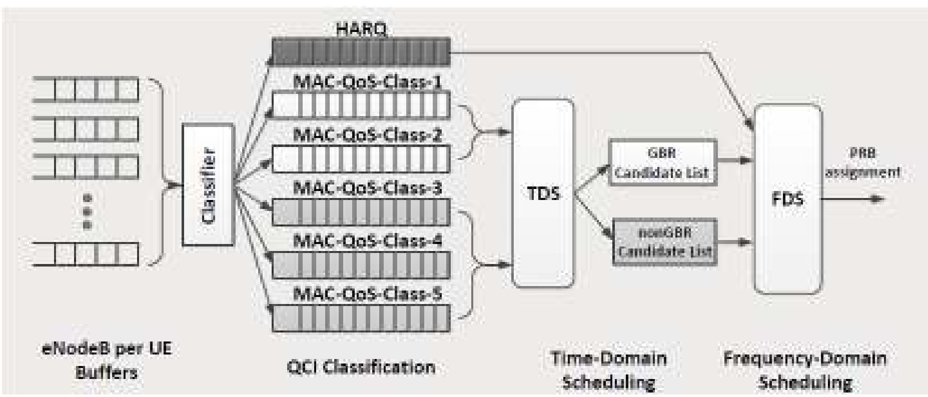


Fig.5.3. The parts of packet scheduler process

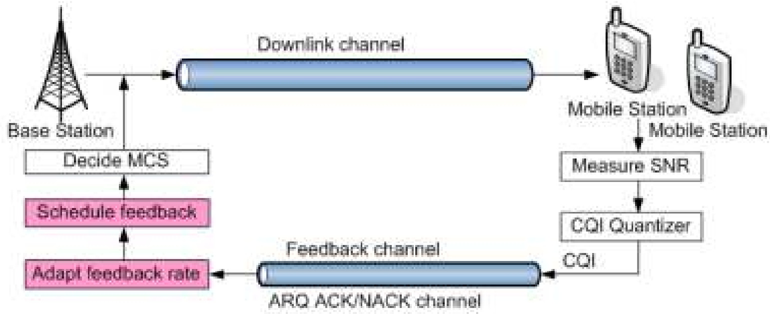


Fig.5.4 User connection to BS

Each UE mobile equipment (MS) measures average SNR all the subcarrier of the preamble except the guard subcarriers and the DC subcarriers. Value of SNR would generate the CQI at the BS. Since feedback load of the SNR quantization increases rapidly with the number of quantization levels. At the BS, if a frame is detected with error, it is stored and a negative acknowledgement (NACK) is feedback. Upon arrival of the retransmission, the BS attempts to decode the second transmission of the frame. If the decoding is successful, an ACK is feedback. If no, the frame is stored and combines all the packets together to decode. The common scheduling flowchart are illustrate in figure 5.5

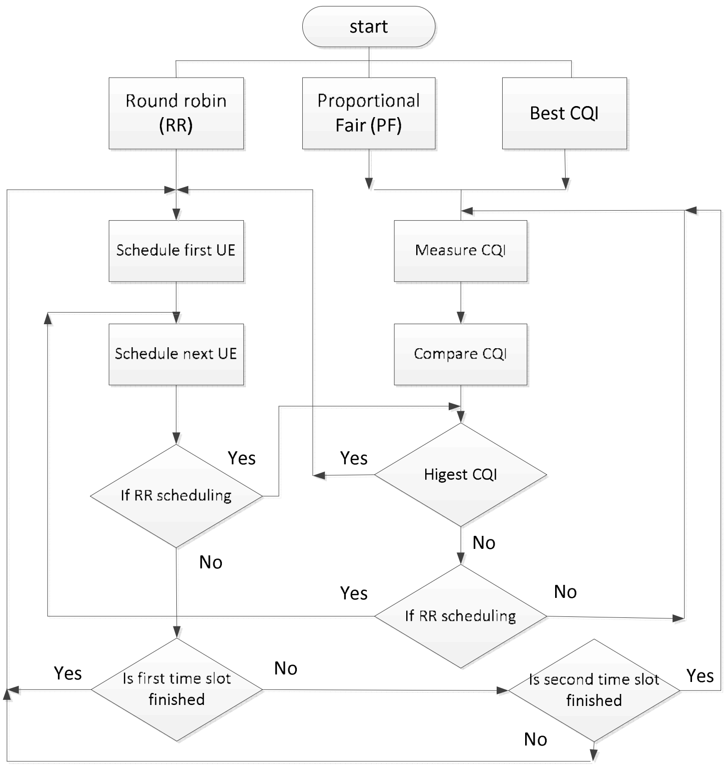


Fig.5.5 Common scheduling flowchart

For evaluation the efficiency of cross layer management, at first we define the utilization functions. This function *(U)* is map network resources utilized by users into real numbers. Also indicate the level of satisfaction of the user which in turn helps in balancing the efficiency and fairness between the users. Utilization can be expressed by [25]

$$U(n_j) = g_j \left\{ \frac{1}{1+e^{-p_j(n_j RB_j)}} - l_j \right\}, \qquad (5.1)$$

where p_j is the priority mark, assigned to user, RB is available resource block, g and l - constant using as normalized function.

The constant are calculate using equations:

$$g_j = \frac{1+e^{p_j RB_j}}{e^{p_j RB_j}}, \qquad (5.2)$$

$$l_j = \frac{1}{1+e^{p_j RB_j}} \qquad (5.3)$$

The total utilization of user j is calculated from

$$U_{T_j} = QoS_j * \{p_j, RB_j, n_j\}. \qquad (5.4)$$

So, the cross layer downlink scheduling and resource allocation process in figure 5.6

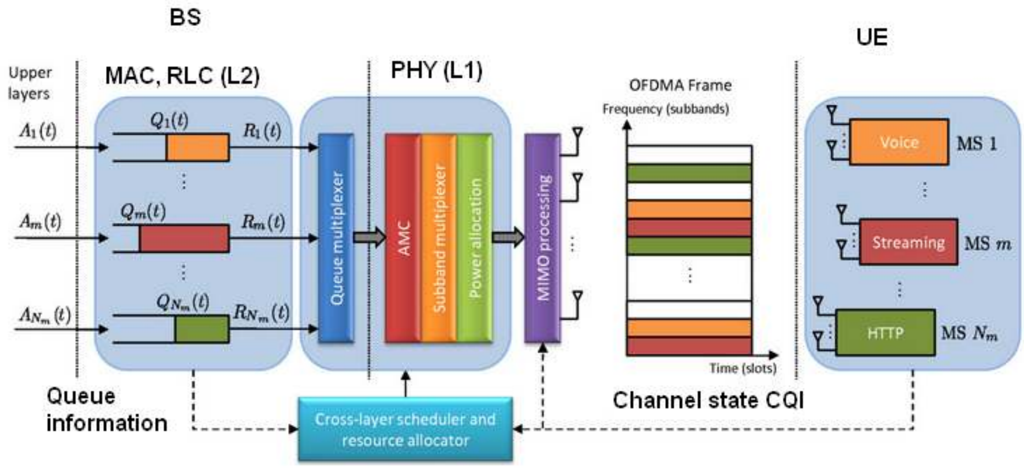


Figure 5.6 .Cross layer downlink scheduling and resource allocation

The resource allocation probability is :

$$P_k(t) = \arg\max_k \left[L_{QoS,j} * \frac{c_k(t)}{B_k(t)} \right], \qquad (5.5)$$

where $L_{QoS,j}$ is the QoS weight of the j th QoS class; c_k - is the normalized channel condition of service k; B_k -is the normalized throughput service k.

At the radio link layer, the bit rate for each RB using different CQI is given by [25]

$$br_j = \frac{r_j \log_s(M_j)}{T_s * N_s} * \sum_{s=1}^{N_s} N_{sc}(s), \qquad (5.6)$$

where N_s – OFDM symbols size; N_{sc} – number of subcarriers ; M_j – MCS size, r_j – code rate, s - number of OFDM symbols.

The data rate achieved by user k can be expressed as

$$R_k = \sum_{n=1}^{N} Ra_{k,n} \sum_{j=1}^{L} b_k * br_j \quad , \tag{5.7}$$

where Ra - resource assignment indicator (1 or 0), b_k - the choice of MCS for user k indicator (1 or 0).

The relative channel scheduling choosing coefficient is

$$k = \arg\max_k \frac{[R_k(t)]^{\vartheta}}{[C_k(t)]^{\gamma}} \; . \quad \text{if} \begin{array}{lll} \vartheta = 1 & \gamma = 1 & PF \\ \vartheta = 1 & \gamma = 0 & BCQI \\ \vartheta = 0 & \gamma = 1 & RR \end{array} \tag{5.8}$$

Having the QoS parameter we need to evaluate the QoE. Therefore was proposed relationship QoS/QoE model. The change in QoE (MOS), for a change in QoS, depends on the current level of QoE:

$$\frac{\partial QoE}{\partial QoE} \alpha - QoE \Rightarrow \alpha * e^{\beta QoS} + \gamma \tag{5.9}$$

This equation linearized and $\log(QoE) = \log(\alpha) - \beta QoS$

Because mostly of dependences of LTE network parameter is not linear, and accordance other authors solution, the relationship is expressed as logarithmic dependency using fairness index.

$$MOS_k(\subset QoS) = \begin{cases} 1 & if \quad RS_k = 0 \\ \log\left[(1-F_i)^2 - \left(F_i * f\{QoS_i\}^2\right) + G)\right] & if \quad RS_k \subset \{RS_1 ... RS_n\}. \\ 5 & if \quad \arg\max \sum F_k \end{cases} \tag{5.9}$$

Fairness index is used to measure the fairness among UE is given by equation

$$F_i(RS_1, RS_2, ... RS_N) \frac{\left[\sum_{n=1}^{N} RS_N\right]^2}{N \sum_{n=1}^{N} (RS_N)^2}, \tag{5.10}$$

where N – number of UE; RS – number of resource block for each UE.

5.2 Simulations scenario

Any research facilities and vendors are investigating aspects of LTE. For that purpose, commercially available simulators applied in industry, as well simulators applied in academia have been developed. But many of them are not flexibly, because we do not have possibilities to integrate new or our created models. Some universities and research institutes have also developed such simulators, but to the authors' knowledge none with publicly available source code. But was founded two academic simulators with license, which provide many possibility and research parameters of LTE network. Was chosen Vienna LTE system simulator, which platform is Matlab. This simulator offers a high degree of flexibility. In the simulator where we carried out our simulation work, 3 created blocks was added: CQI, Scheduling, MOS model. The common simulator structure is presented in figure 5.7

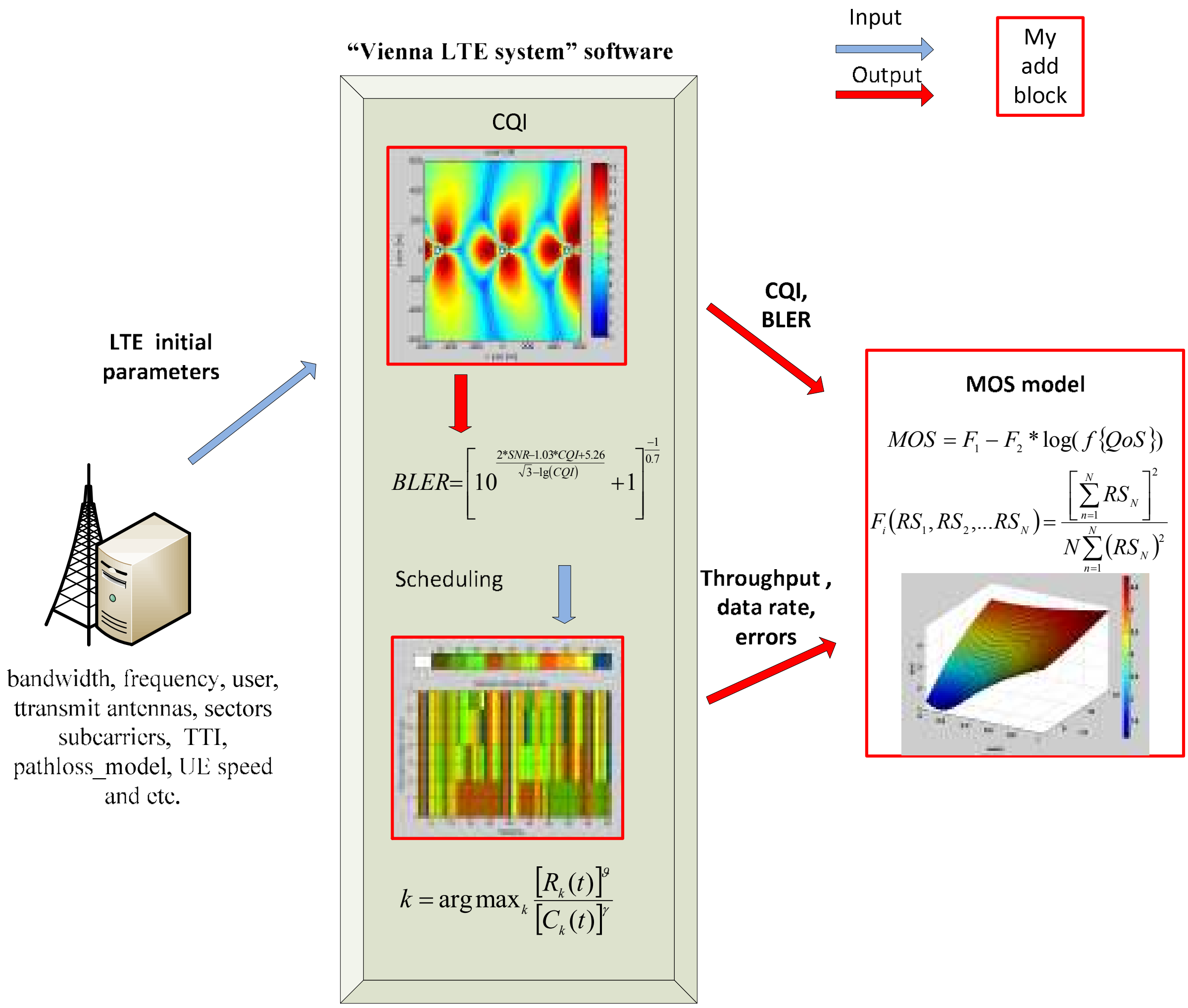


Figure 5.7. Common simulator structure for evaluation cross layer resources management

The LTE PHY layer subframe and resource structure are presented in the figure 5.8 [16].The frame structure changes depending on the cyclic prefix type, bandwidth and duplexing modes.

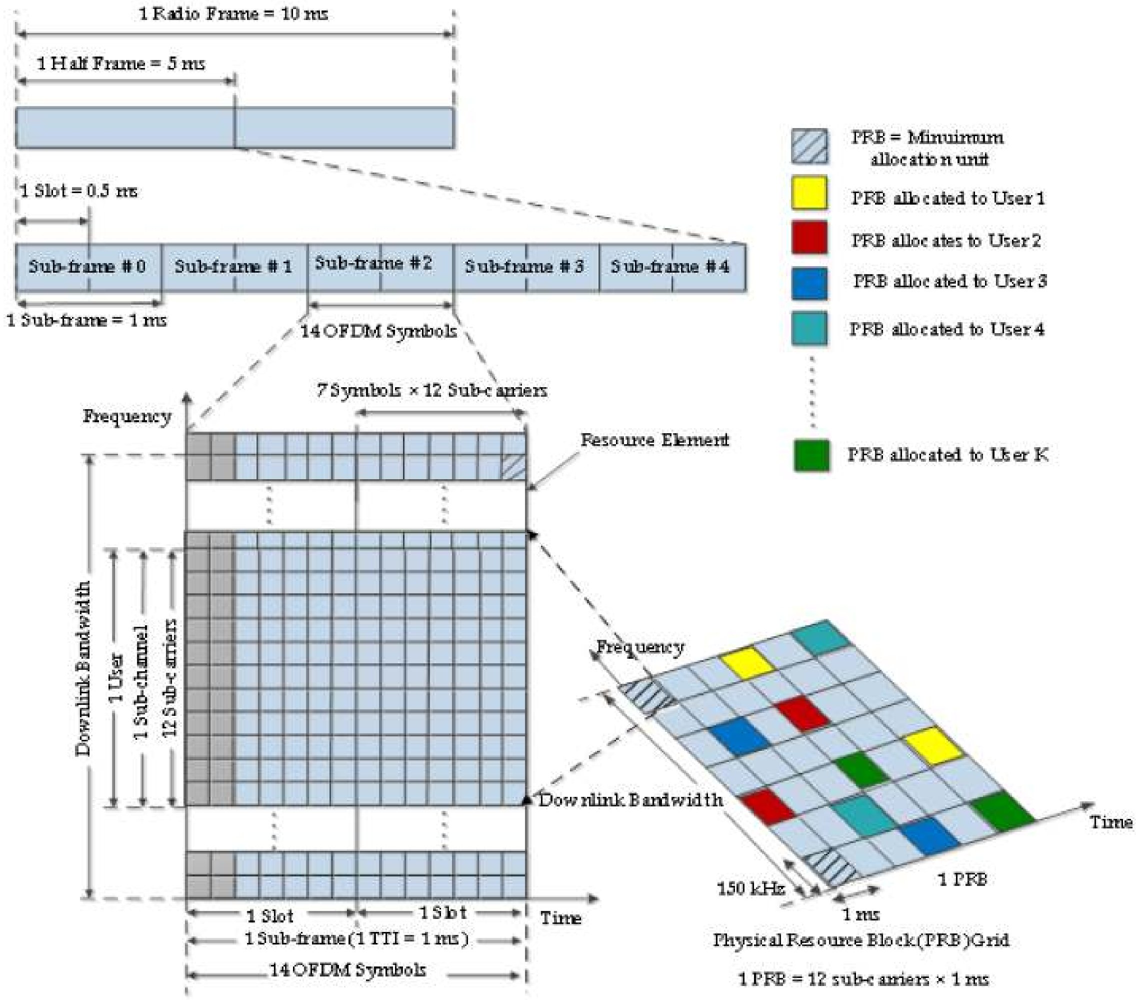


Figure 5.8 The LTE PHY layer resource structures [16]

The main LTE input parameter for configuration:

- Frequency - 1.8GHz
- System bandwidth – 10MHz
- Number of control symbols – 2
- Number of users allocated – 1
- Number of resource blocks dedicated to the above user – 50
- Resource block start index – 0
- Number of Transmit antennas – 1
- Number of resource blocks(RBN) across the 10MHz =50
- Number of subcarriers/tones per RBM =12
- Number of subcarriers per symbol = 50 x 12 = 600
- Number of symbols per subframe =14
- Number of subcarriers per subframe = 14 x 600 =8400
- Number of reference signals subcarriers per RB =2

- Subcarriers occupied by PBCH =72 (Central 6 RBs, remains unchanged for all LTE bandwidths, configurations)
- Number of symbols in which PBCH is present =4 (First 4 symbols of second slot)
- Subcarriers occupied by PSS =72 (Central 6 RBs, remains unchanged for all LTE bandwidths, configurations)
- Subcarriers occupied by SSS =72 (Central 6 RBs, remains unchanged for all LTE bandwidths, configurations)
- Signal propagation - “urban” environment model
- TTI- 1 ms
- User movie rate – 3km/h
- Cell range - 5km
- Cell - macro

5.2 Simulation results

At first was simulated the dependence of BLER versus SNR for different CQI. The dependence is important because if users want high accuracy of the received data, the ratio between the number of erroneous blocks and the total number of received blocks very small. This ratio is evaluated using parameter BLER. The BLER is considered directly in the evaluation of the throughput. BLER is given by equation:

$$BLER = \left[10^{\frac{2*SNR-1.03*CQI+5.26}{\sqrt{3}-\lg(CQI)}} + 1 \right]^{\frac{-1}{0.7}} \tag{5.11}$$

The UE sends CQI feedback to indicate the data rate, which can be supported by the downlink channel and this helps the eNodeB to select appropriate MCS level. For every different SNR the CQI value is different and the BLER and the throughput are also changing. The flexibility of modulation type makes the LTE system more efficient. In case of a bad channel quality the CQI value will be equal to one and the probability of error and lost packets decreases. The UE uses the PUSCH channel to report the CQI values. CQI value indicates the highest modulation and the code rate at which the block error rate (BLER) of the channel being analysed does not exceed 10 %. The UE sends CQI feedback to indicate the data rate, which can be supported by the downlink channel and this helps the eNodeB to select appropriate MCS level. For every different SNR the CQI value is different and the BLER and the throughput are also changing. The flexibility of modulation type makes the LTE system more efficient. In case of a bad channel quality the CQI value will be equal to one and the probability of error and lost packets decreases. The UE uses the PUSCH channel to report the CQI values.

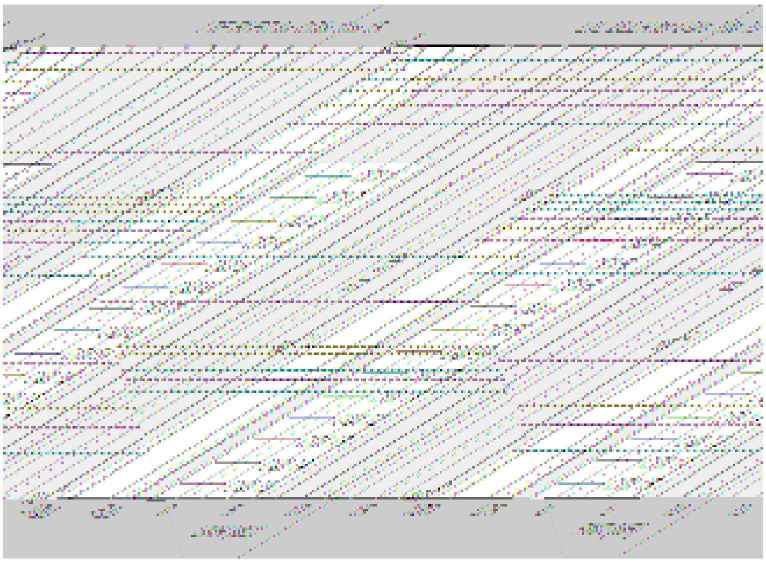


Figure 5.9 The dependence of BLER versus SNR for different CQI

.Based on the downlink SNR, the UE needs to determine CQI such that it corresponds to the highest modulation and coding Scheme .When SNR is high, more efficient modulation type is used. It will not increase the erroneous number of packets comparing to the low SNR situation. For the low SNR the CQI value is also lower and the modulation type of transmission is adapting to the current channel quality. Thus, it reduces the probability of error to occur. Each curve is spaced approximately 2 dB from each other.

The Channel Quality Indicator (CQI) for one user is depicted below and it can be seen that with single user using the whole network the channel Quality is always higher than expected and it is positive in LTE eNode. The CQI for three users is depicted below and it can be seen that the three users form a pattern and the resource is scheduled according to that and also it can be seen that the quality is not decreased when compared with one user CQI.

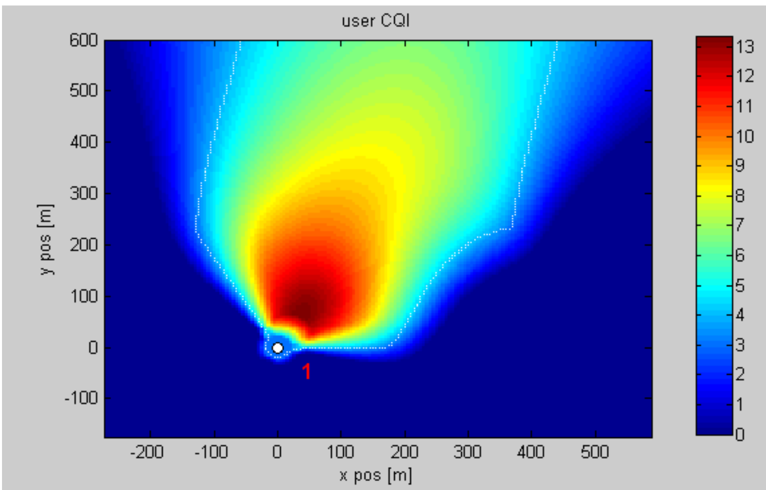


Figure. 5.10 One user CQI over LTE eNode

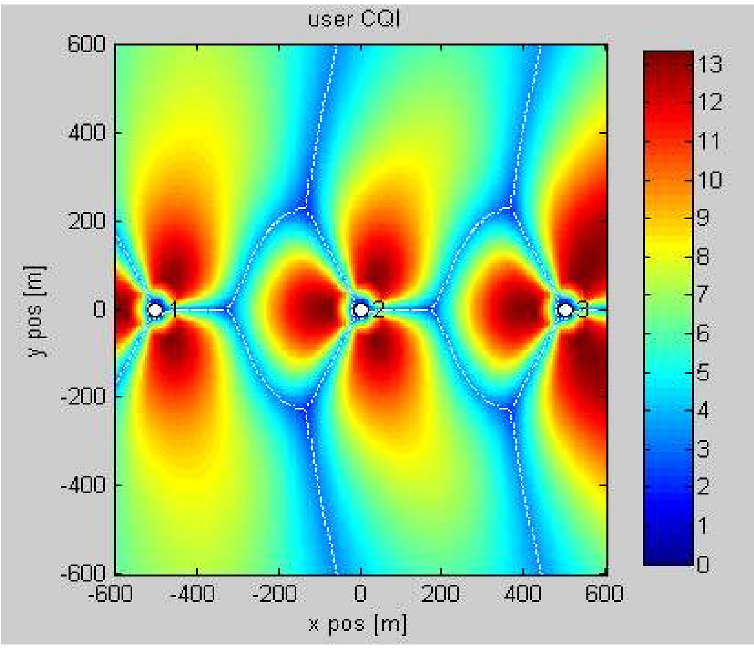


Figure. 5.11 Three users CQI over LTE eNode one cell in 3 sectors

The Resource allocation for different users have been studied and have depicted in the below figure 5.12. There are seven block groups and 10 users and using CQI scheduling the resources are scheduled based on the quality of the channel. It can be seen that from the above figure that only user 1, user 3, user 5, user 7 have only used all the resources out of the 10 users which in default have to use the resources. It is because of the channel quality and the other users experienced loss of quality and it is seen that only 40 percentage of the users have been satisfied by using this scheduling algorithm

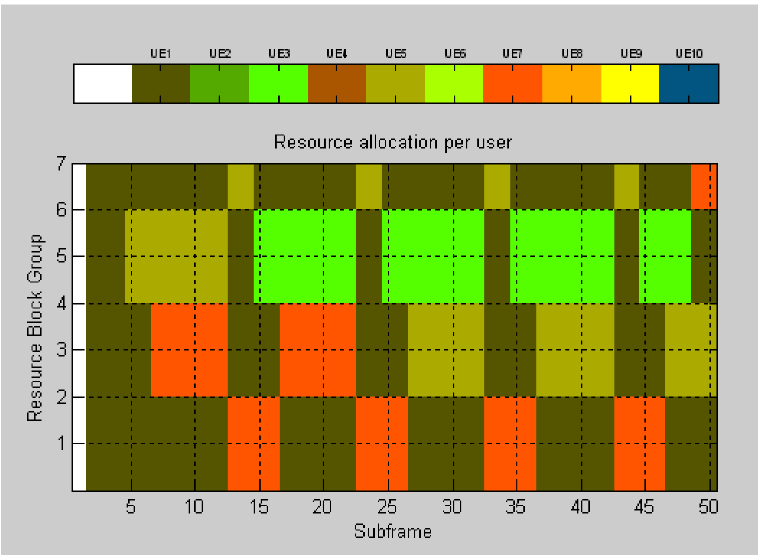


Figure. 5.12 Resource allocation per user (7 block group and 10 users) using best CQI scheduling

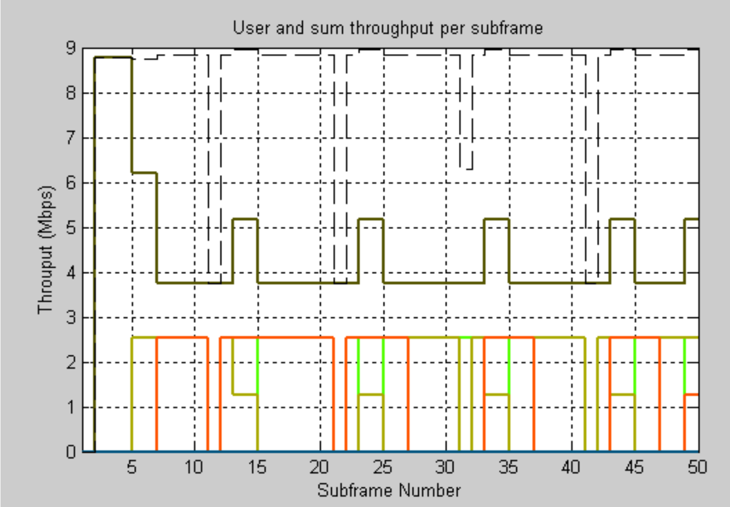


Figure. 5.13 Throughput per subframe using best CQI scheduling

It can be seen from the above figure that only one or two users have achieved the maximum and throughput and three users have achieved average throughput per sub-frame. It is because the quality of the channel is not up to the mark. The transport block statuses of ten users have been depicted in above diagram. Only four users have received the data with quality and the other users have not even responded by the network for the request which have been requested by the user.

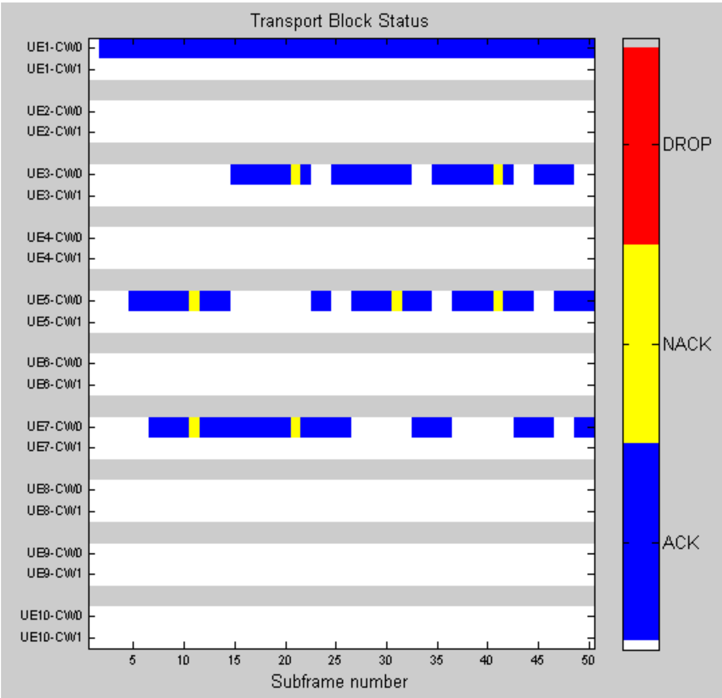


Figure. 5.14 Transport block status using best CQI scheduling

Each user irrespective of their SNIR values, we see the Best CQI scheduler all slots more resources to the users having a higher SNIR than the other the allocation of resources by Round

Robin algorithm in which each user gets allocated the same number of resources without taking into consideration any other parameters.

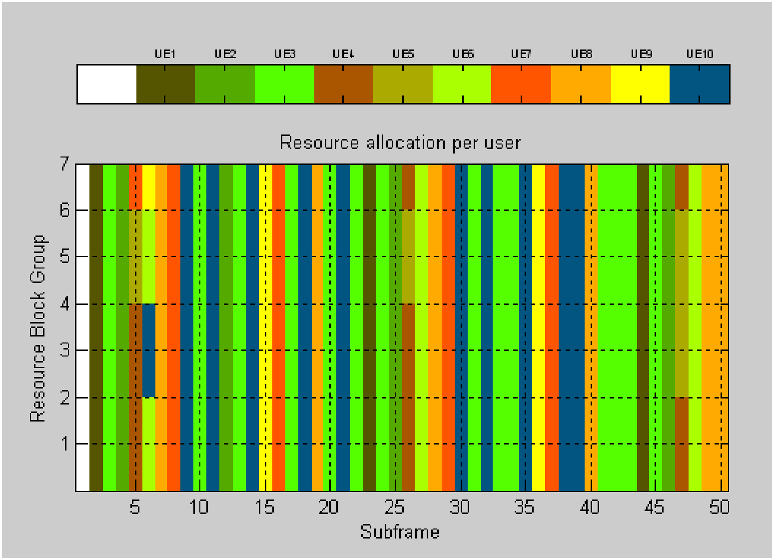


Figure. 5.15 Resource allocation per user (7 block group and 10 users) using Round robin (RR) scheduling

The resource allocation per user using Round robin (RR) scheduling is shown in above figure and it is clear that all the users have allocated with the resources with one condition time slots. The scheduler allocates time for each slots and allocates the resources. For example, if the time difference is 10 seconds then all the users will be allocated 10 seconds to use the resources and then the next user is allocated with the resources after 10 seconds irrespective of before user finishing or not finishing the resource usage. Then after sometimes the user which is allocated with resources before will be again allocated with resources by priority of work and the work is finished by the users. It is seen that the resource allocation is purely based on time and the amount of time allocated is the key for this scheduling algorithm.

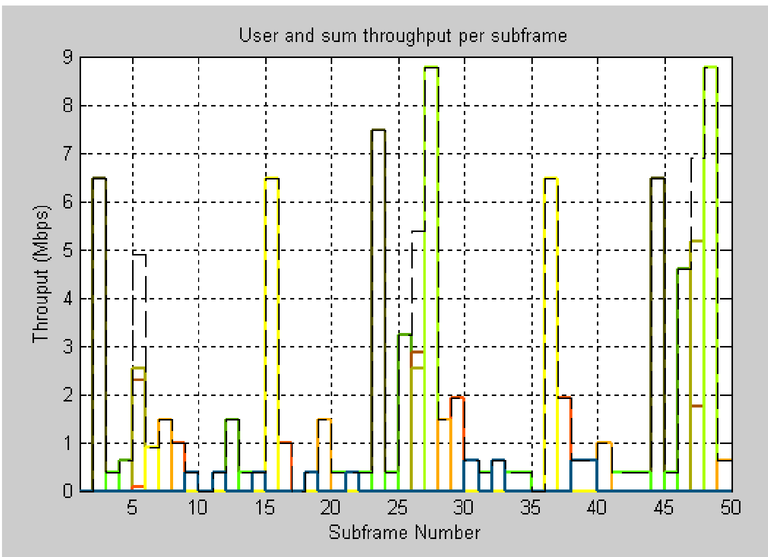


Figure. 5.16 Throughput per subframe using Round robin (RR) scheduling

It is evident that the resources have been scheduled by time slots and all the users have been allocated resources based on the request by users.Throughput with subframe have been depicted for ten users with seven block group and it can be seen that all the users have achieved average throughput per subframe according to their timeslots. The Transport block status with respect to subframe for Round Robin scheduling is show below and it can be seen that all the users have average quality of experience but only some users have high quality of experience because of time slots.

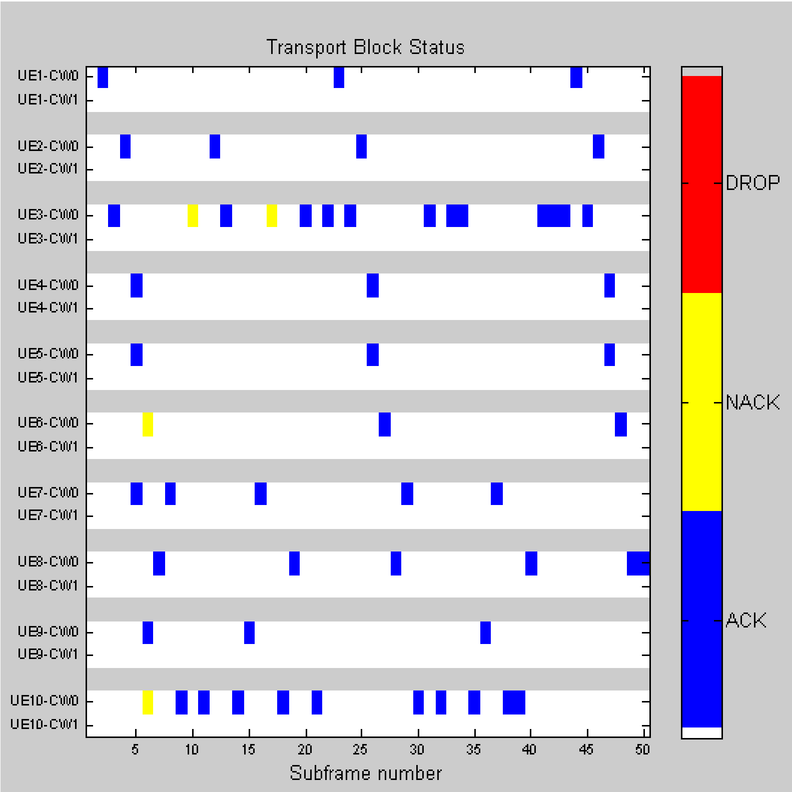


Figure. 5.17 Transport block status using Round robin (RR) scheduling

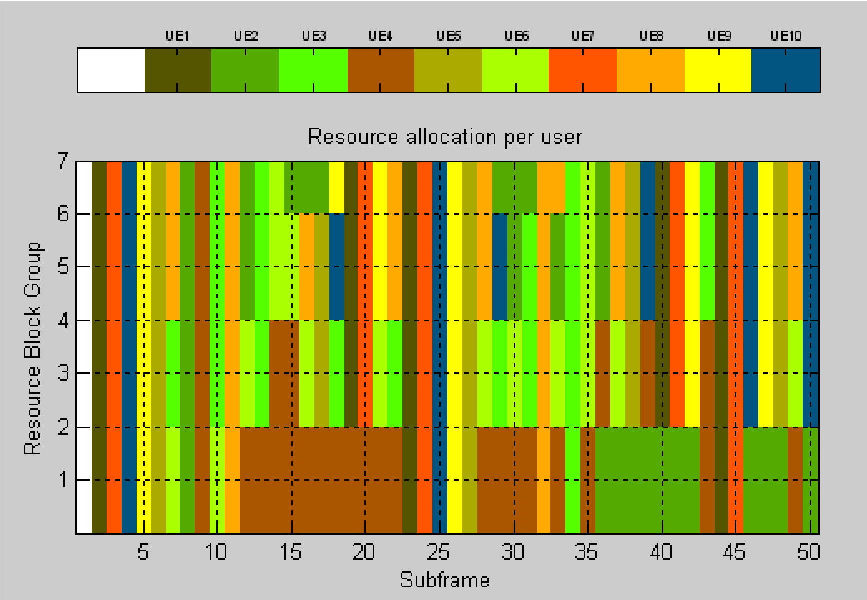


Figure. 5.18 Throughput per subframe using Proportional Fair (PF) scheduling

It can be seen that all the users have high throughput per subframe because in proportional fair scheduling the network assigns the resources in such a way that it offers high throughput per subframe and having priority scheduling to offer all users at least minimal quality of service.

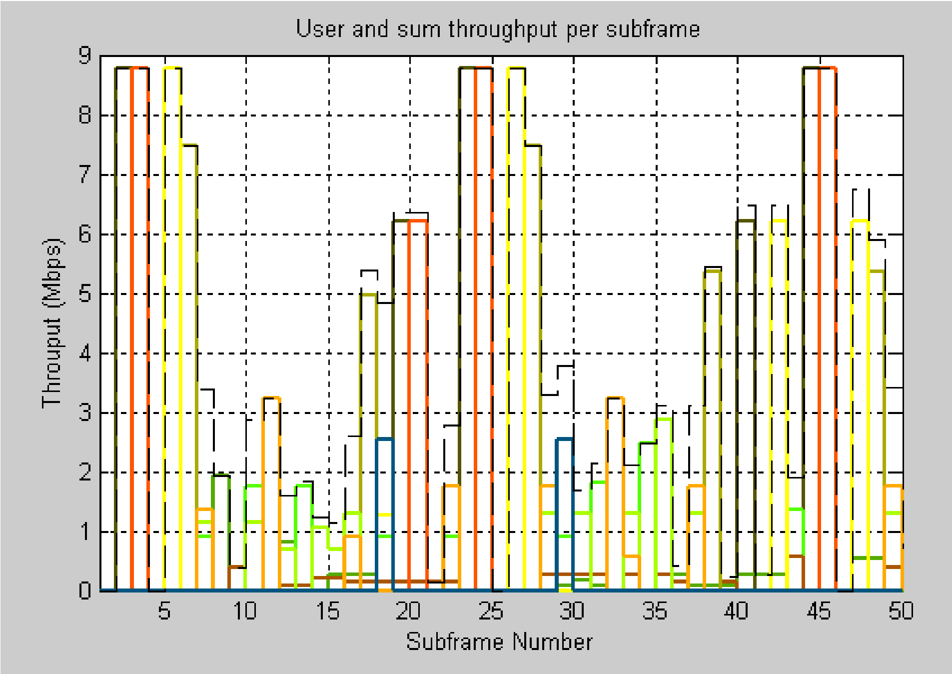


Figure. 5.19 Throughput per subframe Proportional Fair (PF) scheduling

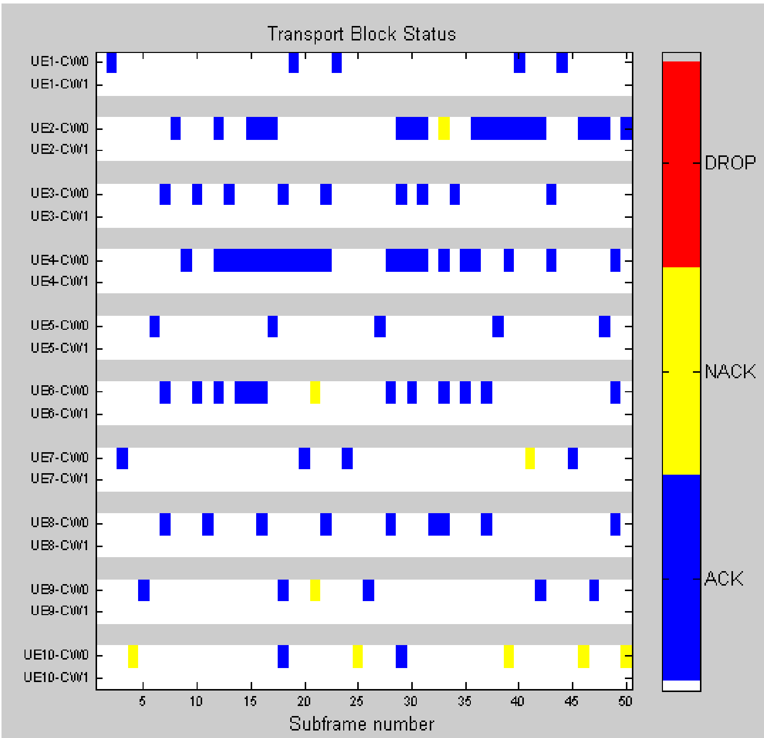


Figure. 5.20 Transport block status using Proportional Fair (PF) scheduling

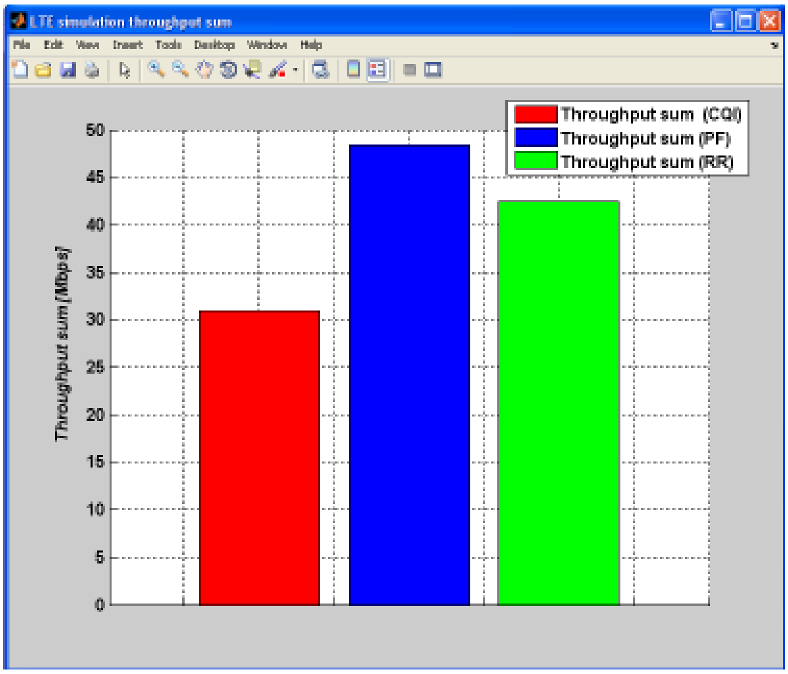


Fig. 5.21 Compare all scheduling

The comparison for three scheduling algorithm have been shown in above figure. The proportional fair scheduling has high throughput when compared to other two scheduling algorithm because of the assigning the resources in a fair way that all the users have experienced quality of service at minimal priority.

The round robin scheduling algorithm has average throughput because of the assigning of resources based on time slots giving each users a default time to use the network and the disadvantage is that the users have to abruptly stop using network because of the assigned time for each users this makes round robin scheduling weaker.

The channel quality indicator scheduling algorithm is the worst scheduling algorithm but it is widely used in the telecommunication industry. In this scheduling the users have a very few chances of using the network because of channel quality parameter value which is sent to eNode b from the base station at regular interval of times. If the channel is little bit low then the required level then the users will lose the quality of service and the network cannot be used by the users.

The Best CQI scheduling optimizes the user throughput by assigning the resource block to the user with the good channel quality. The Round Robin scheduling is fair in the long term since it equally schedules the user. We can see that the throughput of the PF scheduling is the highest. Best CQI scheduler is a very low fairness among the users, because this scheduler gives the resources only to the user with the best channel conditions. The users that have all the time a bad channel quality will be not scheduled at all. The PF scheduler has the best fairness among the users.

The next simulation was done for investigation the MOS dependences from different parameters. We evaluate $MOS \Rightarrow loss, CQI$ and $MOS \Rightarrow datarate, successfull\ transmission$.

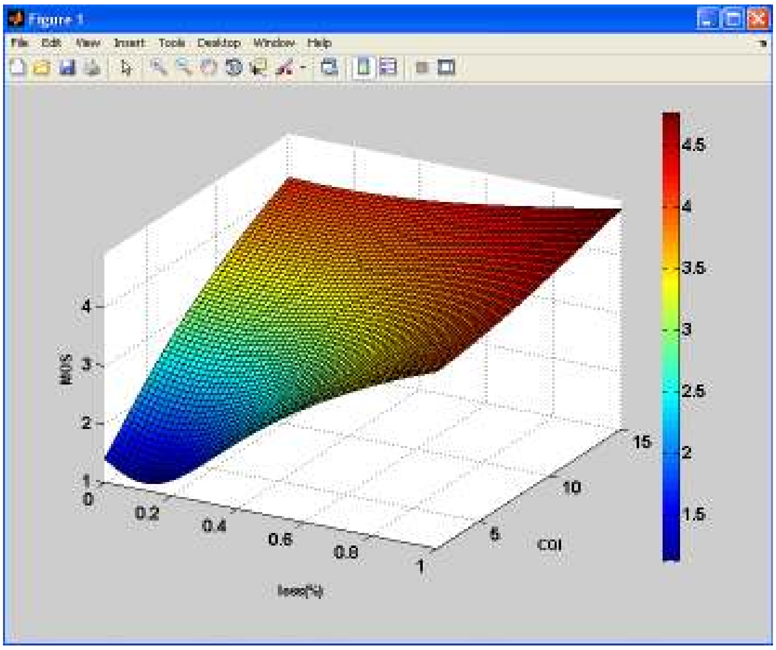


Figure. 5.22 QoE (MOS) evaluation using best CQI scheduling (loss, CQI)

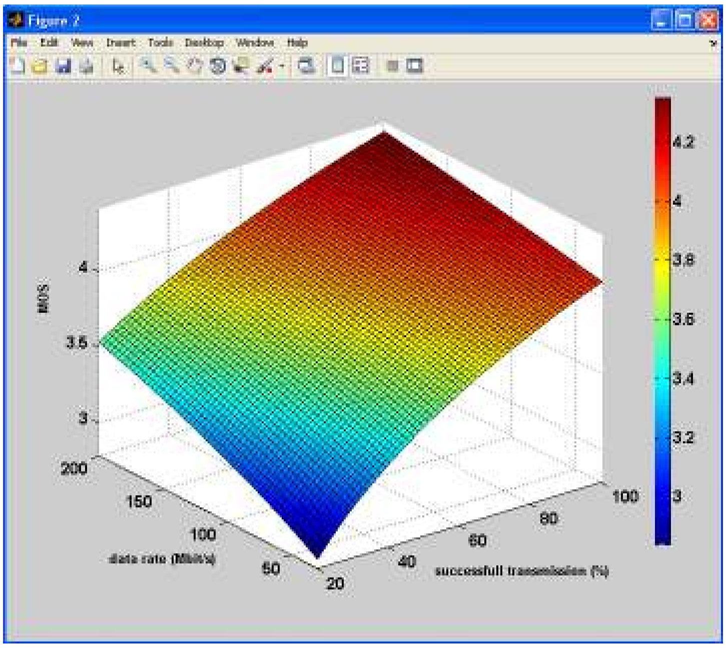


Figure. 5.23 QoE (MOS) evaluation using best CQI scheduling (data rate, successful transmission)

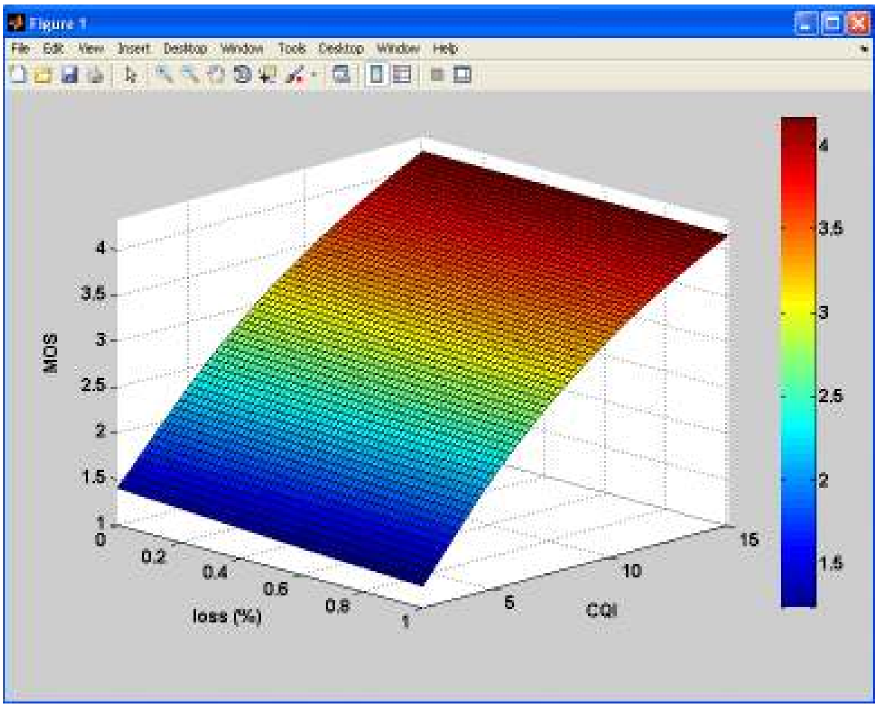


Figure. 5.24 QoE (MOS) evaluation using Proportional Fair (PF) (loss, CQI)

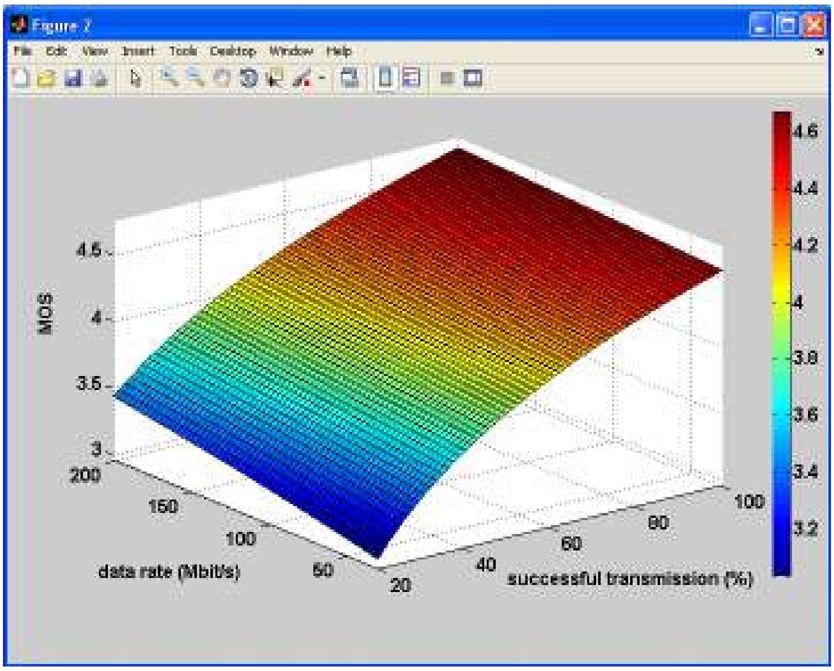


Figure. 5.25 QoE (MOS) evaluation using Proportional Fair (PF) scheduling (data rate, successful transmission)

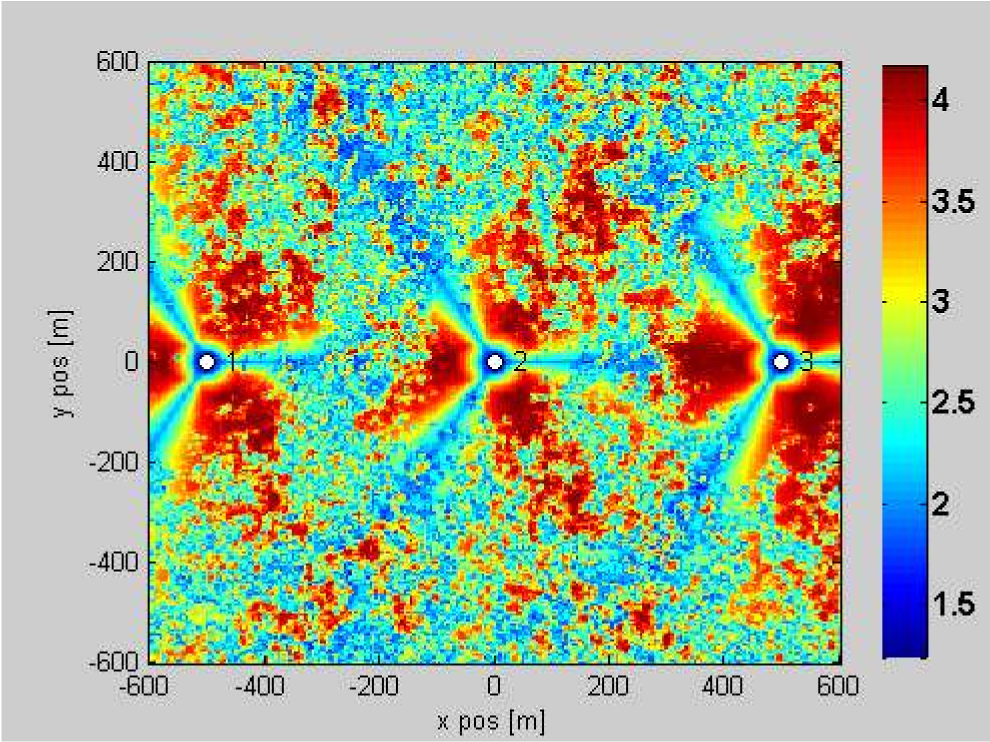


Figure. 5.26 User common QoE (MOS) evaluation in one cell

The mean opinion score increases when the channel quality parameter is increased and satisfied and it decreases the quality of experience of a user if the channel quality level is less than the required level which is sent to eNodeB. When the data rate is high the percentage of successful transmission is high and the quality of experience is high when compared to low data rate where the successful transmission is less and the user experiences low quality of service. The figure 5.22-5.25 illustrate, that CQI scheduling has sudden influence of QoE (MOS) the other scheduling.

6 Conclusion

1. If we want to favour the throughput we can improve the Best CQI scheduling and PF. But if we favour the fairness we can improve the new scheduling algorithm or Round Robin scheduling.
2. It is found that proportional fair will give very good data rate in most cases. Round robin provides the UE with good fairness but proportional fair maintain a balance between fairness and throughput and so, proportional fair may still be a better choice.
3. According to the simulation results the best scheduler between Round Robin, Proportional Fair and Best CQI in respect to the fairness, became the Proportional Fair algorithm. We observe the Proportional Fair scheduler assigning resources in terms of fairness in the beginning and then trying to balance the fairness and best throughput results for each user.
4. We can observe that Round Robin algorithm delivers fairness to all the users, the Best CQI algorithm has the Maximum throughput but not all users are able to enjoy the best speed and the Proportional Fair algorithm tries to strike a balance between fairness and achieving the Maximum throughput

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