بسم الله الرحمن الرحيم

Sudan University of Science & Technology

College of Graduate Studies

Performance Evaluation of Downlink Scheduling Algorithms in Long Term Evaluation (LTE) Network

تقويم اداء خوارزميات الجدولة للوصلة الهابطة في شبكات التطوير طويل الأمد

A thesis Submitted as Partial Fulfillment for Degree of M.Sc in Electronic Engineering (Communication)

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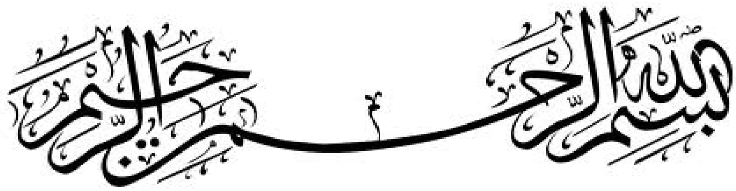

قـــال تــعــالــى:

﴿قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ﴾

الله العظيم صدق

سورة البقرة الآية (32)

Dedication

I dedicate this research to

My mother and father soul

My sisters and my brother

My teachers

My friends and my colleagues

Acknowledgments

First and for most thank to ALLAH for giving me mind and strength to carry out this research and for involve us with all blessings and givens.

I would like to express my sincere appreciation to my supervisor Dr. Mohamed Hussien Mohamed for his valuable guidance and advices throughout this work.

Special thanks go to those who helped me during simulation work, and research writing.

Abstract

Long Term Evolution is standardized by the 3rd Generation Partnership Project to provide a high data rate up to 100 Mbps and 50 Mbps for downlink and uplink transmission respectively and can operate in different bandwidths ranging from 1.4MHz up to 20MHz. To enhance system's data rate and ensure quality of service, the Radio Resource Management Scheduling Mechanisms plays a very crucial components to guarantee the Quality of Service performance for different services.

scheduler assigns the shared resources (time and frequency) among users terminal, in this thesis the focus is on the downlink scheduling. we modeled and evaluated the performance of Round Robin, Proportional Fairness and best channel quality indicator (CQI) scheduling algorithms. The performances are compared in term in throughput and bit error rate using MATLAB.

// المستخلص

تم وضع معيار التقويم طويل المدي بواسطه مشروع شراكة الجيل الثالث لتوفير سرعة نقل بيانات عالية تصل إلى 100 ميغا بت في الثانية و 50 ميغا بت في الثانية للوصلة الهابطة والوصلة الرافعة على التوالي، والتي تعمل في عرض نطاق ترددي مختلف يتراوح بين 1.4 ميقا هيرتز. لتحسين معدل نقل البيانات وضمان جودة الخدمة، فان 20هيرتز ويصل الى إدارة جدوله الموارد الراديوية تلعب دورا مهما وذلك لضمان جودة أداء الخدمة للخدمات المختلفة.

يقوم المجدول بتعين الموارد المشتركة (الوقت والتردد) بين المستخدمين، في هذه البحث تم تم تنفيذ ومحاكاة وتقييم أداء خوارزمية جولة روبن، .التركيز على جدولة الوصلة الهابطة خوارزمية نزيهة النسبي و خوارزمية أفضل مؤشر نوعية. تمت مقارنة الأداء في معدل الإنتاجية و معدل خطا الاشارة باستخدام برنامج الماتلاب .

List of contents

List of figures

List of tables

Abbreviation

3GPP	Third Generation Partnership Project
3GPP2	Third Generation Partnership Project 2
AAA	Authorization, Authentication and Accounting
AMC	Adaptive Modulation and Coding
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BS	Base Station
CDD	Cyclic Delay Diversity
CDMA	*Code Division Multiple Access*
CP	Cyclic Prefix
CQI	Channel Quality Indication
CS	Circuit Switch
DCI	Downlink Control Information
DFT	*Discrete Fourier transform*
DL	Downlink
eNB	Evolved Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency-Division Duplex
GSM	Global System for Mobile communications
HOL	Head of Line
HSS	Home Subscriber Server
ICI	Inter Carrier Interference
IFFT	Inverse Fast Fourier Transform
IMS	IP Multimedia Subsystem
ISI	Inter-Symbol Interference
LTE	Long-Term Evolution
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MMSE	Minimum Mean Square Error
NAS	Non-Access Stratum
OFDMA	Orthogonal Frequency Division Multiple Access
PAPR	Peak-to-Average Power Ratio
PCEF	Policy and Charging Enforcement Function
PCRF	Policy and Charging Rules Function

PDCCH	Physical Downlink Control Channel
PDN	Packet Data Network
Ped-B	Pedestrian-B
PF	Proportional Fair
PRBs	Physical Resource Blocks
PS	Packet Switched
QAM	*Quadrature Amplitude Modulation*
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RE	Resource Element
RR	Round Robin
SC-FDMA	Single Carrier Frequency Division Multiple Access
SGW	Serving Gateway
SINR	Signal-to-Interference-plus-Noise Ratio
SISO	Single Input Single Output
SNR	Signal-to- Noise Ratio Power
SM	Spatial Multiplexing
TDD	Time- Division Duplex
TTI	*Transmission Time Interval*
TxD	Transmit Diversity
UE	*User Equipment*

CHAPTER ONE

INTRODUCTION

1.1Background

In the recent years, the world was introduced to mobile broadband. Multimedia applications through the Internet have gathered more attention. Applications such as live streaming, online gaming and mobile TV are require higher data rate.

Various technology standards bodies began to explore options for their 4G wireless technology offerings. Two groups, the Third Generation Partnership Project (3GPP), representing the family of networks generally referred to as GSM, and the Third Generation Partnership Project 2 (3GPP2), representing the family of networks generally referred to as CDMA, are working together to lay the foundation for LTE.

In December 2008, the LTE specification was published as part of Release 8. The initial deployment of LTE was expected in 2009. The first release of LTE namely release-8 [1,2].

LTE provides a high data rate up to100 Mbps in downlink (DL) and can operate in different bandwidths ranging from 1.4MHz to 20MHz. Indeed, advantages of LTE design are higher user bit rates, lower delays, increased spectrum efficiency, reduced cost and operational simplicity. To gain these goals LTE uses several technologies, which include Orthogonal Frequency Division Multiple Access (OFDMA) [3], Single Carrier Frequency Division Multiple Access (SC-FDMA) [4] and Multiple Input Multiple Output (MIMO) [5]. LTE uses OFDMA for downlink and SC-FDMA for uplink transmission [6].

To optimize system performance, scheduling divides and allocates radio resources among different users simultaneously, keeping quality of service (QoS).Scheduling algorithms is employed to select different users in time domain and different Physical Resource Blocks (PRBs) in frequency domain depending on the available RB and bandwidth requirements of the user while ensuring fairness and minimum delay.

In this thesis, the key design aspect of LTE scheduling and the performance analysis of three existing algorithms Round Robin, Best CQI and Proportional Fair are given under variable conditions and accordingly, the variation in their results in terms of the performance metrics like throughput, packet loss, delay time, spectral efficiency, fairness etc.

In Round Robin scheduling algorithm, the UEs are assigned the resources in round-robin fashion, without taking into account channel conditions. Best CQI algorithm allocates the resource blocks to the UEs with highest CQI on RB during a TTI [7], Round-Robin algorithm offers fairness with respect to time to all UEs, but it is less efficient with respect to throughput because it doesn’t take into account channel variations. The Best CQI algorithm is efficient, but it is not fair to all users. The UEs, such as those at the cell edges, which face bad channel conditions, will always not get RBs allocated. Hence such users always starve of radio resources, which is practically not acceptable. So, fairness should also be taken into account along with focus on spectral efficiency.

In [8], the Proportional Fair for the fair scheduling algorithms is made, in which RB allocation is done to all chosen UEs in a TTI, selecting UEs one after another starting from the one with highest CQI onwards in order. Once a UE gets RB, it is not assigned further till other users are assigned RBs or tilling [8] and explores the possibility of improving overall throughput of the cell, besides maintaining fairness to users. The performance of three algorithms is investigated using a MATLAB based LTE link level simulator.

1.2Problem statement

LTE technology presents a very challenging multiuser problem: Several User Equipment (UEs) in the same geographic area require high data rates in a finite bandwidth with low latency

1.3Objectives

The purpose of this thesis is how to divides and allocates radio resources among different users simultaneously. We implement and simulate the downlink scheduling in LTE. We have also investigated the impact of the scheduling algorithms on the throughput and on the bit error rate.

1.4 Motivation

The motivation to work on this project comes from the fact that LTE is the future of mobile broadband. It is expected that in the future 80% of all mobile broadband users will be served by LTE [9]. The time and frequency are scared resources. The scheduler is a key element in the BS since it determines to which users the resource blocks should be assigned.

The resource allocation algorithms for scheduling improve the performance of by increasing the spectral efficiency at the wireless interface and consequently enhancing the system capacity.

In this thesis ,Round Robin scheduling, best CQI scheduling and Proportional Fair have been selected because of their characteristics.

1.5 Project Methodology

LTE System Level Simulator [10] is used to evaluate the performance of the three scheduling algorithms, Round Robin, Best CQI, and Proportional Fair. The simulator is MATLAB-based and implements a standard compliant LTE downlink. It can carry out simulations in downlink, single-cell and multi-user scenarios.

1.6 Thesis Outline

The thesis is consist of five chapters, in chapter one an introduction along with problem statement, motivation, objectives and project methodology are included, while in chapter two includes a study and analysis to LTE structure and explains the related work one the downlink scheduling algorithms in LTE, in chapter three the methodology is included, while chapter four presents the simulation results, in the last chapter the draws the conclusion and gives recommendations for future works.

CHAPTER TWO

LITERATURE REVIEW

2.1 LTE Overview

The Long Term Evolution (LTE) is standardized by the 3GPP in Release 8 for the development of wireless broadband networks with very high data rates [2] .LTE provides better services to mobile users who need a lot of bandwidth for multimedia applications such as live streaming, online gaming, and mobile TV.

2.2 LTE Specification

To achieve its goals, LTE must satisfy the following specification [4, 11] shown in table

Table (2.1): specification of LTE

Parameter	**Value**
Data rate (SISI, 20 MHz)	100 Mb/s downlink ,50 Mb/s uplink
Maximum data rate	300Mb/s (20 MHz, 4x4 MIMO) **75**Mb/s (20 MHz, 64QAM)
Maximum user per cell	200
Channel bandwidth	1.4 MHz up to 20 MHz
Duplex scheme	FDD and TDD
Spectrum Efficiency	Downlink 3 to 4x HSDPA Rel.6 Uplink 2 to 3x HSDPA Rel.6
Modulation type	Downlink :QPSK, 16QAM and 64 QAM Uplink:QPSK,16QAMand 64 QAM (optional)
Parameter	**Value**
Access scheme	OFDMA (downlink)& SC-FDMA (Uplink)
Supported antenna configuration	Downlink: 4x2, 2x2, 1x2, 1x1 Uplink: 1x2, 1x1

Latency	Idle to active less than 100 ms Small packet ~ 10ms
Coverage	Full performance up to 5 Km Slight degradation 5Km-30Km

2.3 LTE Standards

The 3G evolution continued in 2004, when a workshop was organized to initiate work on the 3GPP Long-Term Evolution (LTE) radio interface. The result of the LTE workshop was that a study item in 3GPP TSG RAN was created in December 2004. The first 6 months were spent on defining the requirements, or design targets, for LTE. These were documented in a 3GPP technical report and approved in June 2005. Most notable are the requirements on high data rate at the cell edge and the importance of low delay, in addition to the normal capacity and peak data rate requirements. Furthermore, spectrum flexibility and maximum commonality between FDD and TDD solutions are pronounced. During the fall of 2005, 3GPP TSG RAN WG1 made extensive studies of different basic physical layer technologies and in December 2005 the TSG RAN plenary decided that the LTE radio access should be based on OFDM in the downlink and DFT-preceded OFDM in the uplink. TSG RAN and its working groups then worked on the LTE specifications and the specifications were approved in December 2007 [1,2]. Work has since then continued on LTE, with new features added in each release, as shown in Figure2.1

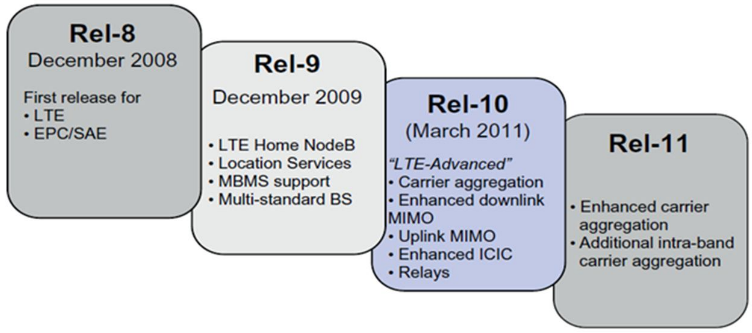

Figure (2.1) LTE Standards Releases

2.4 Network Architecture

Figure 2.2 shows the LTE network reference model, which is a logical representation of the network architecture. The network reference model identifies the functional entities in the architecture and the reference points between the functional entities over which interoperability is achieved.

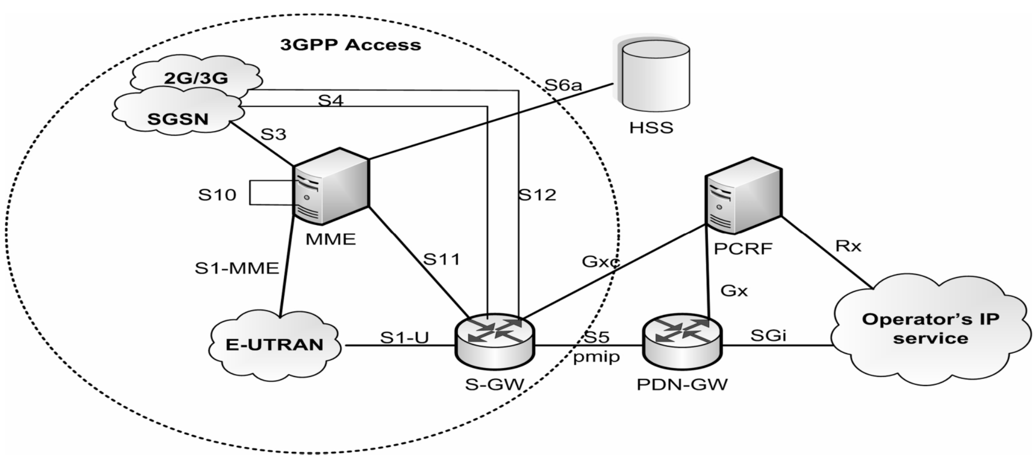

Figure (2.2) LTE reference model

The overall architecture has two distinct components: the access network and the core network. The access network is the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) [12]. The core network is

all-IP core network and is fully Packet Switched (PS). Services like voice, which are traditionally Circuit Switched (CS), will be handled using IP Multimedia Subsystem (IMS) network. The core network is called the Evolved Packet Core (EPC). Network complexity and latency are reduced as there are fewer hops in both the signaling and data plane. The EPC is designed to support non-3GPPP access supports for mobile IP. To improve system robustness security, integrity protection, and ciphering have been added and represented by Non-Access Stratum (NAS) plane, which is an additional layer of abstraction to protect important information like key and security interworking between 3GPP and non-3GPP network [13]. Apart from the network entities handling data traffic, EPC also contains network control entities for keeping user subscription information represented by Home Subscriber Server (HSS), determining the identity and privileges of a user and tracking his/her activities, i.e., Authorization, Authentication and Accounting (AAA) server, and enforcing charging and QoS policies through a Policy and Charging Rules Function (PCRF). Note that E-UTRAN and EPC together constitute the Evolved Packet System (EPS).
The following are the key functional nodes/network elements in the LTE architecture:

2.4.1 Evolved Node B (eNB)

- eNodeB is the entity that supports air interface and performs radio resource management
- Provides radio resource management functions such as IP header compression, user data encryption, and routing the user date to the Serving Gateway
- The radio interface provided by eNodeB can be shared by several operators by having separate MME, SGW & PDN Gateway.

2.4.2 Serving Gateway (SGW)

- It serves as the mobility anchor for the user plane.
- It takes care of inter-eNodeB handovers & User Equipment (UE) mobility between 3GPP networks.
- It is responsible for routing/forwarding data packets between the eNodeB& PDN Gateway

2.4.3 Packet Data Network Gateway (PDN GW)

- It provides the UE with connectivity to the external packet data networks such as Internet.
- It serves as the anchor point for intra-3GPP network mobility, as well as mobility between 3GPP and non-3GPP networks.
- It takes care of Policy and Charging Enforcement Function
- (PCEF), which includes Quality of Service (QoS), online/offline flow-based charging data generation, deep-packet inspection, and lawful intercept.

2.4.4 Mobility Management Entity (MME)

- It manages mobility, UE identities and security parameters
- It operates in the Control plane and provides functions such as managing session states, authentication, mobility with 3GPP 2G/3G nodes, and roaming.

2.5 OFDMA and SC-FDMA

LTE has selected orthogonal frequency division multiple access (OFDM) in the downlink and single-carrier frequency-division multiple access (SC-FDMA) in the uplink.

OFDMA is a multiple access scheme based on the well-known orthogonal frequency-division multiplexing (OFDM) modulation technique. Its main principle is to split the data stream to be transmitted onto a high number of narrowband orthogonal subcarriers by means of an inverse fast Fourier transform (IFFT) operation, which allows for an increased symbol period. The latter, together with the use of a guard interval appended at the beginning of each OFDM symbol, provides this technology great robustness against multipath transmission [4,13]. A realization of this guard interval is the so-called cyclic prefix (CP), which consists of a repetition of the last part of an OFDM symbol. As long as the CP is longer than the maximum excess delay of the channel, degradations due to intersymbol interference (ISI) and intercarrier interference (ICI) are avoided. Furthermore, the goal of employing narrowband subcarriers is to obtain a channel that is roughly constant over each given sub band, which makes equalization much simpler at the receiver. Finally, since these subcarriers are mutually orthogonal, overlapping between them is allowed, yielding a highly spectral efficient system. Despite all these benefits, OFDM also presents some drawbacks: sensitivity to Doppler shift, synchronization problems, and inefficient power consumption due to high PAPR.

SC-FDMA is a multiple access scheme based on the single-carrier frequency-division multiplexing (SC-FDM) modulation technique, sometimes also referred to as discrete Fourier transform (DFT)-spread OFDM. Its main principle is the same as for OFDM; thus, the same benefits in terms of multipath mitigation and low-complexity equalization are achievable. The difference though is that a DFT is performed prior to the IFFT operation, which spreads the data symbols over all the subcarriers carrying information and produces a virtual single- carrier structure. As a consequence, SC-FDM presents a lower PAPR than OFDM. This property makes SC-FDM attractive for uplink transmissions, as the user equipment (UE) benefits in terms of transmitted power efficiency [4,12,13]. On one hand, DFT spreading allows the frequency selectivity of the channel to be exploited, since all symbols are present in all subcarriers. Therefore, if some subcarriers are in deep fade, the information can still be recovered from other subcarriers experiencing better channel conditions. On the other hand, when DFT dispreading is performed at the receiver, the noise is spread over all the subcarriers and generates an effect called noise enhancement, which degrades the SC-FDM performance and requires the use of a more complex equalization based on a minimum mean Square error (MMSE) receiver.

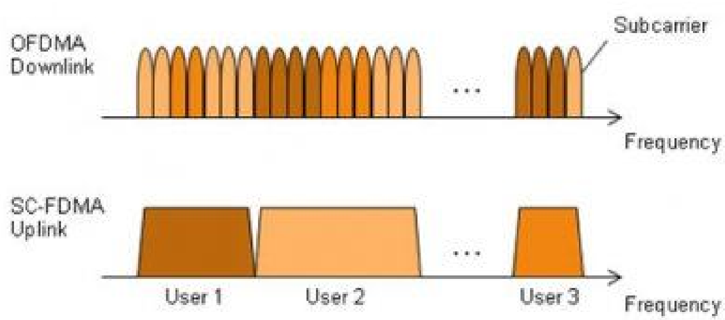

Figure (2.3): OFDMA and SC-FDMA

2.6 Spectrum Flexibility

LTE communication is available in different frequency bands, of different sizes. Furthermore the communication can take place both in paired and unpaired bands. Paired frequency bands means that the uplink and downlink transmissions use separate frequency bands, while unpaired frequency bands downlink and uplink share the same frequency band. In LTE, downlink and uplink transmissions are grouped into radio frames of length 10 milliseconds (ms). Each radio frame is divided into 10 sub frames of 1ms duration, which each sub frame is further divided into 2 slots of 0.5 ms duration. Each slot consists of 7 or 6 OFDM symbols for normal or extended cyclic prefix, respectively [14].

The LTE frame structure is illustrated in the Figure 2.5

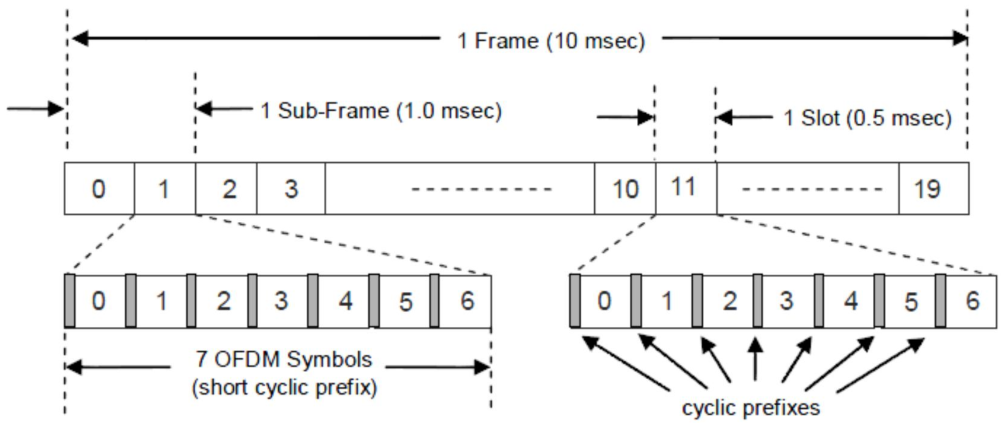

Figure (2.4):LTE Frame structure

The spectrum is very flexible and allows LTE to use different bandwidths ranging from1.4 MHz to 20 MHz. The larger the bandwidth is, the higher LTE data rates.

2.7 Downlink physical resource

Orthogonal Frequency Division Multiplex (OFDM) is the core of LTE downlink transmission [15] .The smallest modulation structure in LTE is one symbol in time vs. one subcarrier in frequency and is called a Resource Element (RE).REs are further aggregated into Resource Blocks (RB), with the typical RB having dimensions of 7 symbols by 12 subcarriers. The number of symbols in a RB depends on the Cyclic Prefix (CP) in use. During the use of normal CP, the RB contains seven symbols, whereas in the case of extended CP, which is used due to extreme delay spread or multimedia broadcast modes, the RB contains six symbol [14].It is a straightforward to see that each RB has 12x7 = 84 resource elements in the case of normal cyclic prefix and12x6 = 72 resource elements in the case of extended cyclic prefix.

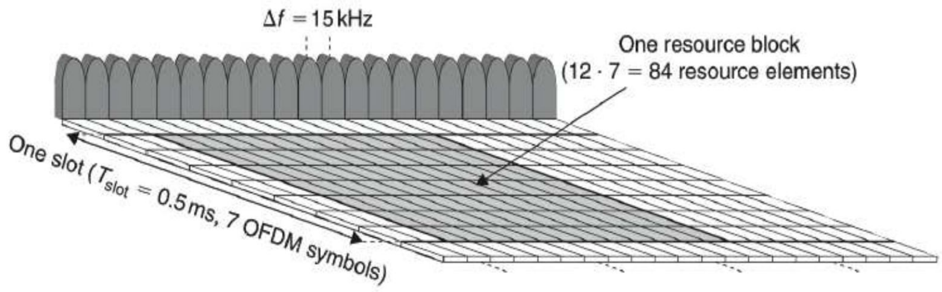

Figure (2.5): LTE downlink physical resource based on OFDM

The resource grid refers to a number of resource blocks in the available bandwidth [16] .The number of RB in are source grid varies according to the size of the bandwidth. The number of sub-carriers in the 180 kHz span is 12 for 15 kHz sub-carrier spacing.

2.7.1 Downlink reference signals

Reference symbols (reference signals) are embedded in the Physical resource block (PRB) which is used to perform channel estimation, as shown in Figure 2.7. Reference signals are inserted in the first and fifth OFDM symbols of each slot in the case of the short CP and during the first and fourth OFDM symbols in the case of the long CP. Thus there are four reference symbols within one PRB.

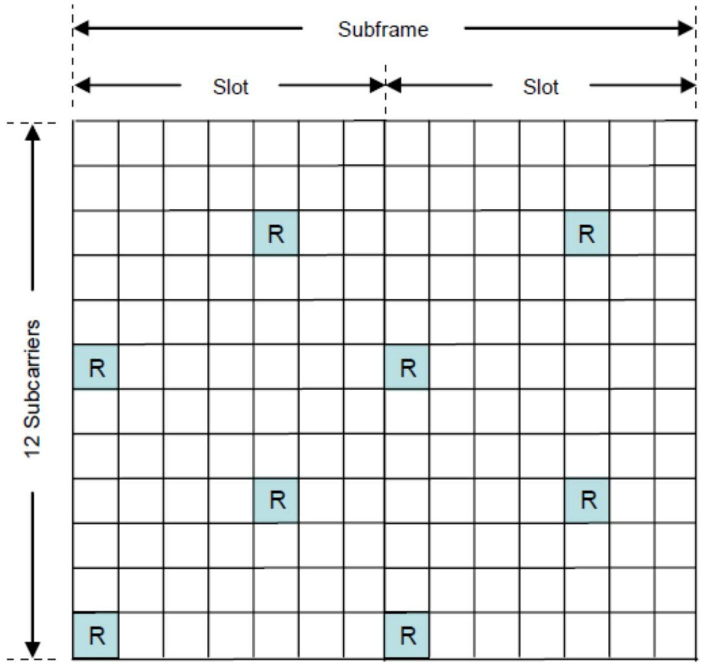

Figure (2.6): reference signal

2.8 MIMO Technology

Multiple-input and multiple-output (MIMO) is when a radio system has multiple antennas in both the transmitter and the receiver. This way is possible to achieve a greater performance. This is done by exploiting the multipath propagation behavior of telecommunication signals [5].

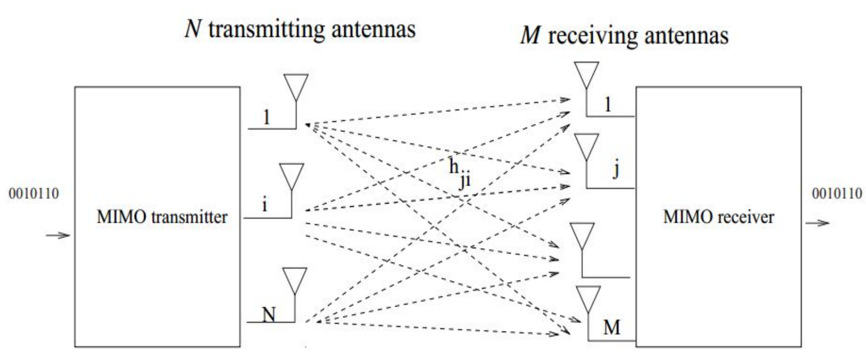

Figure (2.7) MIMO Technology

The MIMO system in LTE presents the following features:

- Transmit Diversity (TxD): On Transmit Diversity mode, the transmitter will send copies of the same data stream by each antenna. This will introduce redundancy on the system. This redundancy makes possible to reduce fading and also have a better signal-noise ratio (SNR) at the receiver. Since all the antennas are transmitting the same information there is no increase in data speed

- Spatial Multiplexing (SM): On Spatial Multiplexing mode, the transmitter will send different signal by each antenna. Exploiting the fact that each signal from each antenna will go through a different path to get to the receiver it is possible to exploit that in order to reconstruct the signal on the receiver. Since there are many signals being transmitted in parallel it becomes possible to get higher data rates, but no diversity gains will be obtained. It is important to remind that it is possible only because each signal goes through a different path, but since in real world there will be path correlations, that will be a big constrains in order to operate in this mode.

- Beam forming: An antenna array with closely spaced elements is used to focus de energy in the direction of the terminal. This is achieved by adapting the amplitude and gain of each antenna element to form the beam.

- Cyclic Delay Diversity (CDD): It is the increase of a delay in each signal by adding antenna specific cyclic shifts. Those results in an additional multipath behavior increasing frequency diversity what will reduce inter symbol interference and improve SNR.

2.9 LTE Scheduling Mechanisms

The design of LTE downlink scheduler is a complex process and it poses a number of challenges such as - maximization of system capacity, ensuring fairness to all users, QoS provisioning, reducing complexity etc. A good scheduler should be capable of exploiting fast variations in channel conditions, besides maintaining fairness between the users.

The scheduler entity have a role to assigns resources blocks every TTI, based on the channel condition feedback received from User Equipment in the form of Channel Quality Indicator (CQI) send by the UEs to the eNodeB, to indicate the data rate supported by the downlink channel. Every value of CQI, index in the range 1 to 15, corresponds to the highest Modulation and Coding Scheme (MCS) and the amount of redundancy included [17]. Using the OFDMA technique in LTE system, the resource allocation is done in time and frequency domain

2.9.1 Procedure of Downlink Scheduling

In LTE system, the scheduling algorithms assume that the eNodeB would receive the CQI feedback, every TTI, as a matrix with dimensions Number_UEs x RB_grid_size. The value of each field in the matrix is the CQI feedback of each user for each RB.

	RB_1	RB_2			RB_m
UE_1	$M_{1.1}$	$M_{1.2}$	. . .		$M_{1.1}$
UE_2	$M_{2.1}$	$M_{2.2}$	. . .		$M_{1.1}$
	: .	: .			: .
UE_n	$M_{n.1}$	$M_{n.2}$			$M_{n,m}$

Figure(2.8): Metric values for each user and each RB

For example the k-th RB is allocated to the j-th user if its metric mj;k is the largest one among all i-UEs, i.e., if it satisfies the equation:

$$m_{j;k} = \max_i \{m_{i;k}\} \qquad (2.1)$$

The whole process of downlink scheduling can be divided in a sequence of operations that are repeated, in general, every TTI (see figure 2.10):

1) The Evolved Node B prepares the list of flows which can be scheduled in the current TTI .Flows could be formulated only if there are packets to send at MAC layer and UE at receiving end is not in the idle state.

2) Each UE decodes the reference signals, reports CQI (Channel Quality Indicator) to eNB which helps to estimate the downlink channel quality. The eNB can configure if the CQI report would correspond to the whole downlink bandwidth or a part of it which is called sub-band.

3) Then the chosen metric is computed for each flow according to the scheduling strategy using the CQI information. The sub-channel is assigned to that UE that presents the highest metric.

4) For each scheduled flow, the eNB computes the amount of data that will be transmitted at the MAC layer i.e. the size of transport block during the current TTI. The AMC (Adaptive Modulation and Coding module) at MAC layer selects the best MCS (Modulation and Coding Scheme) that should be used for the data transmission by scheduled users. Link adaptation involves tailoring the modulation order (QPSK, 16-QAM, 64-QAM) and coding rate for each UE in the cell, depending on the downlink channel conditions.

5) Physical Downlink Control Channel (PDCCH) is used to send the information about the users, the assigned Resource Blocks, and the selected MCS to terminals in the form of DCI (Downlink Control Information).

6) Each UE reads the PDCCH payload .If a particular UE has been scheduled; it will try to access the proper PDSCH payload [18]

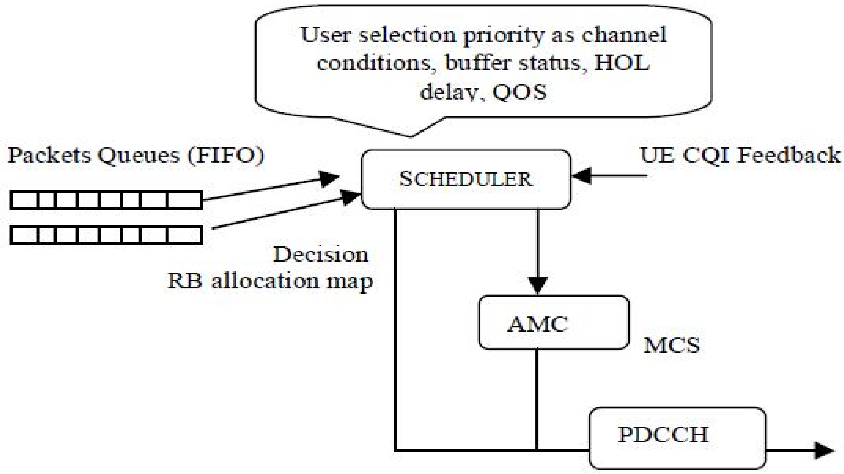

Figure (2.9): General Model of packet scheduler

The users are prioritized by packet scheduler on the basis of a scheduling algorithm being used. These algorithms while making scheduling decisions, takes into account the instantaneous or average channel conditions, Head of Line (HOL) packet delays, status of receiving buffer or type of service being used [19].

2.10.2 Downlink Resource Scheduling Algorithms

In LTE cellular network, there are three basic scheduling algorithms. These algorithms are compared in term of fairness and overall throughput. These schedulers are the basic Round Robin, the best CQI and the Proportional Fair.

The Round Robin allocates resources to each UE, completely neglecting channel quality or data rate. Initially, the terminals are ordered randomly in a queue. The new terminals are inserted at the end of the queue. The first terminal of this queue is assigned all the available resources by scheduler, and then put it at the rear of the queue. The rest of steps follow the same way, until no terminal applies for resources.

The metric of i-th user on the *k*-th RB can be translated from its behavior as

$$m_{j;k} = t - Ti \qquad (2.2)$$

Where t is the current time and *Ti* refers to the last serving time instant of the user.
On one hand, it seems to be a fair scheduling, since every terminal is given the same amount of resources. On the other hand, it neglects the fact that certain terminals in bad channel conditions need more resources to carry out the same rate, so it is absolutely unfair. This scheme is impractical in LTE because different terminals have different service with different QoS requirements [20].

The best CQI, every TTI, to the user having the largest SNR, so users that have the fading peak are likely to be scheduled all the time, while other that experience deep fades are not scheduler at all. Best CQI scheduler has to maximize system throughput but it totally ignores fairness. The received SNR of then^{th} RB signal of thek^{th}user at the t^{th}TTI can be expressed by[21,22]:

$$SNR_{k,n}(t) = \frac{S_{k,n}(t)H_{k,n}(t)}{NoB/N} \qquad (2.3)$$

Where are $S_{k,n}(t)$, $H_{k,n}(t)$the allocated transmission power and channel gain on n^{th}sub-carrier at t^{th}TTIrespectively, $No$is the power spectral density of AWGN, B is the bandwidth and N is the number of sub-carriers.The instant data rate of each user is determined and the BS serves each user at this rate. The instant service rate on the *nth* sub-carrier att^{th} TTI is got by

$$R_{k,n}(t) = B/N \log_2(1 + SNR) \tag{2.4}$$

Where,$R_{k,n}(t)$is the K^{th}user transmission rate at t^{th} time slot, *B* is the total bandwidth and *N* is the number of subcarriers [23,24].

The Proportional Fair scheduler provides balance between fairness and the overall system throughput. PF algorithm function as follows: the eNodeB received the feedback of the instantaneous channel quality condition (CQI), in terms of a requested data rate $R_{k,n}$ (t), for each user ***k*.** Then, it keeps track of the moving average throughput $T_{k,n}$ $(t)$of each UE ***k*** on every physical resource block (PRB) ***n*** in a past window of length ***tc***. In time slot ***t***, the Proportional Fair scheduler gives apriority to the UE ***K**** in the t^{th}time slot and PRB ***n*** that satisfy the maximum relative channel quality condition:

$$K^* = \frac{R_{k,n}(t)}{T_{k,n}(t)} \tag{2.5}$$

Where,$R_{k,n}(t)$,***n*=*1*,*2*,…,*N*** is instantaneous data rate of k^{th}user in t^{th}TTI and n^{th}Resource Block.

The average throughputs

$$T_{k,n}(t+1) = \begin{cases} \left(1 + \frac{1}{t_c}\right) T_{k,n}(t) \frac{1}{t_c} R_{k,n}(t) & k = k^* \\ \left(1 + \frac{1}{t_c}\right) T_{k,n}(t) & k \neq k^* \end{cases} \tag{2.6}$$

The length of the window size $t_c$parameters controls the system latency. It means the trade-off between fairness and throughput. The larger value of $t_c$is t_c=∞, in this situation the allocation resources according to PFS algorithm is decided solely by instantaneous SNR, leading to maximum system throughput and poor fairness characteristics. In this case, the

Proportional Fair scheduler approaches Maximum Rate algorithm. On the other hand, the lower value of $t_c$parameter is t_c =1in this situation scheduling becomes fair [21, 22] and approaches the Round Robin algorithm

CHAPTER THREE

METDOLOGY

3.1 Best Channel Quality Indicator

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 RB. The MS must feedback the Channel Quality Indication (CQI) to the BS to perform the Best CQI. In order to perform scheduling, terminals send Channel Quality Indicator (CQI) to the base station (BS). Basically in the downlink, the BS transmits reference signal (downlink pilot) to terminals. These reference signals are used by UEs for the calculation of the CQI. A higher CQI value means better channel condition [6,8,14,21,25,26,27].

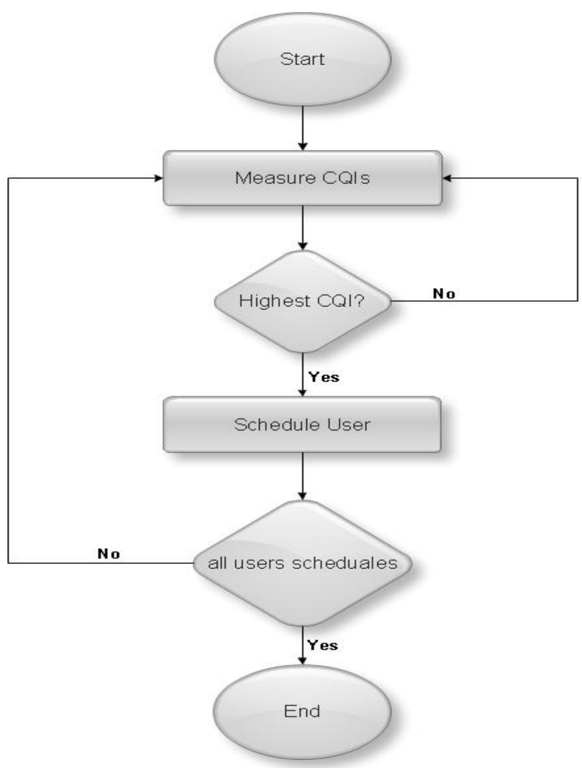

Figure: (3.1) Best CQI flow Chart

3.2 Round Robin

The 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. In Round Robin (RR) scheduling the terminals are assigned the resource blocks in turn (one after another) without considering CQI. 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 [6,8,14,21,25,26,27,].

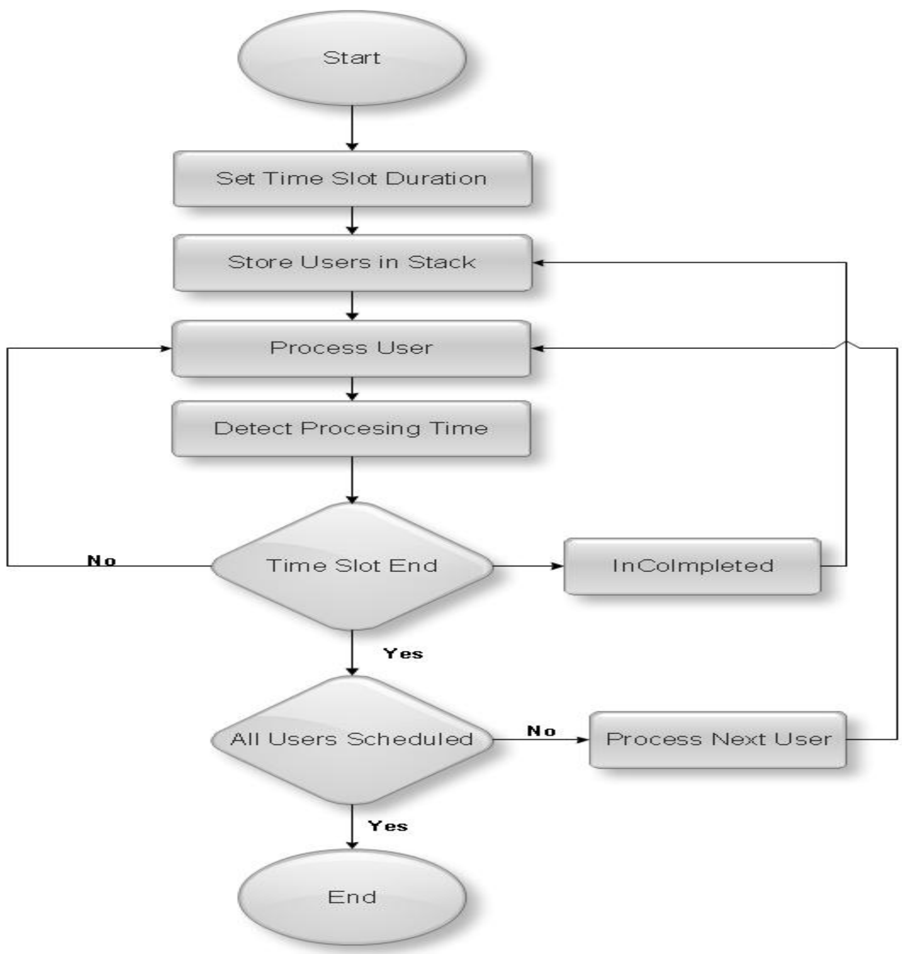

Figure (3.2) Round Robin flow chart

3.3 Proportional Fair

This algorithm allocates more resources to a user with relatively better channel condition. For scheduling users, this algorithm not only considers channel condition but also tries to maintain fairness among the users. Therefore, the highest throughput of cell together with degree of fairness is provided. 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. Thus, Proportional Fair (PF) scheduling may be the best option [6,8,14,21,25,26,27].

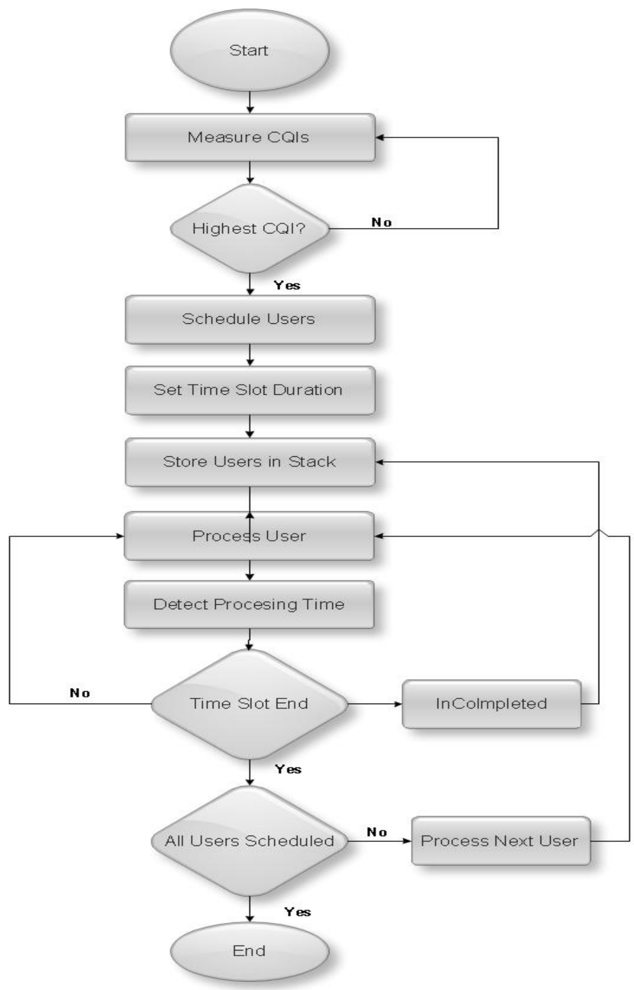

Figure (3.3): Proportional Fair flow chart

3.4 Simulation Scenarios

In this project four scenarios were implemented to evaluate the performance of the long term evolution (LTE) scheduling algorithms.

The selected scheduling algorithms are Best-CQI, Round Robin and proportional fair, the simulation parameters used in this project illustrated on the following table

Table (4.1): simulation parameters

Parameters	Value
Channel type	ITU-Pedestrian B
Number of Base station	1
Scheduling Algorithms	Round Robin Best CQI Proportional Fairness
Number of users	5,10,15
Bandwidth (MHz)	1.4,3,5
Numbers of subframes	100
Transmission mode	SISO

3.4.1 Scenario no I

In this scenario the number of users is set to 5 with a bandwidth of 1.4 MHz, and the system was evaluated in term of Signal to noise ratio to throughput.

In the same scenario the number of users is set to 10 users with the same bandwidth configuration 1.4 MHz also the scenario include an increasing of users to 15 user.

A comparison between all three different user settings was done in term of the SNR to Throughput for all three algorithms.

3.4.2 Scenario no II

In this scenario the number of users is set to 5 with a bandwidth of 3.0 MHz, and the system was evaluated in term of Signal to noise ratio to throughput.

In the same scenario the number of users is set to 10 users with the same bandwidth configuration 3.0 MHz also the scenario include an increasing of users to 15 users.

A comparison between all three different user settings was done in term of the SNR to Throughput for all three algorithms.

3.4.3 Scenario no III

In this scenario the number of users is set to 5 with a bandwidth of 5.0 MHz, and the system was evaluated in term of Signal to noise ratio to throughput.

In the same scenario the number of users is set to 10 users with the same bandwidth configuration 5.0 MHz also the scenario include an increasing of users to 15 user.

A comparison between all three different user settings was done in term of the SNR to Throughput for all three algorithms.

3.4.4 Scenario no IV

In this scenario the number of users is set to 15 with a bandwidth of 1.4, 3.0 and 5 MHz, and the system was evaluated in term of Signal to noise ratio to bit error rate.

A maximum number of users were set to 15 users as a worst case and a comparison of all three algorithms with different bandwidth, settings was done in term of the SNR to bit error rate for all three.

CHAPTER FOUR

RESULT AND DISSCUSSION

A simulation was made using MATLAB programming environment, three scheduling algorithms has been selected to be evaluated including Best-CQI, Round Robin and Proportional Fair .The simulations are carried out for frequency-selective channels modeled by ITU for Pedestrian-B (Ped-B) channels. Simulations are performed for 5, 10 and 15 users, choosing the bandwidths of 1.4, 3 and 5 MHz .A single cell, multi-user scenario is chosen for simulation.

4.1Results of Scenario No.1

In the following graphs represent the result of the signal to noise ratio to the throughput, the x axes represent the SNR in dB and the y axes represent the throughput in Mbps, a comparison of three algorithms were done to evaluate the system throughput for each.

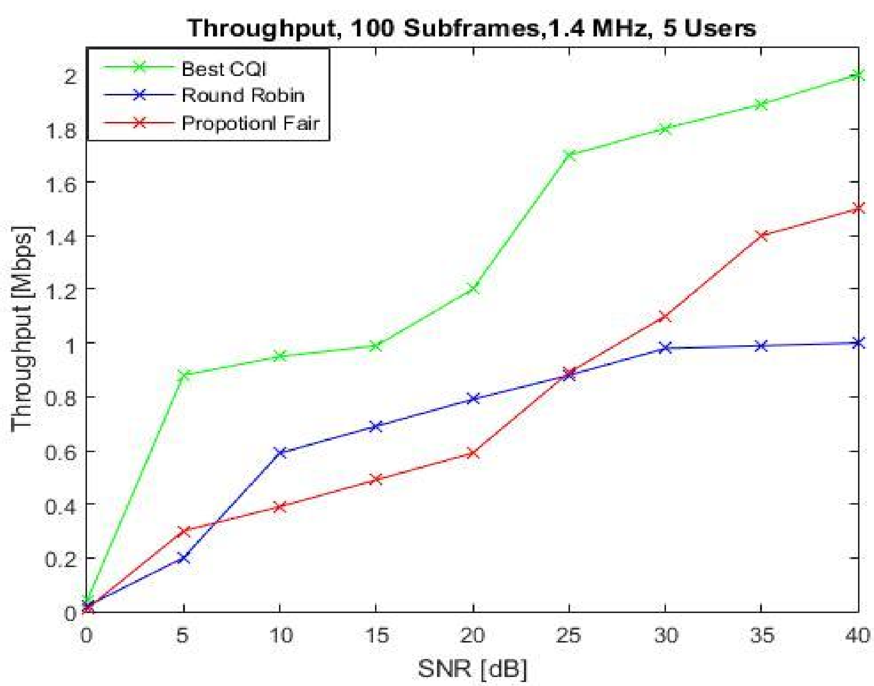

Figure (4.1): Throughput vs. SNR at 1.4 MHz and Five Users

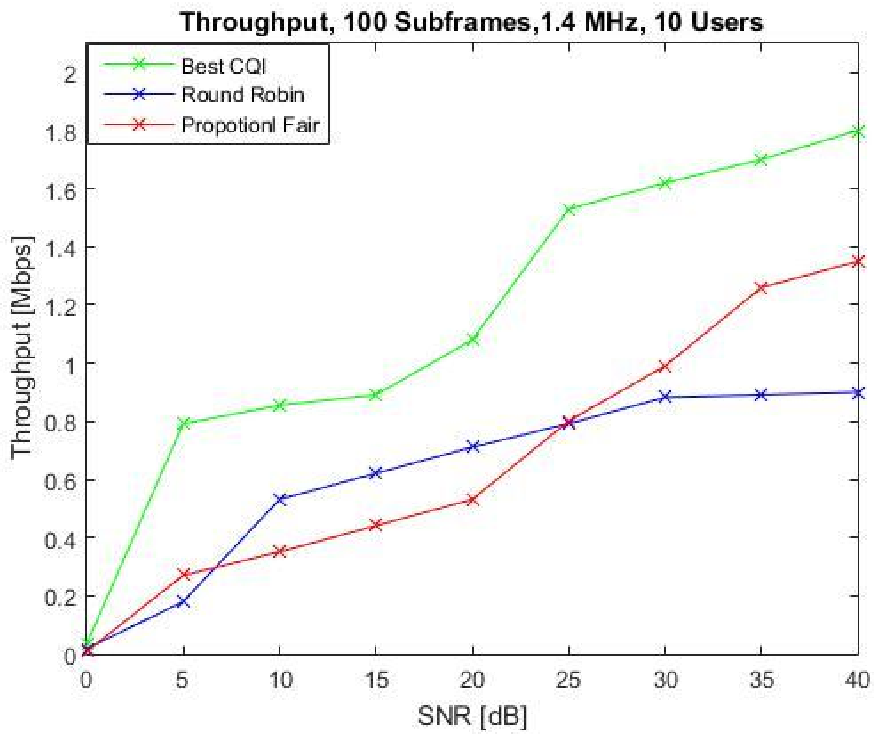

Figure (4.2): Throughput vs. SNR at 1.4 MHz and Ten Users

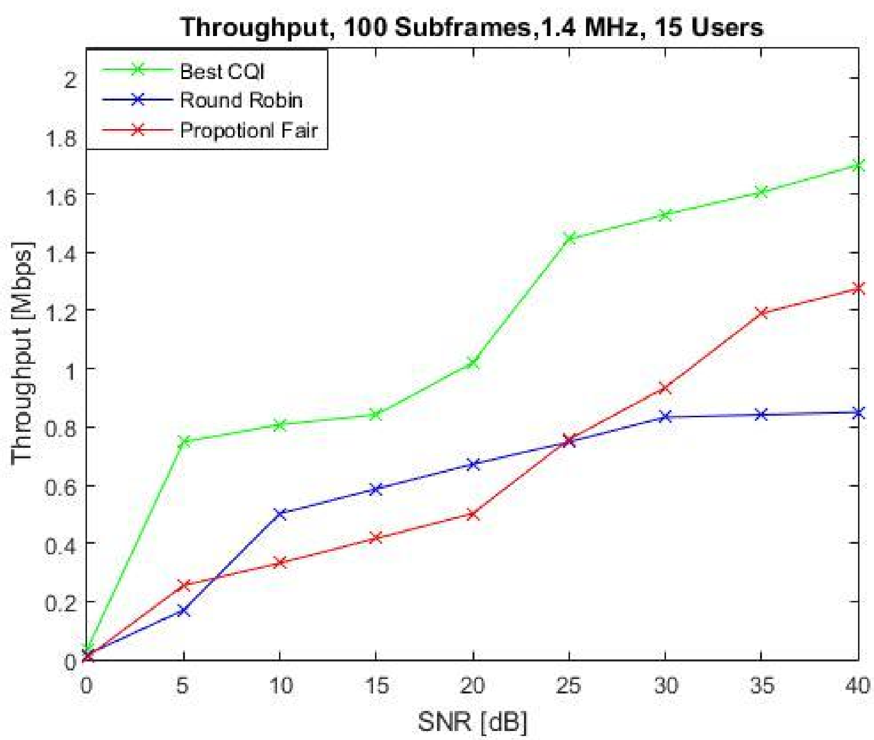

Figure (4.3): Throughput vs. SNR at 1.4 MHz and Fifteen Users

Increasing SNR from 0 dB until 40 dB the throughput of Round Robin take closely value which are 1Mbps, 900Kbps and 750Kbps at 40 dB for 5 users, 10 users and 15 users respectively. While rapidly increase in Best CQI and proportional fair (2 Mbps &1.4 Mbps at 5 users, 1.8 Mbps &1.375 Mbps at 10 users and 1.7Mbp & 1.3Mbp at 15 users respectively).

The throughput of Best CQI had a highest value of throughout at any SNR compared to Round Robin and Proportional Fair, but when compared Round Robin with Proportional Fair we found that at 0-5 dB the Proportional Fair had throughput higher than Round Robin by 66.7%, while at 7-25 dB the throughput of the Round Robin are higher by 71%.

At 25 dB the throughput of round robin was equal to throughput of proportional fair (900 kbps at 5 users, 780 kbps at 10 users and 750 kbps at 15 users). It was clear that as increasing the number of users in same bandwidth the throughput will decrease.

4.2 Results of Scenario No.2

In the following graphs represent the result of the signal to noise ratio to the throughput, the x axes represent the SNR in dB and the y axes represent the throughput in Mbps, a comparison of three algorithms were done to evaluate the system throughput for each.

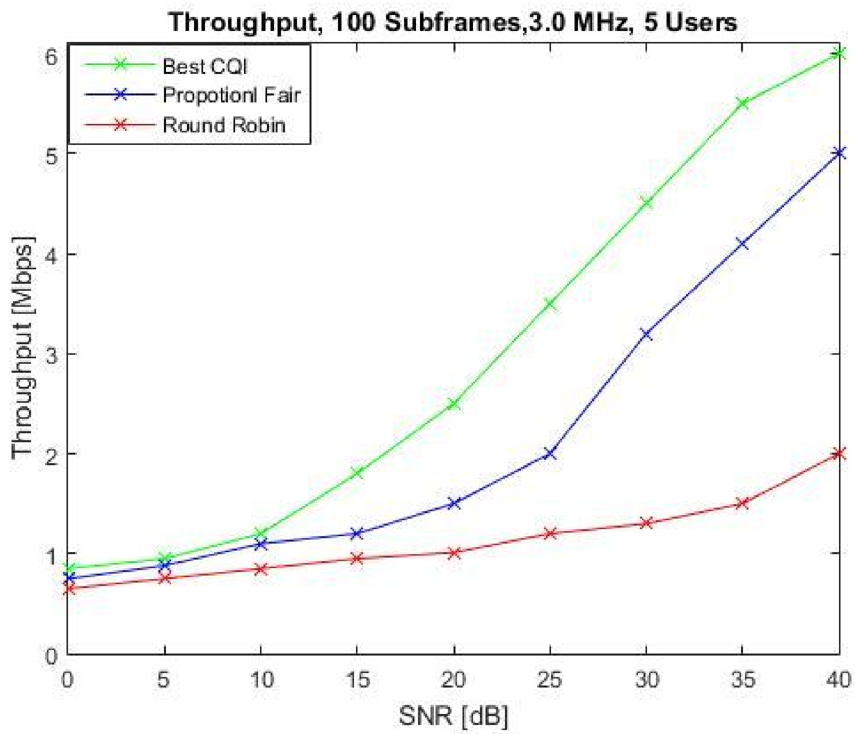

Figure (4.4): Throughput vs. SNR at 3.0 MHz and five Users

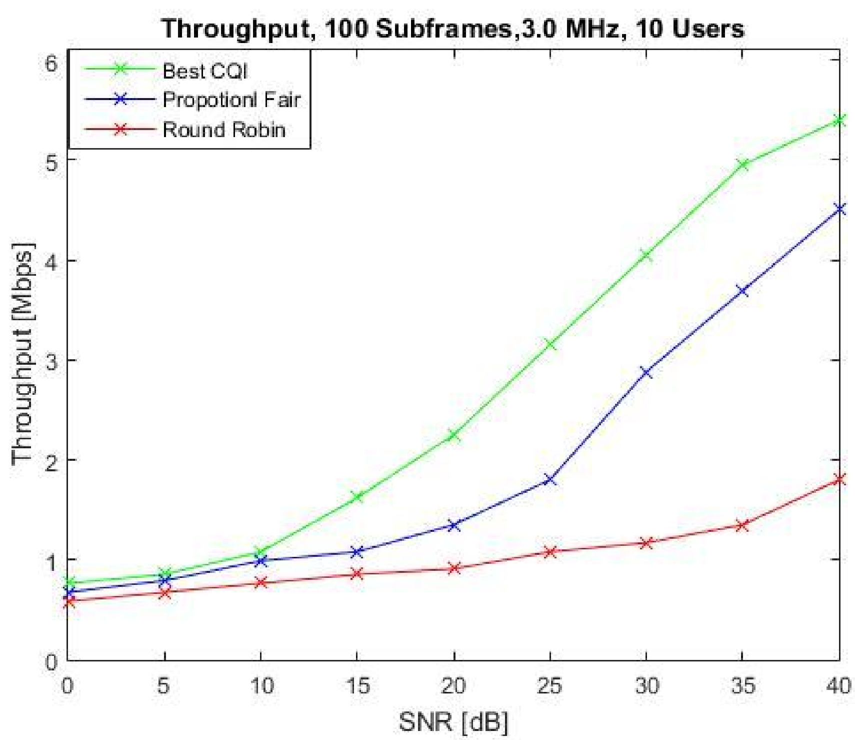

Figure (4.5): Throughput vs. SNR at 3.0 MHz and Ten Users

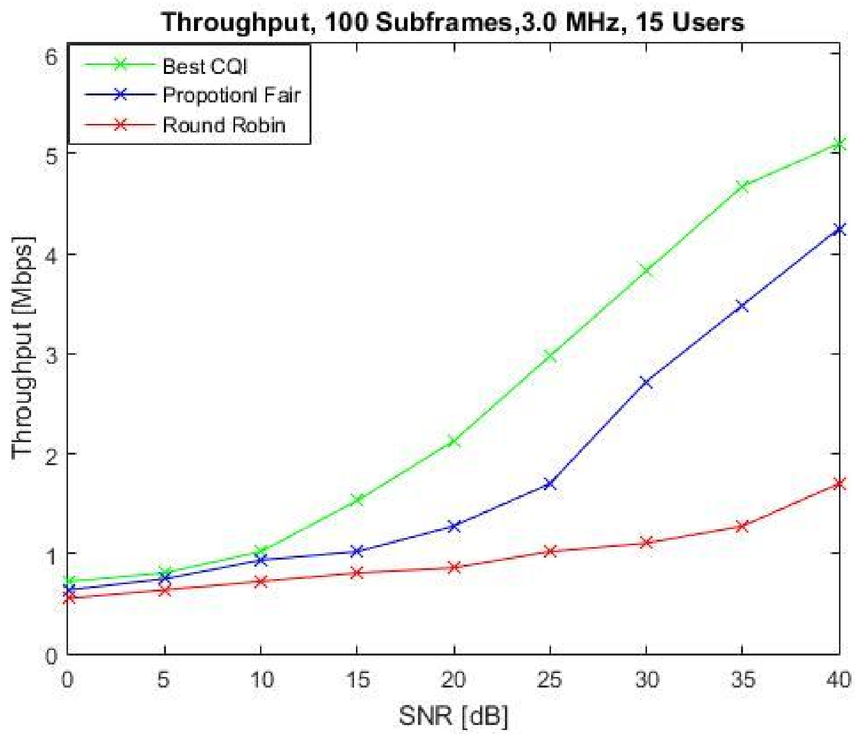

Figure (4.6): Throughput vs. SNR at 3.0 MHz and Fifteen Users

In this scenario the performance of proportional fair are more evaluated compare to pervious scenario. While increasing the SNR it was found that the Best CQI has a maximum throughput follow by proportional fair and lastly round robin.

At low level of SNR (from 0 to 10 dB) the throughput of third algorithm takes very closely value. for example at 5dB, 5 users it was found 900kbps, 850kbps and 800kbps for best CQI, Proportional fair and round robin respectively.

4.3Results of Scenario No.3

In the following graphs represent the result of the signal to noise ratio to the throughput, the x axes represent the SNR in dB and the y axes represent the throughput in Mbps, a comparison of three algorithms were done to evaluate the system throughput for each

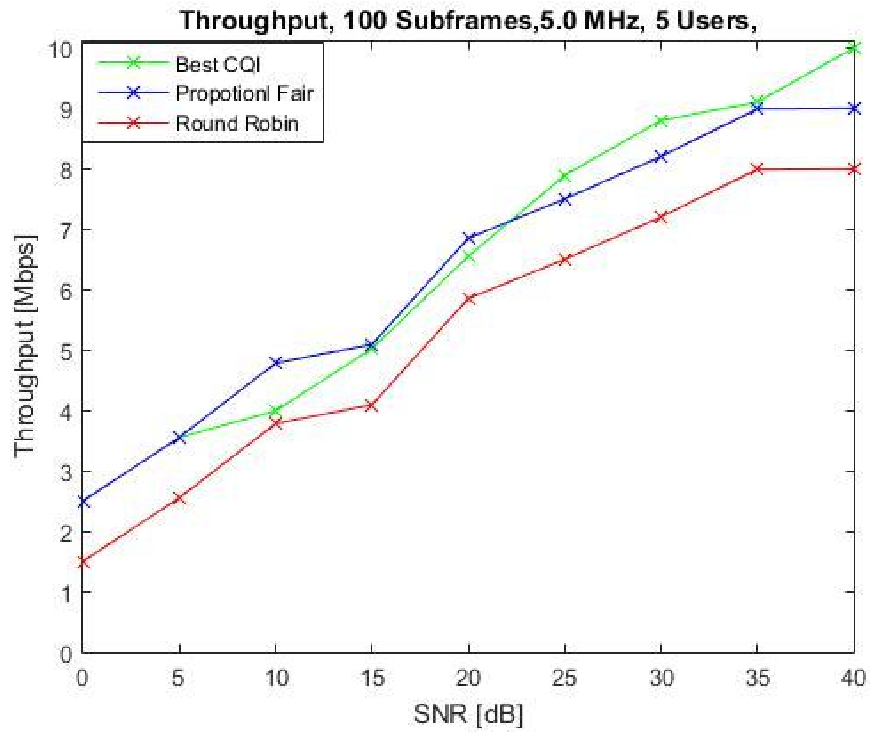

Figure (4.7): Throughput vs. SNR at 5.0 MHz and Five Users

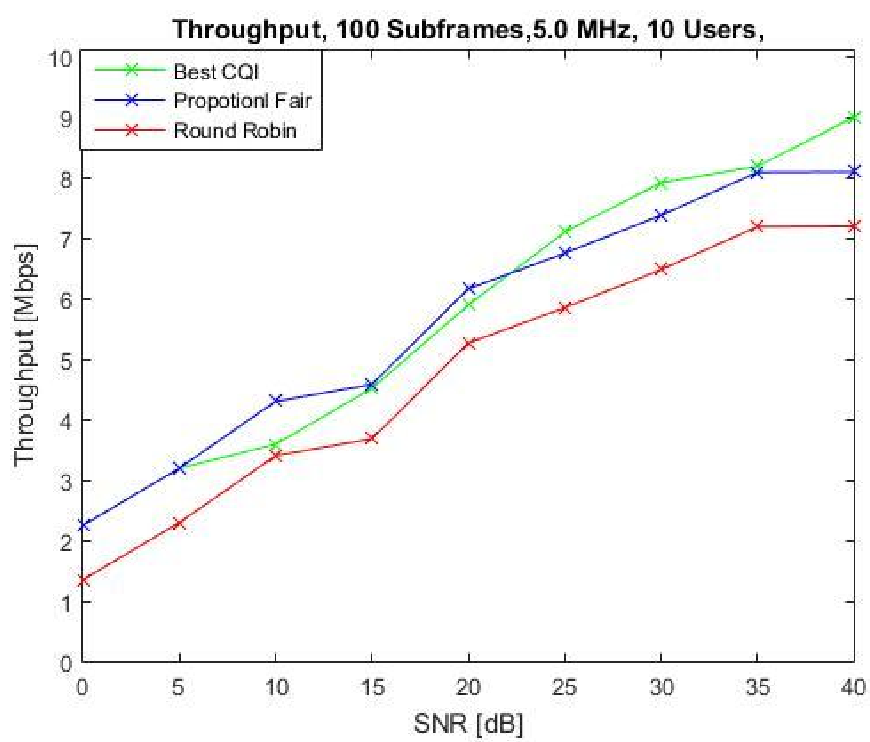

Figure (4.8): Throughput vs. SNR 5.0 MHz and Ten Users

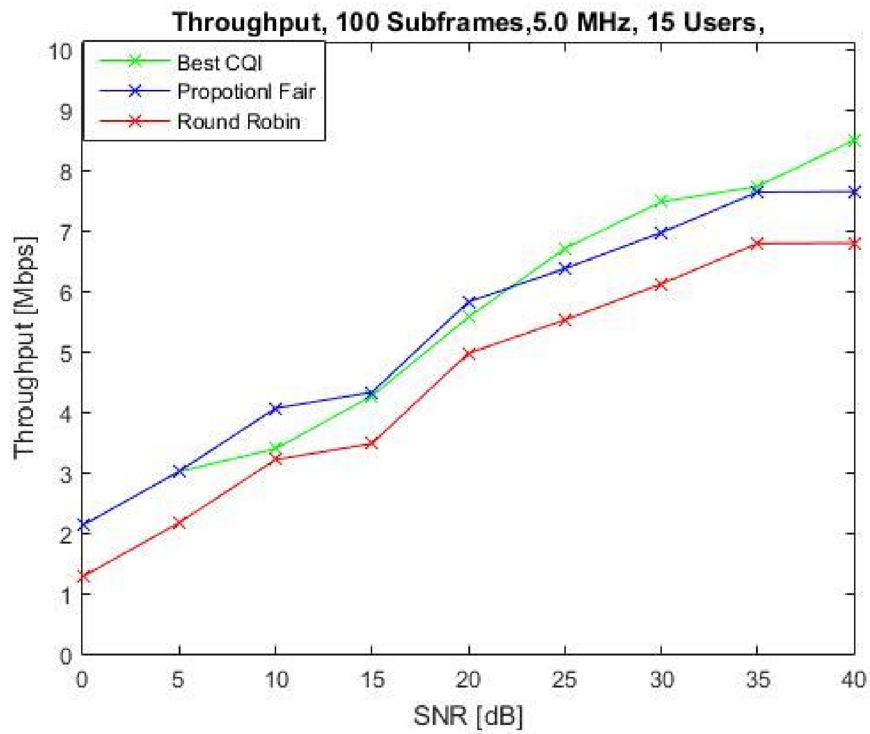

Figure (4.9): Throughput vs. SNR 5.0 MHz and Fifteen Users

In this scenario the comparison between three algorithms in the term of throughput was more complicated. Form 0-5 dB the throughput of best CQI and Proportional Fair are equal and higher that Round Robin by 66%. Then little degradation occur to Best CQI compare to Proportional Fair until 22 dB. An example, according to 10 dB the highest value of throughput measured was Proportional Fair (5 MHz in 5 users, 4.5 MHz in 10 users and 4.25 MHz in 15 users) following by Best CQI (4 MHz in 5 users, 3.5 MHz in 10 users and 3.25 MHz in 15 users) and finally Round Robin (3.75 MHz in 5 users, 3.4 MHz in 10 users and 3.15 MHz in 15 users). The throughput of Round Robin is less than Proportional Fair and Best CQI and any SNR

4.4 Results of Scenario No.4

The following graph represent the result of the signal to noise ratio to the Bit Error Rate, the x axes represent the SNR in dB and the y axes represent the BER, a comparison of three algorithms were done to evaluate the Bit error rate for each.

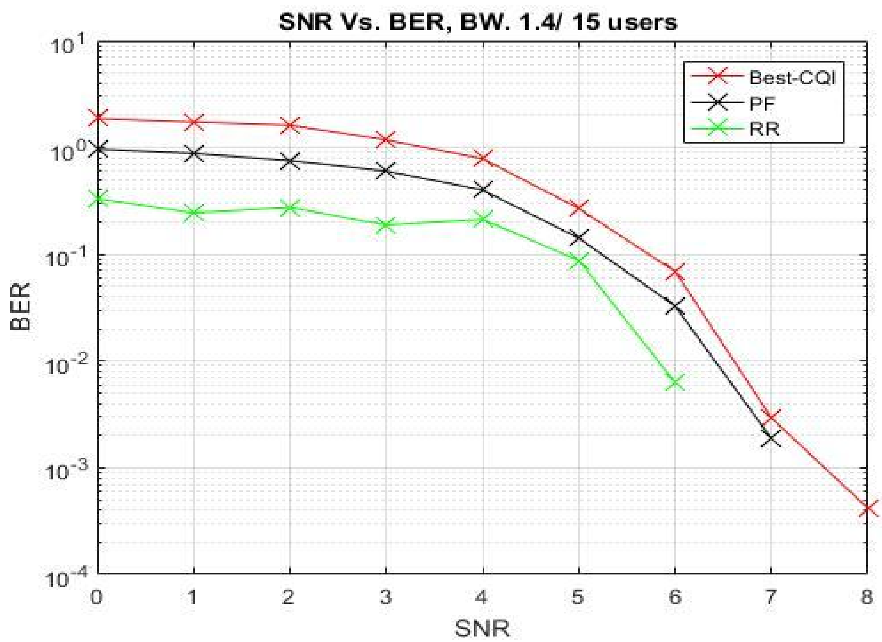

Figure (4.10) : BER vs. SNR @ 1.4 and 15 User

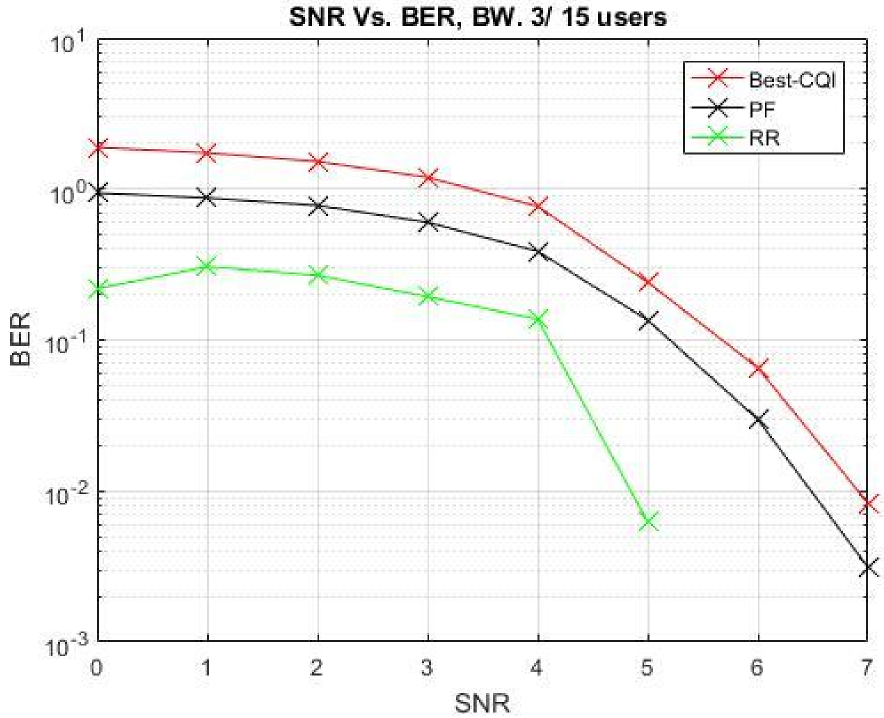

Figure (4.11): BER vs. SNR at 3.0 and 15 User

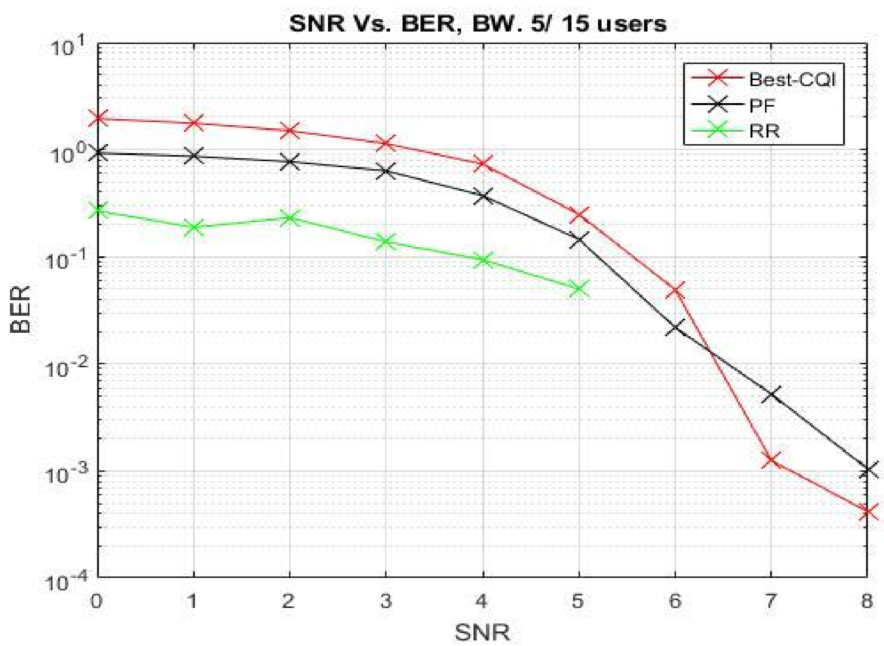

Figure (4.12) : BER vs. SNR @ 5.0 and 15 User

While increasing the SNR It was found that the Best CQI has a maximum Bit Error Rate following by proportional fair and round robin has the minimum Bit Error Rate.

the best CQI, the SNR was starts from 0 to 8 dB, while examining the results of Best CQI it was found that it has a minimum bit error rate at 8dB SNR, and proportional fair at 8 dB SNR, and the round robin is 5 dB SNR. Also the increasing of bandwidth and fixed number of users the bit error rate decreases

CHAPTER FIVE
CONCLUSION AND FUTURE WORK

5.1 Conclusion

The scheduler is a very important element of the base station. It assigns the resource blocks to different users. In this thesis three scheduling algorithms: Best CQI, Round Robin scheduling and proportional fair used. As the name implies, the Best CQI scheduling assigns the resource blocks to the user with the higher CQI. In Round Robin scheduling the terminals are assigned the resource blocks in turn (one after another) and the proportional fair assigns the resource blocks to the user with the highest CQI in the first slot period of each sub-frame whereas in the second slot period the scheduler assigns the resource blocks in turn to each user .

The impact of the scheduling schemes on the throughput and on Bit error rate was investigated. The Best CQI scheduling maximizes the throughput by scheduling the user with the good channel quality and the Round Robin scheduling is fair since it equally schedules the terminals, while Proportional Fair algorithm balance between throughput and fairness.

These scheduling algorithms have been implemented in a MATLAB and a comparative analysis between the scheduling algorithms based on their throughputs for different scenarios (different scheduling methods, different bandwidth and different number of users) was carried out.

Depending on the bandwidth used the throughput take different shape.

In the case of 1.4 MHZ, the throughput of Best CQI had a highest value of throughout at any SNR compared to Round Robin and Proportional Fair, but when compared Round Robin with Proportional Fair we found that at 0-5 dB the Proportional Fair had throughput higher than Round Robin by 66.7%, while at 7-25 dB the throughput of the Round Robin are higher by 71%. At 25 dB the throughput of round robin was equal to throughput of proportional fair. So at low level of SNR (less than 5 dB) it is better to select Proportional fair, but at high level of SNR (more than 25 dB) round robin become the best choice.

In the case of 3.0 MHZ, throughput of the Best CQI scheduling is the highest following by proportional fair and Round Robin.

In the case of 5.0 MHz, The throughput of Round Robin is less than Proportional Fair and Best CQI and any SNR. At low SNR(form 0-5 dB) the throughput of best CQI and Proportional Fair are equal . at SNR up to 22 dB the performance of proportional fair are higher than Best COI

Also it was found that the throughput is decreased while the number of users increased in the same bandwidth settings.

Moreover in the SNR to BER results concluded that Best CQI has a maximum Bit Error Rate following by Proportional Fair and finally Round Robin has the minimum Bit Error Rate . also the increasing of bandwidth and fixed number of users the bit error rate decreases.

5.2 Future work

More research still can be done in the LTE downlink scheduling because it is a very interesting field. The first step is in finding a trade-off between throughput and fairness. Future work can be done in the order to optimize the throughput in Proportional fair.

Depending on the goal of the scheduling algorithm we want to design, we may choose to improve the throughput, the fairness or both of them.

If favor of the throughput demanded improving the Best CQI scheduling and the Proportional Fair. But if favor of the fairness improving Proportional Fair algorithm and Round Robin scheduling.

MIMO is one of the technologies to increase the throughput. More advanced and complex techniques can be also designed with the same goal, Also examine the impact of the Bit error rate and the throughput for Vehicular Channel.

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Appendix

Simulation program in MATLAB

```
close all
clear all
clc
tic

%%
% Generating and coding data
u1=42;
u2=25;
u3=10;


t_data=randint(9600,1)';
t_data_user_1=randint(9600,1)';
t_data_user_2=randint(9600,1)';
t_data_user_3=randint(9600,1)';

u1_arrive_time=42;
u2_arrive_time=25;
u3_arrive_time=10;

if (u1<u2) && (u1<u3)
x=1;
total_time=200;
time_slot=25;

for t=1:total_time
si=1; %for BER rows
%%
for d=1:100;
data=t_data(x:x+95);
x=x+25;
k=3;
n=6;
s1=size(data,2);  % Size of input matrix
j=s1/k;

%%
% Convolutionally encoding data
constlen=7;
codegen = [171 133];    % Polynomial
trellis = poly2trellis(constlen, codegen);
codedata = convenc(data, trellis);

%%
%Interleaving coded data

s2=size(codedata,2);
j=s2/4;
matrix=reshape(codedata,j,4);

intlvddata = matintrlv(matrix',2,2)'; % Interleave.
intlvddata=intlvddata'
```

```
%%
% Binary to decimal conversion

dec=bi2de(intlvddata','left-msb');

%%
%16-QAM Modulation

M=16;
y = qammod(dec,M);
% scatterplot(y);

%%
% Pilot insertion

lendata=length(y);
pilt=3+3j;
nofpits=4;

k=1;

for i=(1:13:52)

    pilt_data1(i)=pilt;

    for j=(i+1:i+12);
        pilt_data1(j)=y(k);
        k=k+1;
    end
end

pilt_data1=pilt_data1';   % size of pilt_data =52
pilt_data(1:52)=pilt_data1(1:52);    % upsizing to 64
pilt_data(13:64)=pilt_data1(1:52);   % upsizing to 64

for i=1:52

    pilt_data(i+6)=pilt_data1(i);

end



%%
% IFFT
ifft_sig=ifft(pilt_data',64);

%%
% Adding Cyclic Extension

cext_data=zeros(80,1);
cext_data(1:16)=ifft_sig(49:64);
for i=1:64

    cext_data(i+16)=ifft_sig(i);

end
```

```
%%
% Channel

 % SNR

 o=1;
for snr=0:2:50

ofdm_sig=awgn(cext_data,snr,'measured'); % Adding white Gaussian
Noise

%%
%                   RECEIVER
%%
%Removing Cyclic Extension

for i=1:64

    rxed_sig(i)=ofdm_sig(i+16);

end

%%
% FFT

ff_sig=fft(rxed_sig,64);

%%
% Pilot Synch%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=1:52

    synched_sig1(i)=ff_sig(i+6);

end


k=1;

for i=(1:13:52)

    for j=(i+1:i+12);
        synched_sig(k)=synched_sig1(j);
        k=k+1;
    end
end


% scatterplot(synched_sig)

%%
% Demodulation
dem_data= qamdemod(synched_sig,16);


%%
% Decimal to binary conversion
```

```
bin=de2bi(dem_data','left-msb');
bin=bin';


%%
% De-Interleaving


deintlvddata = matdeintrlv(bin,2,2); % De-Interleave
deintlvddata=deintlvddata';
deintlvddata=deintlvddata(:)';



%%
%Decoding data
n=6;
k=3;
decodedata =vitdec(deintlvddata,trellis,5,'trunc','hard');  %
decoding datausing veterbi decoder
rxed_data=decodedata;

%%
% Calculating BER
rxed_data=rxed_data(:)';
errors=0;


c=xor(data,rxed_data);
errors=nnz(c);

 for i=1:length(data)

%
     if rxed_data(i)~=data(i);
         errors=errors+1;
%
     end
 end


BER(si,o)=errors/length(data);
o=o+1;

 end % SNR loop ends here
 si=si+1;
end % main data loop

%%
% Time averaging for optimum results

for col=1:25;        %%%change if SNR loop Changed
    ber(1,col)=0;
for row=1:100;


        ber(1,col)=ber(1,col)+BER(row,col);
    end
end
```

```
ber=ber./100;

%%
figure()
i=0:2:48;
semilogy(i,ber);
title('BER vs SNR');
ylabel('BER');
xlabel('SNR (dB)');
grid on

end

%% user 2

%%
% Generating and coding data
t_data=randint(9600,1)';
t_data_user_1=randint(9600,1)';
t_data_user_2=randint(8500,1)';
t_data_user_3=randint(7500,1)';
x=1;
si=1; %for BER rows
%%
for d=1:100;
data=t_data(x:x+95);
x=x+25;
k=3;
n=6;
s1=size(data,2);  % Size of input matrix
j=s1/k;

%%
% Convolutionally encoding data
constlen=7;
codegen = [171 133];    % Polynomial
trellis = poly2trellis(constlen, codegen);
codedata = convenc(data, trellis);

%%
%Interleaving coded data

s2=size(codedata,2);
j=s2/4;
matrix=reshape(codedata,j,4);

intlvddata = matintrlv(matrix',2,2)'; % Interleave.
intlvddata=intlvddata';



%%
% Binary to decimal conversion

dec=bi2de(intlvddata','left-msb');

%%
%16-QAM Modulation

M=16;
```

```
y = qammod(dec,M);
% scatterplot(y);

%%
% Pilot insertion

lendata=length(y);
pilt=3+3j;
nofpits=4;

k=1;

for i=(1:13:52)

    pilt_data1(i)=pilt;

    for j=(i+1:i+12);
        pilt_data1(j)=y(k);
        k=k+1;
    end
end

pilt_data1=pilt_data1';   % size of pilt_data =52
pilt_data(1:52)=pilt_data1(1:52);    % upsizing to 64
pilt_data(13:64)=pilt_data1(1:52);   % upsizing to 64

for i=1:52

    pilt_data(i+6)=pilt_data1(i);

end



%%
% IFFT
ifft_sig=ifft(pilt_data',64);

%%
% Adding Cyclic Extension

cext_data=zeros(80,1);
cext_data(1:16)=ifft_sig(49:64);
for i=1:64

    cext_data(i+16)=ifft_sig(i);

end



%%
% Channel

 % SNR

 o=1;
for snr=0:2:50
```

```
ofdm_sig=awgn(cext_data,snr,'measured'); % Adding white Gaussian
Noise


%%
%                   RECEIVER
%%
%Removing Cyclic Extension

for i=1:64

    rxed_sig(i)=ofdm_sig(i+16);

end

%%
% FFT

ff_sig=fft(rxed_sig,64);

%%
% Pilot Synch%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


for i=1:52

    synched_sig1(i)=ff_sig(i+6);
end

k=1;

for i=(1:13:52)

    for j=(i+1:i+12);
        synched_sig(k)=synched_sig1(j);
        k=k+1;
    end
end


% scatterplot(synched_sig)


%%
% Demodulation
dem_data= qamdemod(synched_sig,16);


%%
% Decimal to binary conversion

bin=de2bi(dem_data','left-msb');
bin=bin';


%%
% De-Interleaving
```

```
deintlvddata = matdeintrlv(bin,2,2); % De-Interleave
deintlvddata=deintlvddata';
deintlvddata=deintlvddata(:)';

%%
%Decoding data
n=6;
k=3;
decodedata =vitdec(deintlvddata,trellis,5,'trunc','hard');  %
decoding datausing veterbi decoder
rxed_data=decodedata;

%%
% Calculating BER
rxed_data=rxed_data(:)';
errors=0;

c=xor(data,rxed_data);
errors=nnz(c);

 for i=1:length(data)

%
     if rxed_data(i)~=data(i);
         errors=errors+1;
%
     end
 end


BER(si,o)=errors/length(data);
o=o+1;

 end % SNR loop ends here
 si=si+1;
end % main data loop

%%
% Time averaging for optimum results

for col=1:25;        %%%change if SNR loop Changed
    ber(1,col)=0;
for row=1:100;


        ber(1,col)=ber(1,col)+BER(row,col);
    end
end
ber=ber./100;

%%
figure()
i=0:2:48;
semilogy(i,ber);
title('BER vs SNR');
ylabel('BER');
```

```
xlabel('SNR (dB)');
grid on

%% User 3

%% user 2

%%
% Generating and coding data
t_data=randint(9600,1)';
t_data_user_1=randint(9600,1)';
t_data_user_2=randint(8500,1)';
t_data_user_3=randint(7500,1)';
x=1;
si=1; %for BER rows
%%
for d=1:100;
data=t_data(x:x+95);
x=x+25;
k=3;
n=6;
s1=size(data,2);  % Size of input matrix
j=s1/k;

%%
% Convolutionally encoding data
constlen=7;
codegen = [171 133];    % Polynomial
trellis = poly2trellis(constlen, codegen);
codedata = convenc(data, trellis);

%%
%Interleaving coded data

s2=size(codedata,2);
j=s2/4;
matrix=reshape(codedata,j,4);

intlvddata = matintrlv(matrix',2,2)'; % Interleave.
intlvddata=intlvddata';


%%
% Binary to decimal conversion

dec=bi2de(intlvddata','left-msb');

%%
%16-QAM Modulation

M=16;
y = qammod(dec,M);
% scatterplot(y);

%%
% Pilot insertion

lendata=length(y);
```

```
pilt=3+3j;
nofpits=4;

k=1;

for i=(1:13:52)

    pilt_data1(i)=pilt;

    for j=(i+1:i+12);
        pilt_data1(j)=y(k);
        k=k+1;
    end
end

pilt_data1=pilt_data1';   % size of pilt_data =52
pilt_data(1:52)=pilt_data1(1:52);    % upsizing to 64
pilt_data(13:64)=pilt_data1(1:52);   % upsizing to 64

for i=1:52

    pilt_data(i+6)=pilt_data1(i);

end

%%
% IFFT
ifft_sig=ifft(pilt_data',64);

%%
% Adding Cyclic Extension

cext_data=zeros(80,1);
cext_data(1:16)=ifft_sig(49:64);
for i=1:64

    cext_data(i+16)=ifft_sig(i);

end


%%
% Channel

 % SNR

 o=1;
for snr=0:2:50

ofdm_sig=awgn(cext_data,snr,'measured'); % Adding white Gaussian
Noise


%%
%                   RECEIVER
%%
%Removing Cyclic Extension
```

```
for i=1:64

    rxed_sig(i)=ofdm_sig(i+16);

end

%%
% FFT

ff_sig=fft(rxed_sig,64);

%%
% Pilot Synch%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


for i=1:52

    synched_sig1(i)=ff_sig(i+6);

end

k=1;

for i=(1:13:52)

    for j=(i+1:i+12);
        synched_sig(k)=synched_sig1(j);
        k=k+1;
    end
end


% scatterplot(synched_sig)


%%
% Demodulation
dem_data= qamdemod(synched_sig,16);


%%
% Decimal to binary conversion

bin=de2bi(dem_data','left-msb');
bin=bin';


%%
% De-Interleaving


deintlvddata = matdeintrlv(bin,2,2); % De-Interleave
deintlvddata=deintlvddata';
deintlvddata=deintlvddata(:)';
```

```
%%
%Decoding data
n=6;
k=3;
decodedata =vitdec(deintlvddata,trellis,5,'trunc','hard');  %
decoding datausing veterbi decoder
rxed_data=decodedata;

%%
% Calculating BER
rxed_data=rxed_data(:)';
errors=0;


c=xor(data,rxed_data);
errors=nnz(c);

 for i=1:length(data)

%
     if rxed_data(i)~=data(i);
         errors=errors+1;
%
     end
 end


BER(si,o)=errors/length(data);
o=o+1;

 end % SNR loop ends here
 si=si+1;
end % main data loop

%%
% Time averaging for optimum results

for col=1:25;        %%%change if SNR loop Changed
    ber(1,col)=0;
for row=1:100;


        ber(1,col)=ber(1,col)+BER(row,col);
    end
end
ber=ber./100;
 %%
figure()
i=0:2:48;
semilogy(i,ber);
title('BER vs SNR');
ylabel('BER');
xlabel('SNR (dB)');
grid on

end
toc
```

```
tic
ll=1;
RB1=6; % Number of resource block
RB2=15;% Number of resource block
RB3=25;% Number of resource block

band1=1.4
band2=3;
band3=5;

group_users1=5;
group_users2=10;
group_users3=15;

subcarrier1=72;      % while 1.4 MHZ
subcarrier2=180;     % while 3.0 MHZ
subcarrier3=500;     % while 5.0 MHZ

symbol_lte=71.4;     %1 symbol is of 71.4 microseconds for LTE
qam_carry=6;         %perfect idle condition 64 QAM can be used. That
means each symbol is now allowed to carry 6 bits.

datarate1=(subcarrier1 * qam_carry) / symbol_lte;
datarate2=(subcarrier2 * qam_carry) / symbol_lte;
datarate3=(subcarrier3 * qam_carry) / symbol_lte;


RE1=12 * 7 * 2*RB1;
RE2=12 * 7 * 2*RB2;
RE3=12 * 7 * 2*RB3;
% conver to Msps  Mega Symbols per second
RE1=RE1*1000/(10^6); % 1000 to be converted to sseconds
RE2=RE2*1000/(10^6);
RE3=RE3*1000/(10^6);

throuput1_th=RE1*qam_carry; % throughput while RE1 and 1.4
throuput2_th=RE2*qam_carry; % throughput while RE1 and 3
throuput3_th=RE3*qam_carry; % throughput while RE1 and 5

%%
figure(1) % Plot throughput vs number of users throughput 1
for i=1:group_users1
th_t1(i)= throuput1_th/i;
end

x=1:group_users1;
plot (x,th_t1,'color','r','marker','x','MarkerSize',10);

hold on
j=0;
for j=1:10
th_t2(j)= throuput1_th/j;
end

x=1:group_users2;
th_t2=th_t2*10/100+th_t2;
```

```
plot (x,th_t2,'color','g','marker','o','MarkerSize',10);

hold on

for i=1:group_users3
th_t3(i)= throuput1_th/i;
end

x=1:group_users3;
th_t3=th_t3*15/100+th_t3;
plot (x,th_t3,'color','k','marker','*','MarkerSize',10);

axis([1 15 0 25]);
xlabel('Number of Users');
ylabel('Throughput Mbps');
title('Number of users vs. Theoretical Throughput BW[1.4]');
legend('5 Users','10 Users','15 Users')
% end of throughput 1

%%
figure(2) % throughput 2 vs number of users

for i=1:group_users1
th_t11(i)= throuput2_th/i;
end
x=1:group_users1;
plot (x,th_t11,'color','r','marker','x','MarkerSize',10);
hold on

for i=1:group_users2
th_t22(i)= throuput2_th/i;
end
x=1:group_users2;
th_t22=th_t22*10/100+th_t22;
plot (x,th_t22,'color','g','marker','o','MarkerSize',10);

hold on

for i=1:group_users3
th_t33(i)= throuput2_th/i;
end
x=1:group_users3;
th_t33=th_t33*15/100+th_t33;
plot (x,th_t33,'color','k','marker','*','MarkerSize',10);

axis([1 15 0 25]);
xlabel('Number of Users');
ylabel('Throughput Mbps');
title('Number of users vs. Theoretical Throughput BW[3.0]');
legend('5 Users','10 Users','15 Users')

% end of throughput 2

%%
figure() % throughput 3 vs number of users

 for i=1:group_users1
 th_t111(i)= throuput3_th/i;
 end
```

```
 x=1:group_users1;
 plot (x,th_t111,'color','r','marker','x','MarkerSize',10);

 hold on

 for i=1:group_users2
 th_t222(i)= throuput3_th/i;
 end
 x=1:group_users2;
 th_t222=th_t222*10/100+th_t222;
 plot (x,th_t222,'color','g','marker','o','MarkerSize',10);

 hold on

 for i=1:group_users3
 th_t333(i)= throuput3_th/i;
 end
 x=1:group_users3;
 th_t333=th_t333*15/100+th_t333;
 plot (x,th_t333,'color','k','marker','*','MarkerSize',10);

 axis([1 15 0 25]);
 xlabel('Number of Users');
 ylabel('Throughput Mbps');
 title('Number of users vs. Theoretical Throughput BW[5.0]');
 legend('5 Users','10 Users','15 Users')

semilogy(x,ber1,'color','r','marker','x','MarkerSize',10);

    hold on
semilogy(x,ber1,'color','k','marker','x','MarkerSize',10);

hold on
    ber1=ber1-berx;
semilogy(x,ber1(1:25),'color','g','marker','x','MarkerSize',10);

title('SNR Vs. BER, BW. 1.4/ 15 users ');
legend('Best-CQI','PF','RR');

xlabel('SNR');
ylabel('BER');
grid on
hold off

%%

semilogy(x,ber2,'color','r','marker','x','MarkerSize',10);

    hold on


semilogy(x,ber2,'color','k','marker','x','MarkerSize',10);

    hold on

semilogy(x,ber2(1:25),'color','g','marker','x','MarkerSize',10);

title('SNR Vs. BER, BW. 3/ 15 users ');
```

```
 legend('Best-CQI','PF','RR');
 xlabel('SNR');
ylabel('BER');
   grid on

    hold off


    %%
semilogy(x,ber3,'color','r','marker','x','MarkerSize',10);

    hold on

  semilogy(x,ber3,'color','k','marker','x','MarkerSize',10);

    hold on

semilogy(x,ber3(1:25),'color','g','marker','x','MarkerSize',10);

 title('SNR Vs. BER, BW. 5/ 15 users ');
 legend('Best-CQI','PF','RR');
 xlabel('SNR');
ylabel('BER');
    grid on

run proportional.m
run Round_Robin.m
run BestCQI.m
run Aperture_Calc.p
```