DEMONSTRATION OF AN EFFECTIVE 4G LTE NETWORK SIMULATOR TO ANALYZE PERFORMANCE AND ENSURE RELIABLE COMMUNICATION

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By

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Demonstration of an Effective 4G LTE Network Simulator to Analyze Performance and Ensure Reliable Communication

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ABSTRACT

With the growing population, technology is growing without any bounds. With these advancements, we have reached a footing where we cannot imagine the world without communications. This dependability on communications strikes a need for highly reliable and cost effective communication technology from the perspective of the user as well as the service provider. Though the 3GPP's Long Term Evolution (LTE) has been successful to mitigate most of the challenges, there arises a need to foresee the cellular network evolution considering various factors like increase in number of users in a particular area, urbanization etc., and accordingly use the features of LTE to overcome the effects of them before actually deploying the network in the real world. This thesis outlines the requirement for an effective 4G LTE simulator that can model the real world cellular network by considering the various effects on a wireless network like fading, pathloss, number of users and resource allocation. It can then explore various aspects of 4G LTE that contributes towards design and analysis of the network performance for various scenarios supporting deployment of the new network for futuristic operation or optimizing the existing network. In this study we closely look through a System level LTE Simulator developed by the Institute of Telecommunications of The Vienna University of Technology, Austria. Using this simulator we study different scheduling schemes to evaluate performance and demonstrate how important the role of scheduling scheme is to overcome network congestion. We study various features of LTE that help in increasing throughput for various traffic models over a network and demonstrate the role of small cells in increasing the overall throughput of the network by comparing with the existing macro cell network.

Various parameters are varied and results are obtained for various scenarios using the Vienna LTE simulator. These results are then used to demonstrate how Quality of Service (QoS), capacity planning, and resource management are achieved through LTE technology. This study helps the service provider to offer reliable service at lower implementation cost and deploy a network that has ability to sustain the evolution.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the School of Computing and Engineering have examined a thesis titled “DEMONSTRATION OF AN EFFECTIVE 4G LTE NETWORK SIMULATOR TO ANALYZE PERFORMANCE AND ENSURE RELIABLE COMMUNICATION”, presented by Naveen Narasimhaiah, candidate for the Master of Electrical Engineering degree, and certify that in their opinion it is worthy of acceptance.

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CHAPTER 1

INTRODUCTION

The telecommunication industries have grown in an unimaginable way over the past few years. The people of this generation have become so dependent on it that it is almost impossible to find an individual without this small device called "Mobile". Many companies have seen this as an opportunity to grow and establish themselves and have started their race to be the best among service providers. With the growth of its user traffic expected to increase by a factor of 1000 by 2020, all service providers have been thinking of new technology that can efficiently handle this situation. However, currently the 3GPP's Long Term Evolution (LTE) has proven its stand by mitigating most of the present day challenges like spectrum efficiency, capacity, coverage and a lot more. With this importance of LTE, the next goal is to efficiently utilize this technology to deliver best service at reduced cost. In order to achieve this, it is necessary to analyze the performance of LTE under various conditions and have the statistics before the actual deployment or optimizing a network. To obtain these statistics, there exists a need for an efficient 4G LTE network simulator that can simulate the real world network considering various aspects that have an impact on the real world transmitted signal. This simulator can be used to explore various capabilities and features of LTE that contribute towards increasing efficiency of the network. Deploying the network with the help of these results, solve many real world problems and provide a reliable service to the user in cost effective way.

1.1 Motivation for the Project

Currently, the race between technology and implementation is on and technology leads the contest. With the growth of technology, there is a consistent increase in applications requiring high bandwidth. It has been high priority of service provider to carter various needs of user in reliable way to maintain their stand in current cutthroat market. Though development of 4G LTE has mitigated most of the challenges, the next thing that comes to your mind is, how reliable LTE is for extreme communications. In order to analyze this, there exists a need for an effective simulator that can mimic the end user environment and simulate the network as it is deployed in the real world. The results obtained help us to analyze the performance of the LTE on the network and accordingly plan transformation and implementation of the network ensuring reliable communications.

1.2 Objective of the Project

This project involves demonstrating of an effective 4G LTE network simulator in order to study various features of LTE that aid in analysis of performance of network providing a framework and solutions to the problems of network congestion, network densification and efficient deployment. This study involves use of the Vienna LTE Simulator as the network simulator, developed by the Institute of Telecommunications, The Vienna University of Technology, Austria. It is an open source MATLAB based simulator that provides a system level simulation of LTE considering various aspects that have an impact on the real world transmitted signal.

With increase in number of users in a geographical area and tremendous growth in use of high bandwidth applications, traffic and load on the network has increased proportionately leading to network congestion and densification. The need of the hour is an efficient solution to these problems. In order to overcome network congestion, an efficient resource allocation scheme is necessary. In this project we compare and investigate effects of different scheduling schemes on the network. Network densification is another issue making users experience low signal quality in large buildings like malls or large organizations; we demonstrate how all these users can be served in reliable and efficient way by placing femtocells in densely populated or weak coverage areas of macro cells. Femtocells not only increase throughput but also helps in increasing capacity as well as coverage of the system. Using this analysis, we estimate growth of the network and analyze performance accordingly with the help of Vienna LTE simulator. This helps us to optimize existing network or plan new network for its futuristic operation before deployment in real world. This helps the service provider save revenue and ensure reliable communications to user.

CHAPTER 2

BACKGROUND STUDY

2.1 Generation of Cellular Technologies

With the growing technology, the world has witnessed tremendous evolution in every aspect of living from fitness to way we communicate. Communication being an important aspect has seen evolution that revolutionized the world. The Telecommunication networks evolution can be categorized into generations. The first generation (1G) networks supported analog voice communications. The second generation (2G) had a major transformation of digitizing signal. It also increased efficiency and for the first time data services were introduced. 2.5G (GPRS) and 2.75G (EDGE) being the evolution of 2G provided increased speeds and for the first time had packet switched domain implemented in addition to circuit switched domain.

The next evolution was 3G (WCDMA), which has data rates of 200 kbps and led to assortment of “mobile broadband” experience. Many new features like video streaming, conferencing etc. were put forth.

The most talked evolution of telecommunications is the fourth generation (4G) which revolutionized the industry by utilizing various features like high speed and efficiency. Currently it provides access to a wide range of applications such as

IP Telephony, mobile web access, high definition video streaming, real time and interactive gaming and much more.

Recently, Long Term Evolution technology is extensively deployed by all carriers and it can offer as much as 100 Mbps data rate satisfying requirement of major applications effectively. Even though LTE is able to mitigate most of the issues of existing networks there exists a constant demand for higher performance technology due to increasing high bandwidth applications and densification. In the next section we understand the major features and architecture of LTE.

2.2 Long Term Evolution (LTE)

LTE is the common name given to standard of next generation evolution of WCDMA. It evolved from earlier 3GPP system known as Universal Mobile Telecommunication System (UMTS). This new technology is an all IP based network which provides IP based mobile core referred to as the Evolved Packet Core (EPC). The major goals of LTE are increase peak data rates, provide low latency in RAN (Radio Access Network), improve RAN bandwidth and spectral efficiency. The architecture of LTE includes a new base station called the eNodeB and a single core called the Evolved Packet Core that provides access to both IP based voice and data services.

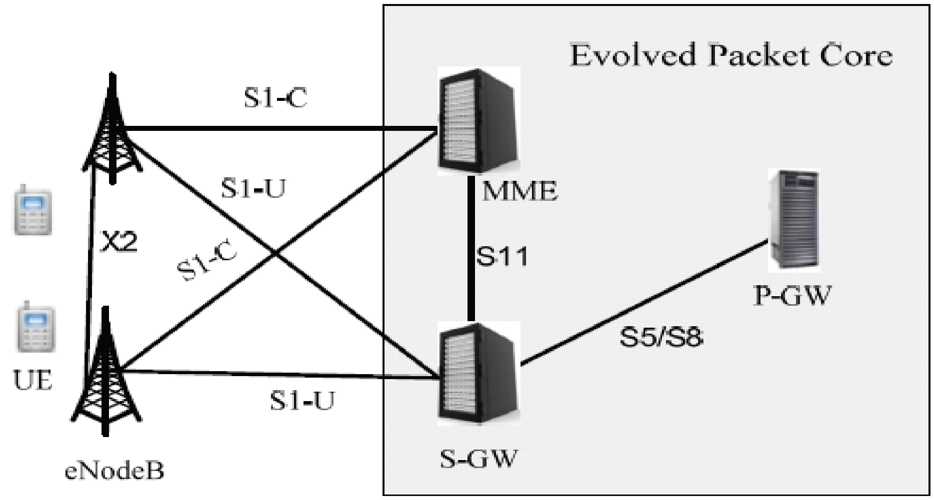


Figure 1: LTE Architecture [6]

The LTE architecture consists of two key components namely the eNodeB and the EPC. The eNodeB sends and receives data from User Equipment (UE). The main functions of eNodeB include cell resource management with QOS realization, MME selection, routing the user data towards S-GW and assist in intra LTE and inter LTE handover. Each eNodeB in a geographical area are interconnected through an interface called X2 interface, which helps in handovers or cell reselection procedures thus maintaining UE in attached state. The next key component is the EPC (Evolved Packet Core), which carries all types of traffic. The EPC consists of Mobility Management Entity (MME) – which is mainly associated with authentication and gateway selection, intra and inter LTE/RAT mobility, bearer management and integrity protection. Serving Gateway (S-GW) – assists in packet routing and forwarding and intra LTE mobility anchor. Packet Data Network

Gateway (P-GW) – allocates the IP address to UE, it acts as a lawful intercept for policy enforcement and also assists in packet routing and forwarding. Policy Charging and Rule Function (PCRF) – manages the QOS in connection by implementing various policies and also keeps track of services accessed by UEs to aid in charging/accounting. Lastly, Home Subscriber System (HSS) – is the database that stores essential information of UEs. It assists in user identification and registration management. Each of these components communicate through particular interface and protocols. The eNodeB and the EPC are connected to each other through the S1 interface. Having understood LTE architecture, the next thing to be thought of is how the mobile communicates using these components. The answer is through a radio bearer which is a logical channel that is established between UE and the eNB [1]. It is also in charge of managing QOS provision on the E-UTRAN interface.

LTE is designed to support wide range of flexible bandwidth ranging from 1.4 MHz to 20 MHz and radio access method is chosen to be different depending on the direction of data/call. Downlink transmission uses the OFDMA (Orthogonal Frequency Division Multiple Access) technique whereas uplink uses the SC-FDMA (Single Carrier – Frequency Division Multiple Access).

2.3 OFDMA – Orthogonal Frequency Division Multiplexing Access

There are different access technologies in communication network that are used for transmission and reception of data. Due to increasing need for efficient utilization of bandwidth there exists a need for choosing an ultimate means of multiplexing technique that can dodge many challenges and achieve maximum efficiency. In LTE, this is achieved by a technique called Orthogonal Frequency Division Multiple Access (OFDMA), which allows the base station to communicate with several UE's at the same time with enumerating advantages of minimum effects of fading and inter-symbol interference as well as increased spectral efficiency. In LTE, downlink transmission uses the OFDMA technique whereas uplink uses the SC-FDMA (Single Carrier – Frequency Division Multiple Access). The figure 2 shows concept of OFDMA in LTE.

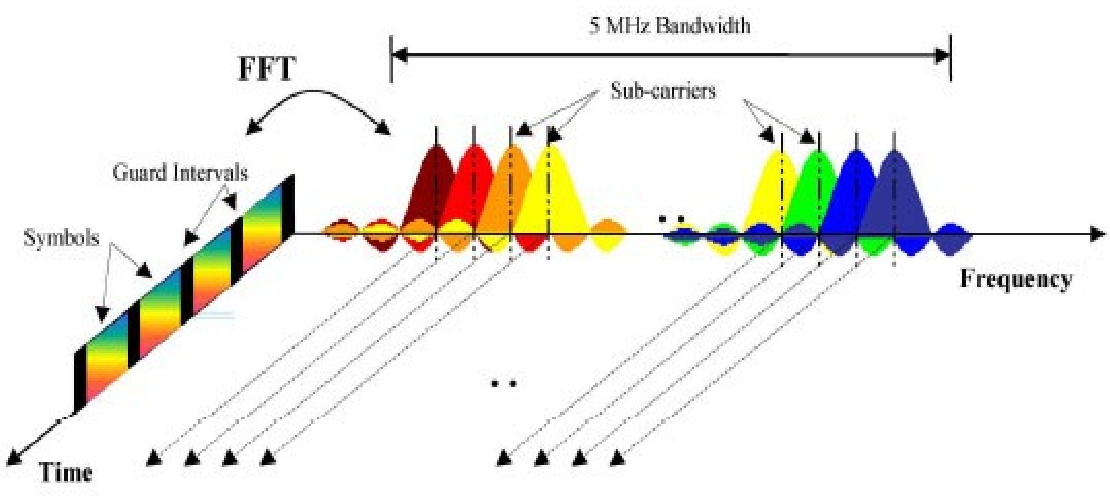


Figure 2: OFDMA in LTE Downlink [7]

OFDMA is a multi-carrier modulation technique where available bandwidth is divided in multiple subcarriers or tones so that multiple users can transmit at same time. The subcarriers are packed in such a way that they overlap and have no guard bands in-between. Overlapping of subcarriers has an advantage of bandwidth savings but at the same time causes interference. This interference is avoided by selecting frequencies that are orthogonal to each other i.e. peak of one tone coincides with zero of other and the receiver detects central frequency of respective tone upon sampling.

2.4 Resource Allocation

With the knowledge of radio access spectrum used by LTE in downlink and uplink, the next important aspect to be thought of is resource allocation. The idea behind resource allocation is that whenever a user requests service, based on various network parameters like channel quality, RSRP (Reference Signal Received Power) and priority, resources are allocated to that particular user. Each system has different performance requirements and depending on this the resource allocation decisions are made. Few metrics that can be thought of are: Quality of Service requirement, size of the buffer, channel quality as reported by the user. If the per RB metric for a particular user is higher than any others requesting the service then that user enjoys the benefit of being allocated.

In order to understand resource allocation, it is very essential to understand how the available bandwidth is split into resource blocks. One of the important feature of LTE is that it can operate over wide range of flexible bandwidth ranging from 1.4MHz to 20MHz. In LTE, chosen bandwidth is divided into number of frames with each radio frame 10ms wide.

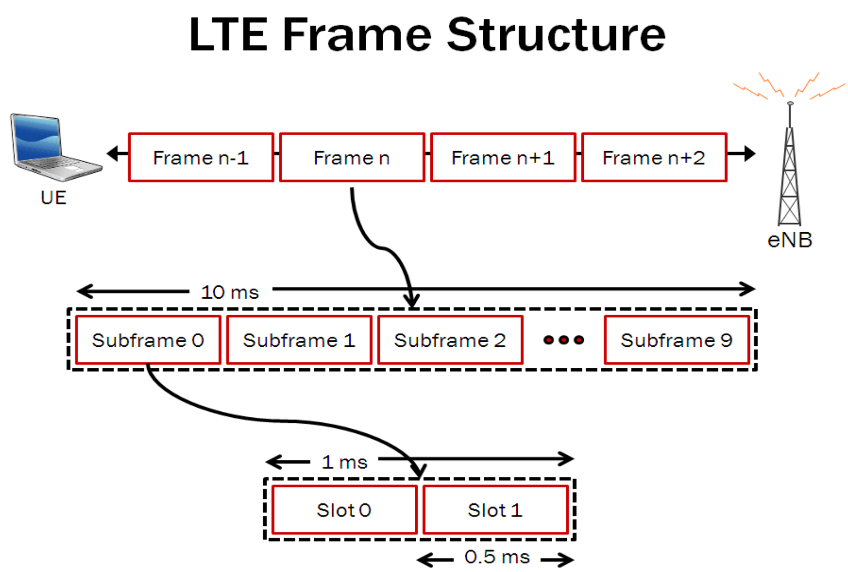


Figure 3: LTE Frame Structure [8]

Each frame of 10ms is further divided into 10 Subframes of 1ms wide. The subframes are further divided into slots and each subframe consists of two slots of 0.5ms wide. It is in this slot that the fundamental unit called the resource block reside and number of resource blocks depend on bandwidth.

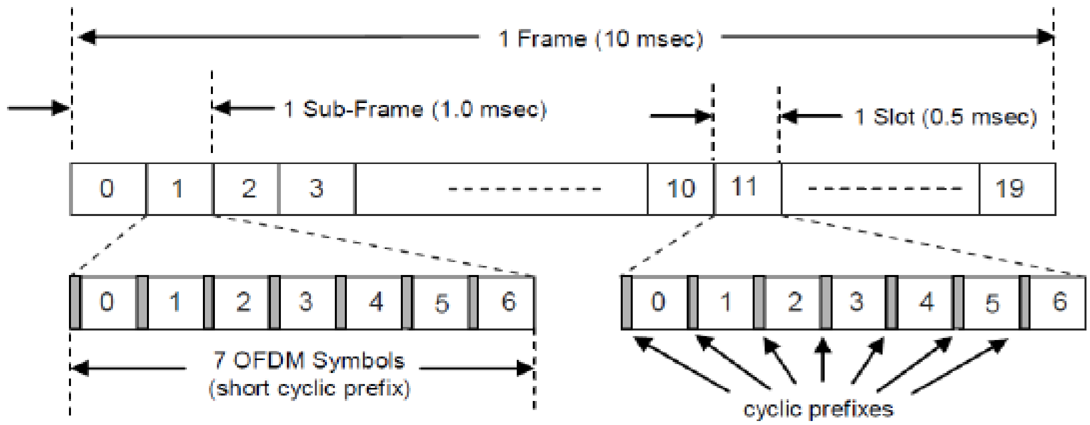


Figure 4: LTE subframe [9]

The figure 4 shows a subframe of 1ms wide. Further each subframe is composed of two slots of 0.5ms wide. Each slot consists of 6 or 7 OFDM symbols depending on the type of cyclic prefix [Normal cyclic prefix – 7 OFDM Symbols, Extended cyclic prefix – 6 OFDM Symbols].

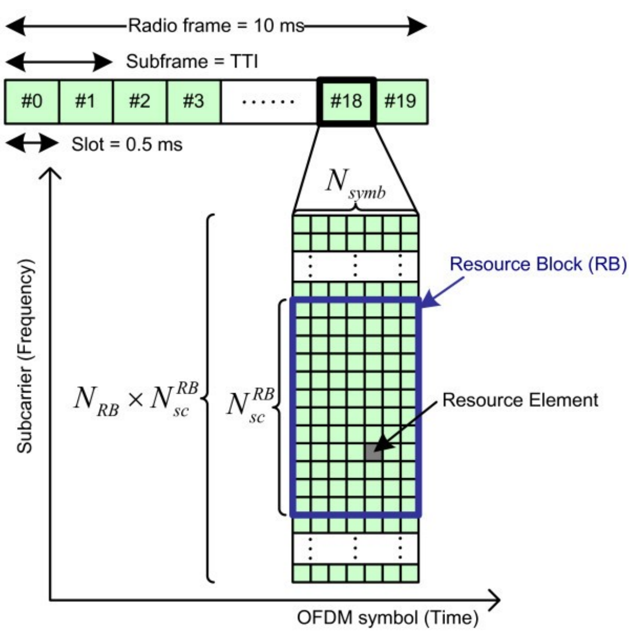


Figure 5: Resource Block [10]

The figure 5 shows the fundamental unit called the Resource Block (RB). Each slot of 0.5ms wide is composed of a grid of OFDM symbols and subcarriers. Each resource block is a grid of 12 subcarriers to 7 or 6 OFDM symbols. The table below shows number of resource blocks available in different bandwidth.

Bandwidth in MHz	1.4	3	5	10	15	20
Number of RB's	6	15	25	50	75	100

Table 1: Bandwidth Vs Number of Resource Blocks

With understanding of need for resource blocks and the parameters that affect the resource allocation, the next thing to be thought of is how these resource blocks are allocated to each users. Based on the type of service and performance requirement, we have different scheduling schemes that allocate resource blocks to users. In the next section we describe various scheduling schemes and the metrics each of them use to allocate resources to users.

2.5 Scheduling

Scheduling is a process of distributing available resources among the users who need service in such a way that Quality of Service [QOS] is maintained. The basic idea is to schedule transmission for UEs that, at current time and on a given frequency, are experiencing "good" channel conditions based on selected metric [1].

In broader sense, the scheduling schemes can be classified into two groups:

- Channel – unaware: These are based on assumption of time-invariant and error free transmission. Ex: Round Robin
- Channel – aware: These are based on channel quality feedbacks which are periodically sent from UEs to the eNB. Ex: Proportional Fair.

We consider Round Robin, Best CQI and Proportional Fair scheduling schemes.

1] Round Robin: Round Robin scheduling scheme is a channel unaware technique in which resources are allocated in order of service requested by user. This scheduling scheme guarantees the fairness among users and does not consider channel quality thus resulting in lower user throughput.

2] Best CQI: The Best CQI scheduling scheme is a channel aware technique that allocates users based on channel conditions. All users report their channel quality to the eNB by sending out a value in response to reference signal sent out by eNB. As the name indicates, users with best channel quality have higher Channel Quality Indicator (CQI) value and they are assigned resources. Since it depends only on channel conditions it achieves higher network throughput but at the cost of fairness.

3] Proportional Fair: The Proportional Fair scheduling scheme is a channel aware scheduling scheme that was developed to overcome drawbacks of Round Robin and Best CQI. It provides fairness in allocation as well as higher throughput and is most used scheduling scheme.

2.6 Femtocells

With increase growth of technology and number of users, the high bandwidth applications have taken their own stand. The need for new spectral bands and efficient management of existing spectrum are increasing at an alarming rate. In order to have new spectrum, higher capacity and handle high volumes of data traffic, there arises a need to deploy additional nodes in that geographical area. But this solution is not easy as it leads to inter-cell interference and also deployment of macro cell accounts for high capital expenditure. To mitigate these challenges a new approach has been designed which involves transforming existing macro network in to a heterogeneous network by deploying low transmit power base stations called small cells along with the existing macro cells. The femtocells being a class of small cells are advantageous because they not only increase the capacity and coverage of the network but also have low implementation cost.

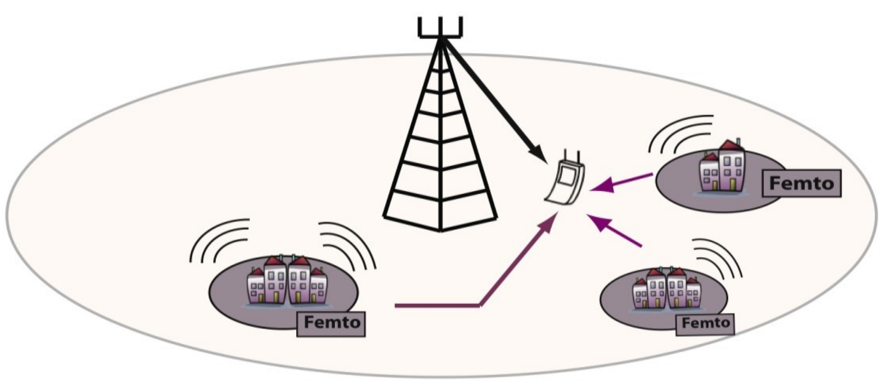


Figure 6: Macro Network with Femtocells [11]

The service provider plans and designs deployment of the femtocells by analyzing traffic pattern over that geographical area because introduction of low-power nodes in a macro network causes imbalance in the network. Due to larger transmit power of the macro base station, handover boundary is shifted closer to femtocells thus creating a strong interference [4] and leading to underutilization of deployed femtocells.

In recent days, most of the interference problems have been resolved making deployment of femtocells an efficient solution for increasing capacity as well as coverage. The main development is ability of femtocells to intelligently control the transmitted power to minimize the degradation of service due to interference. Additionally, at the User Equipment (UE) level, use of interference cancellation receiver helps in receiving strong signal by performing channel gain estimation toward the interfering cell and thus cancelling the interfering signal [4].

CHAPTER 3

PROJECT

3.1 Comparison between Different Scheduling Schemes

This project aims at exploring various features of LTE technology using the Vienna LTE simulator as an efficient 4G LTE network simulator to analyze the performance and ensure reliable communication. The Vienna LTE simulator is an open source MATLAB based simulator developed by The Institute of Telecommunications, The Vienna University of Technology, Austria. It provides a system level simulation of LTE considering various aspects that have an impact on the real world transmitted signal.

With the growing traffic, network congestion is one of the major issues in today's wireless networks. It is of high importance to realize how to eliminate network congestion with increase in number of users and constantly growing high bandwidth applications. One of the ways to overcome network congestion is to schedule users in such a way that each user is served to his minimum need without bringing down the quality of service. The Vienna LTE simulator has implementation of various scheduling schemes that allocate resources to the users requesting the service. In this project, we study the effects of various scheduling schemes on the network as the number of users increase over the geographical area. The scheduling schemes under consideration are Round Robin, Best CQI, and

Proportional Fair scheduling schemes. Using the Vienna LTE simulator we show how the resource blocks are allocated by various scheduling schemes and evaluate performance of these scheduling schemes as the number of users increase in the region of interest. The positions of the users are considered in such a way that each user has good channel conditions i.e. the cell edge users are avoided. The cell edge are avoided because they have lower CQI as they are far from the eNB and experience more interference and fading. We also avoid the users which are very close to base station as these users always tend to have very good channel conditions and on using channel aware scheduling schemes most of resource blocks are allocated to these users and neglecting the users with lower CQI.

This study helps us decide which scheduling scheme is to be considered if throughput is our concern and which scheduling scheme is to be considered if it was fairness.

3.2 Traffic Model Analysis

With increasing number of users in the network, performance of the network also depends on kind of traffic users are flooding the network with. In this thesis, we analyze the operation of various scheduling schemes over different traffic models such as VoIP (Voice over IP), video, gaming, FTP (File Transfer Protocol) and HTTP (Hyper Text Transfer Protocol) with the help of the Vienna LTE simulator. This analysis is important because present day networks have transformed into IP networks and communication units are carried in the form of data packets. Different traffic models have different sizes of data packets and network has a value called Maximum Transmission Unit [MTU], the number of such data packets that collectively need to be sent over the network for the meaningful information to reach to the user depends on the kind of application. For example the video traffic has more data packets to be sent at a faster rate in order to give a better user experience. Using the Vienna LTE simulator we implement different traffic models, obtain results, analyze and develop different ways to increase throughput of the network by using various features of LTE like increasing the system bandwidth and MIMO. As LTE supports wide range of system bandwidth ranging from 1.4 MHz to 20 MHz this study highlights bandwidth requirement for different traffic models and helps us to design the network for its future transformation as per the user traffic over that region.

3.3 Effect of Femtocells on Network Capacity

With the constant increase in number of users in a network, the ability of the macro cell to handle all the data traffic efficiently decreases, making the throughput of the network drop and users experience bad quality of service. Recently, to overcome this problem effectively, a solution has been implemented which not only aids in increasing the capacity and coverage of the network but also helps in increasing the signal strength/connectivity of the cell edge users in the network providing efficient in-building solution to many large organizations. This solution is deployment of small cells (picocells and femtocells) in densely populated areas and at edge of coverage area of the macro network.

In our project, using the Vienna LTE simulator, we demonstrate how the deployment of a femtocell in the macro network increases the throughput of the cell edge users and large number of users in an organization. We firstly consider a macro network with a random user distribution. The distribution is such that there are certain users on the edge of the cell and few are densely packed highlighting the scenario for large buildings such as malls or an organization. For this network, we obtain the network throughput, fairness and average user throughput by using the Vienna LTE simulator. Now for this same network, we then place the femtocells to help the cell edge users and locations where we have user densification like in malls. We obtain the results that were obtained for the macro network and compare the results. After analyzing the results, the importance of the femtocell in the real world network can be emphasized. This study helps us greatly because if a user complains about bad quality of service, using Vienna we can study the network performance of that area then think if by placing the small cells in that area would provide higher quality of service. This can happen before actual deployment of the small cells thus saving a lot of resources for the service provider.

CHAPTER 4

DESIGN: SIMULATOR

4.1 Introduction to the Vienna LTE Simulator

This project involves demonstration of an effective 4G LTE simulator that helps in evaluation of the performance of the 4G LTE Radio Access Technology (RAT). The Vienna LTE Simulator is an open source MATLAB-based simulator developed by the Institute of Telecommunications of The Vienna University of Technology, Austria. This simulator can be used to conduct the link level and system level simulations of LTE in order to demonstrate how crucial the simulations are to evaluate performance of the network before actual deployment or optimization of an existing network.

Reproducibility is one of the major aspects of the foundation for any research. Simulating the results in an environment that is as good as the real world not only validates the results but also provides a strong evidence for its acceptance. In the development and standardization of LTE, and in the implementation process of equipment manufacturers, simulations are necessary to test and optimize algorithms and procedures [3]. The Vienna LTE simulator supports simulations to be carried out on two layers, one is the physical layer [link level] and the other is the MAC and network layer [system level]. The link level simulations assist in investigation of channel estimation, modeling of channel encoding and decoding, Multiple-Input-Multiple-Output [MIMO] gains, adaptive modulation and coding [ACM] and feedback. The system level simulations assist in resource allocation and scheduling, mobility and interference management and network planning optimization.

Here since we are demonstrating the Vienna LTE simulator as an efficient tool to analyze and optimize the network, we use the system level implementation of the Vienna. The simulator consists of two parts: [a] a link measurement model and [b] a link performance model. The link measurement model is the broader depiction of the UE measurements that is very much necessary for link adaptation and resource allocation. The link performance model predicts the BLER of the link, based on the receiver SINR and the transmission parameters [3].

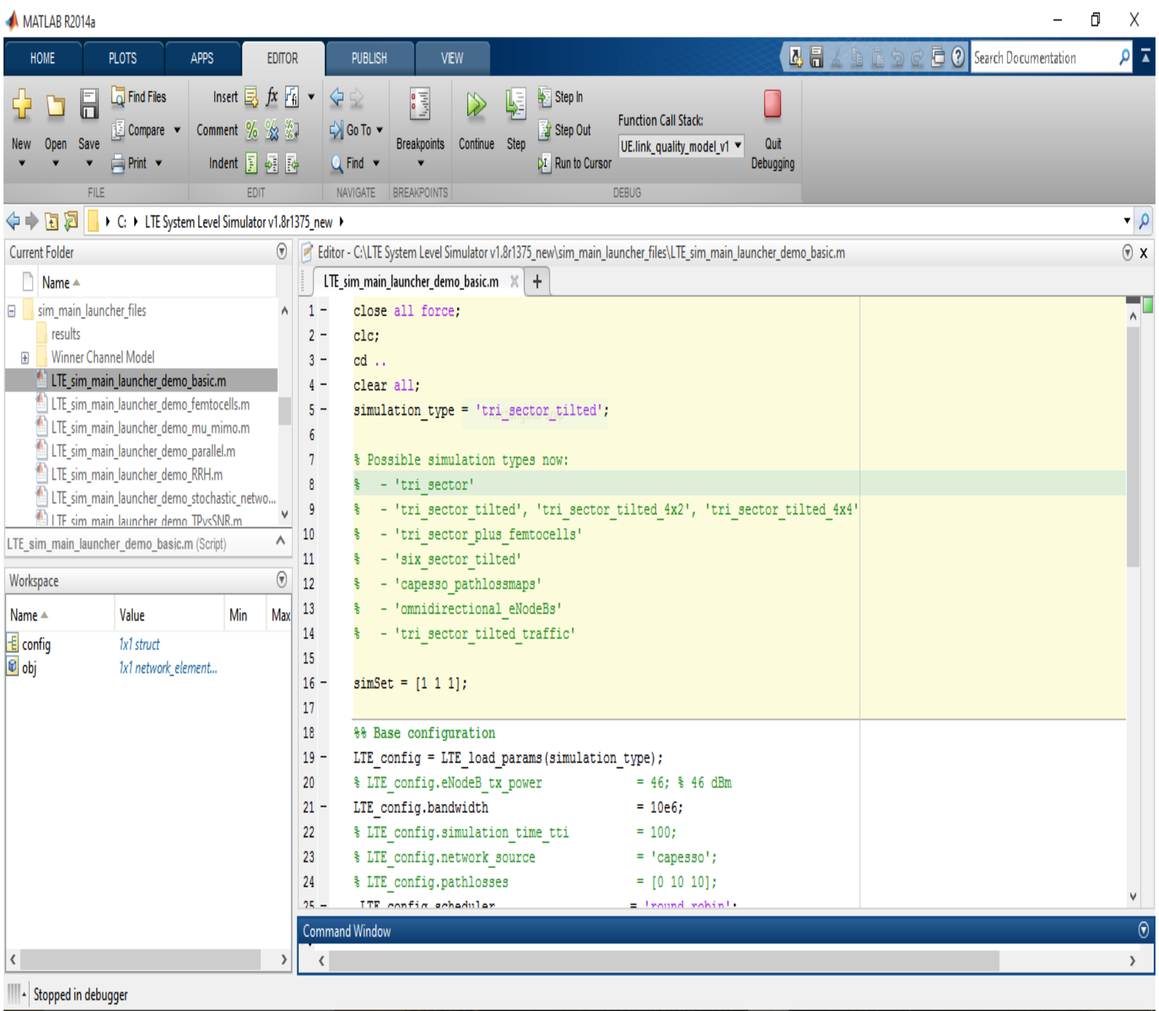
4.2 Operating the Vienna LTE Simulator

In this section we demonstrate how to use the Vienna LTE simulator. The main advantage of the Vienna LTE simulator is that it is an open source simulator which helps a lot of researchers and equipment manufacturers to test, develop and put their ideas into action unlike other existing company grade simulators that require licenses and also provide very minimum scope of development options according to user requirement. The Vienna LTE simulator is a MATLAB-based simulation tool, the main requirement is to possess the MATLAB software with releases from 2008 and later. The mastery level possessed in the MATLAB is directly related to the ease of learning the Vienna LTE simulator. The source code and all the associated files can be obtained by accessing the webpage of the Institute of Telecommunications of The Vienna University of Technology. It requires registration and accepting the license which can be accessed through the website http://www.nt.tuwien.ac.at/research/mobile-communications/vienna-lte-a-simulators/. Based on the research requirement and results to be reproduced, the license for appropriate model is requested. Once the license is approved, the files containing MATLAB source code is sent by the institute.

The simulator mainly consists of four main parts:

- Simulation Launcher: This is the MATLAB file that is used to specify and configure the network parameters that are used by the main file. All simulations are to be started only through this file.
- Simulation Type: This is the code that is used to specific the type of network that is being simulated. For example: We have tri-sector tilted, tri-sector tilted with femtocell, tri-sector tilted with traffic and a few more that specify the environment and allow us to configure certain parameters specific to the environment considered that cannot be accessed through the launcher file

- Simulation Main: This is the main file that simulates the network and produces results according to the parameters given by simulation launcher.
- GUI of Output results: This is the file that shows the graphical representation of simulated network. Even though it is invoked in the Simulation Launcher, it can be seen as a separate entity as the results are shown in GUI format.



The first step is to open the simulation launcher file in MATLAB and configure parameters according to the network to be reproduced or research goals. The second step is to select the environment and configure the additional parameters in the simulation type file. The additional parameters generally that can be configured here are femtocell parameters, various path loss and coupling loss parameters, scheduling parameters, network plots display mode and many more. Next, we hit the run icon in the editor window of MATLAB to run the simulation. The simulation starts and produces the results.

CHAPTER 5

RESULTS AND ANALYSIS

The main objective of the project was to demonstrate an effective 4G LTE network simulator to reproduce the network and evaluate the performance for various conditions enabling the efficient deployment and optimization. With Vienna LTE Simulator being the simulator of interest, in order to demonstrate how effective simulator is, we undertake the following tasks and show how efficiently and easily the simulator reproduces the results that making it an effective simulator.

The first task is performance evaluation of various scheduling schemes with the evolution of the network.

5.1 Performance Evaluation of Different Scheduling Schemes for Macro Cells

In this section we compare and evaluate the performance of different scheduling schemes using the Vienna LTE Simulator. This study helps us to understand how the resources are allocated to each user and the various factors that affect the scheduling. The role of the scheduling schemes is to allocate the resource blocks to users depending on signal quality and channel conditions. The three well known scheduling schemes are Round Robin, Best CQI and Proportional Fair. In this section, we compare these scheduling schemes for their performance evaluation with increase in number of users. The results obtained help us to decide the best scheduling scheme for a network to overcome network congestion and highlight features of the Vienna LTE simulator.

The network under consideration has the following properties.

System Bandwidth	10 MHz [50 Resource Blocks]
System Frequency	2.14 GHz
Number of Transmitter	1
Number of Receiver	1
Number of Users	15, 30, 45, 60, 75, 90
Scheduling Algorithm	Round Robin, Best CQI, Proportional Fair
Channel Model	3GPP TU
Pathloss Model	TS36942 – Urban

Table 2: Network Configuration for comparing scheduling schemes

The network is configured with the above mentioned parameters and the simulation is run on the Vienna LTE simulator. The network configuration is specified in the launcher file and few other parameters are specified in the simulation config file. The number of users are varied from 15 to 90 users with random distribution and the resulting fairness, average user throughput and cell throughout are compared for each scheduling scheme starting from the Round Robin scheduling scheme. The figure 7 shows 15 randomly distributed users in a cell using Round Robin scheduling scheme.

The users are distributed in such a way that most of them have good channel conditions. We avoid the users which are very close to base station because these users always have very good channel conditions and on using channel aware scheduling schemes most of resource blocks are allocated to these users, neglecting the users with lower CQI. To make a valid comparison between the channel aware and channel unaware scheduling algorithms, we consider users that are distributed in the region between the cell center and the cell edge. The users are randomly distributed in the region of interest.

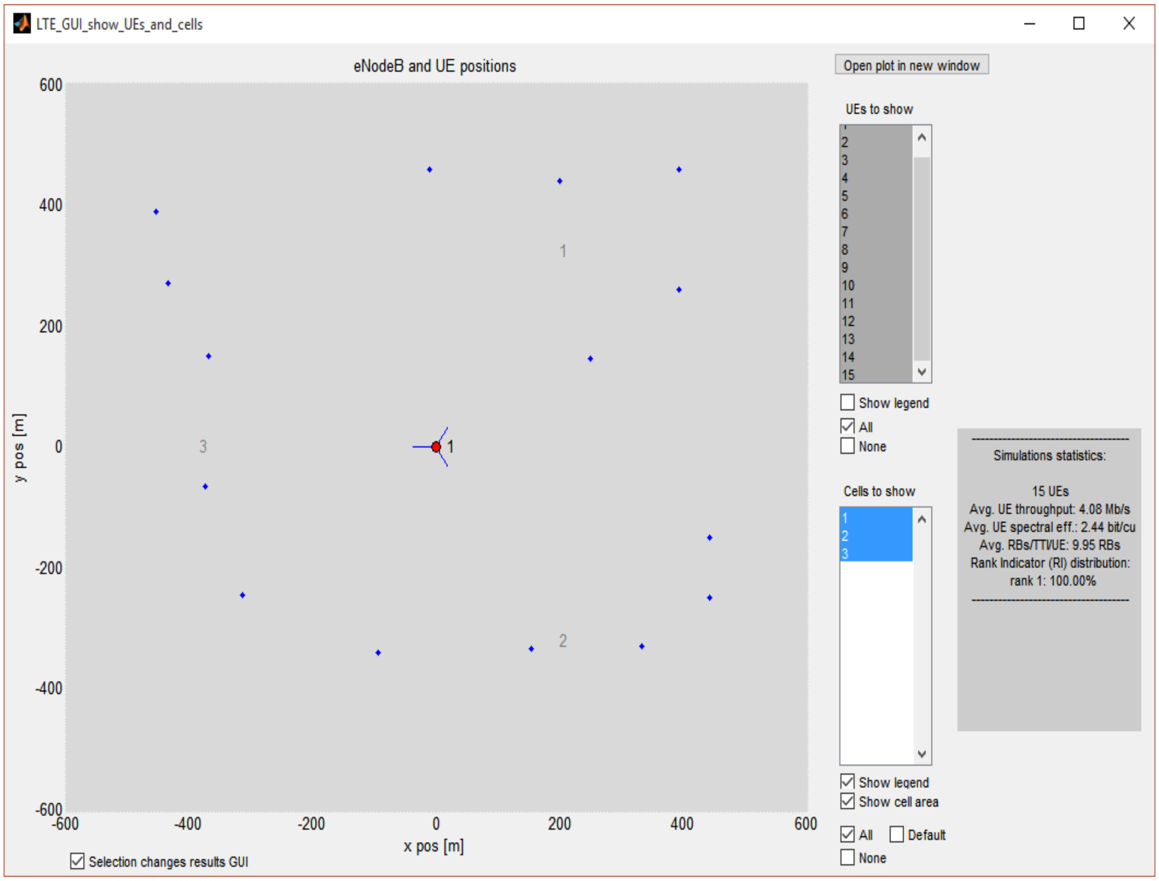


Figure 7: Network under study with 15 users

For this network, simulation is run by attaching each user to its corresponding sector and each sector using the Round Robin scheduling scheme. Since Round Robin allocates the resources to each user requesting the service the fairness of this scheduling scheme is high and the results show the same. For simulation purposes, the traffic model is assumed to be full buffer, meaning that all the users have a packet to send. The figure 8 shows the simulation results for this setup run for 50 TTI's [Transmission Time Interval].

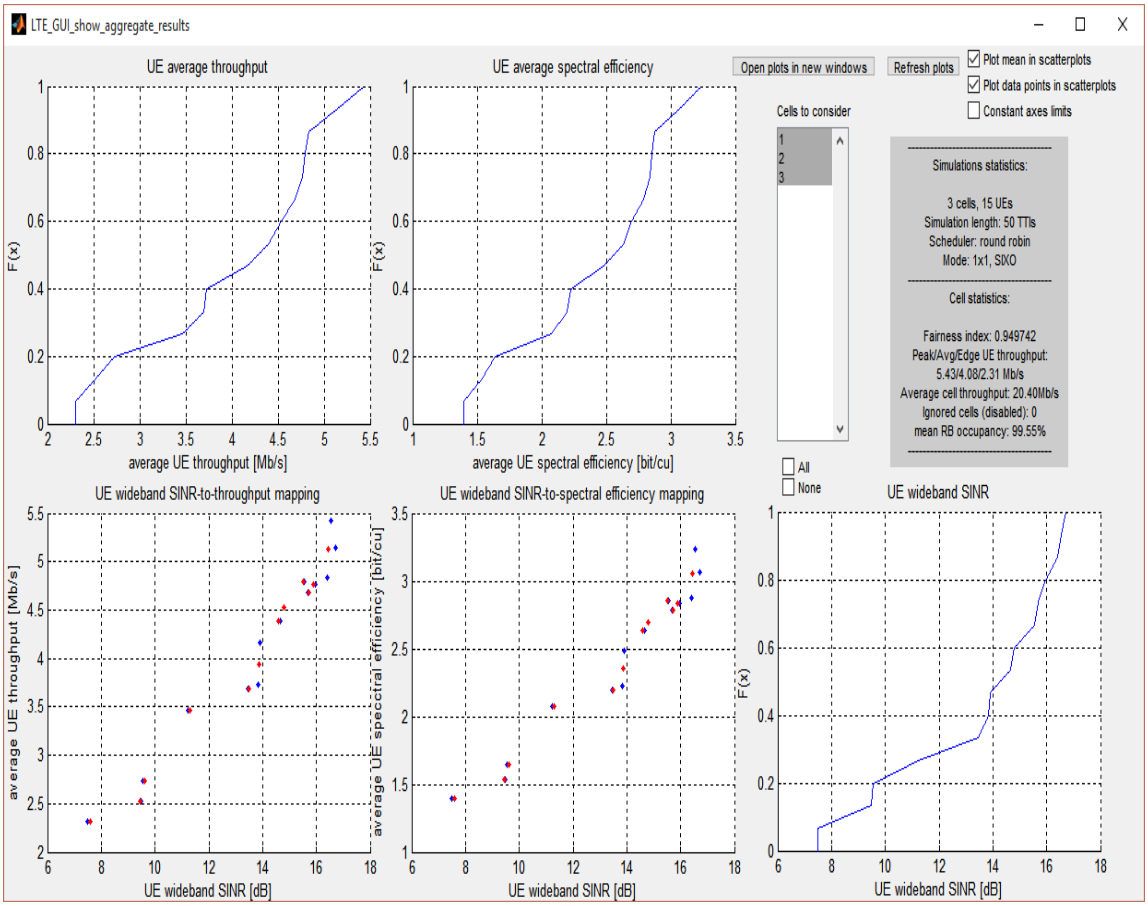


Figure 8: Simulation results for Round Robin scheme with 15 users

The graphs show the various results that help in assessing the network operation based on network configuration. They show how the average throughput varies with the SINR and the spectral efficiency. The upper right corner displays the fairness index, average/peak and edge user throughput and also the total cell throughput. This network shows that the fairness index of the network is 0.95 which is as expected for the Round Robin as it serves all the users requesting service. Each user has average user throughput of 4.08 Mbps. The similar simulations are carried out for the Best CQI and Proportional Fair scheduling scheme with increasing number of users and results are compared to evaluate best scheduling scheme under different network conditions.

The next few figures show the user distribution in the network as the number of users increase. In each trail the number of users are assumed to increase in steps of 15. So the distribution consists of 30, 45, 60, 75 and 90 users.

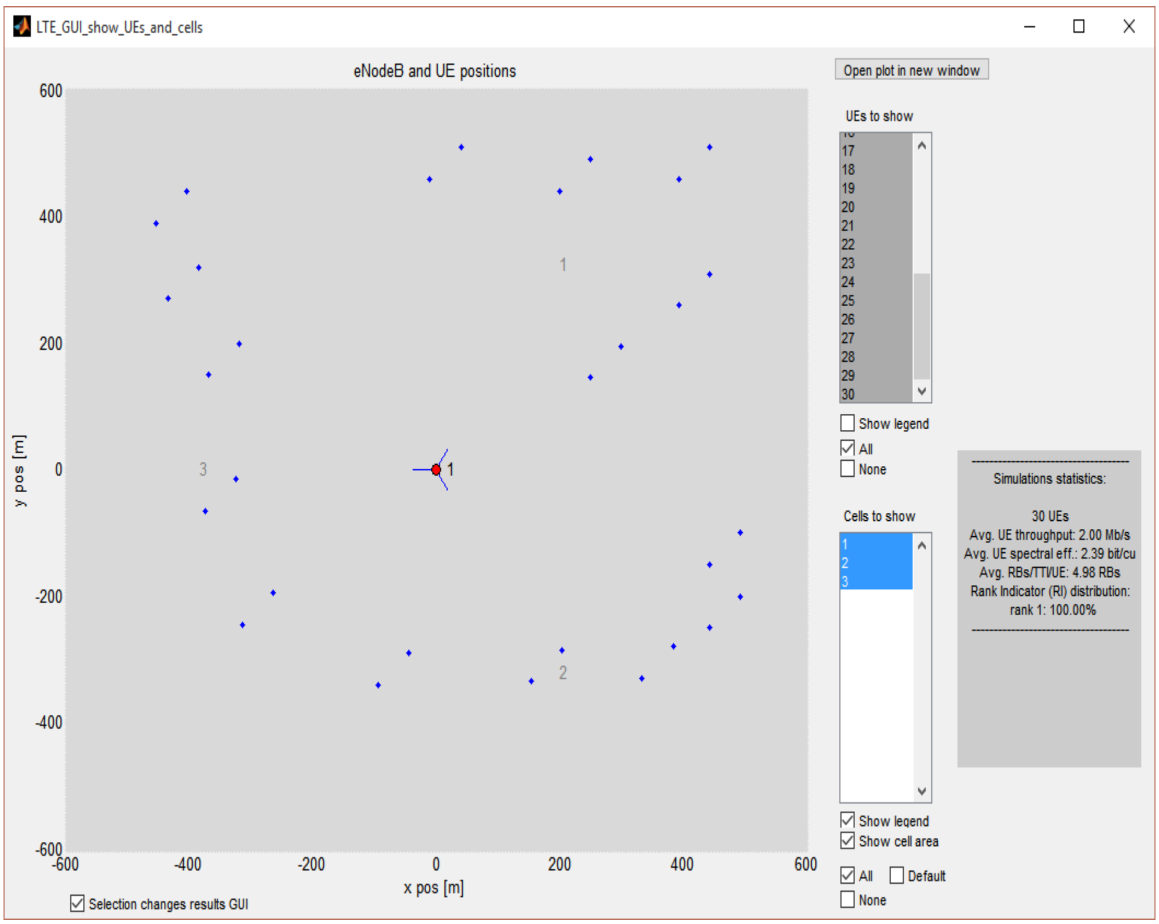


Figure 9: Network under study with 30 users

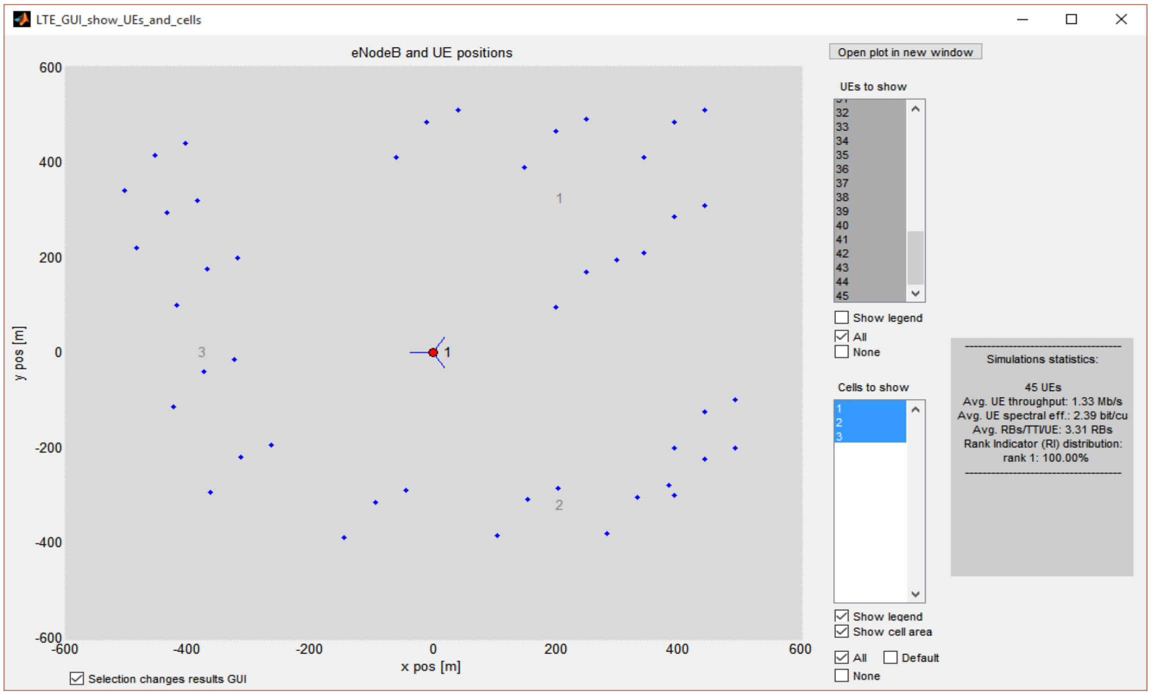


Figure 10: Network under study with 45 users

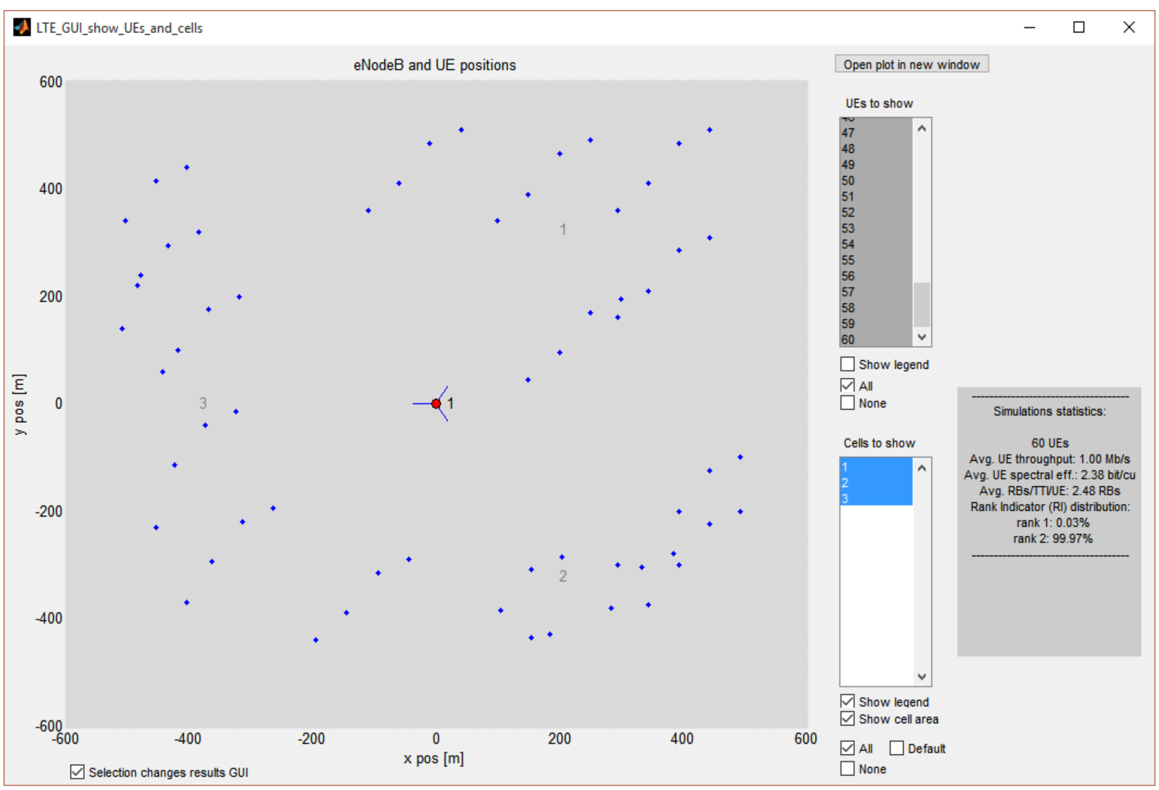


Figure 11: Network under study with 60 users

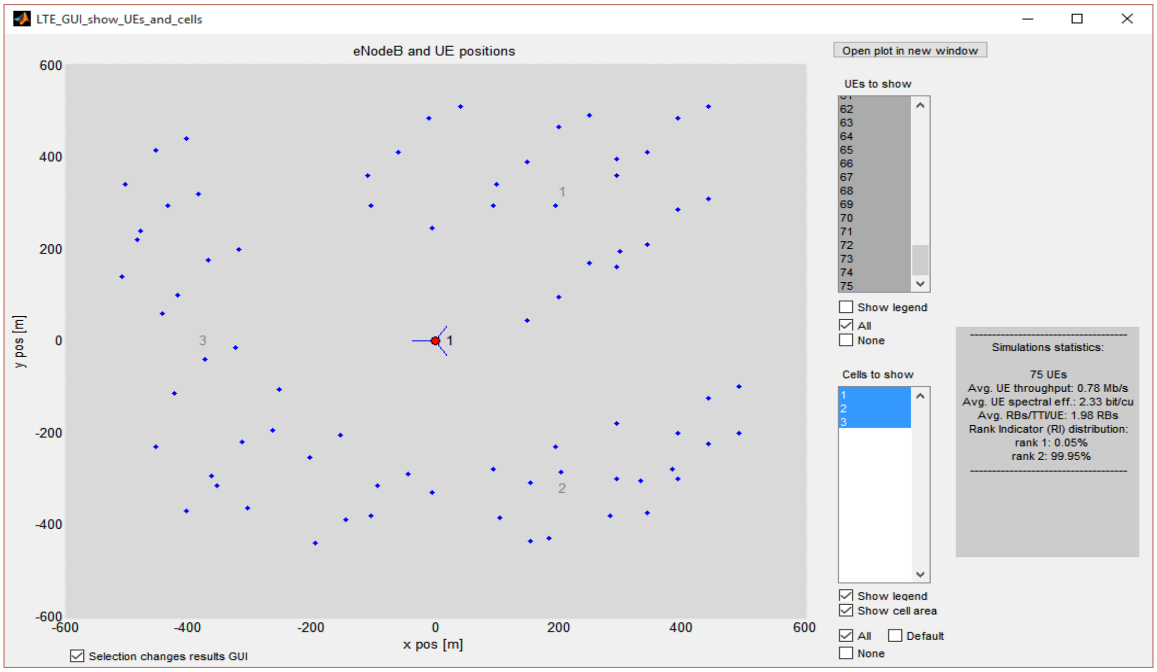


Figure 12: Network under study with 75 users

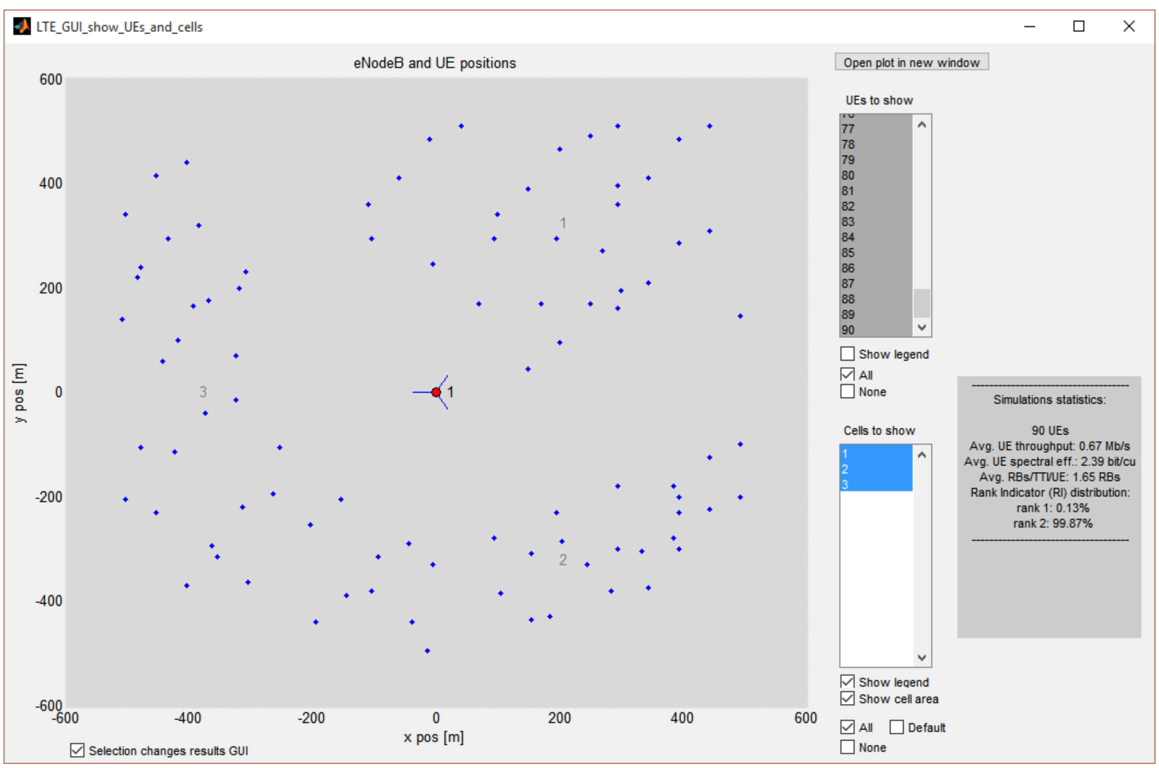


Figure 13: Network under study with 90 users

For each of these networks various measurements are obtained for different scheduling schemes. The figure 14 shows the variation of fairness index for different users for three scheduling schemes under study.

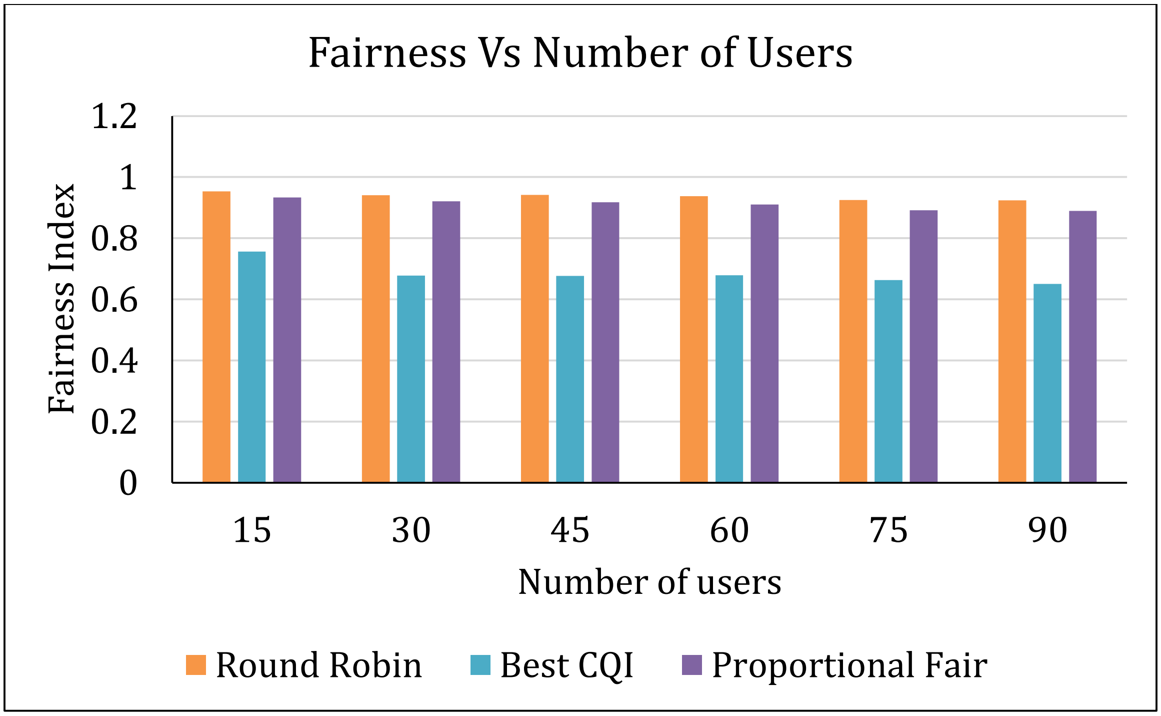


Figure 14: Fairness index of different scheduling schemes

The graph shows that the Round Robin scheduling scheme has the highest fairness index when compared to other two scheduling schemes. The fairness index is the measure of how each user is served in a network if they had requested for resource blocks. We also observe that fairness index decreases in small fractions with increase in number of users. The Proportional Fair scheduling scheme stands next to Round Robin in being fair to allocate the resources to the users. The Best CQI scheduling scheme has the least fairness index among the three scheduling schemes because this scheduling scheme mainly depends on the channel conditions, thus even though a cell edge user has the data to send he is not allocated resources if the channel conditions are bad.

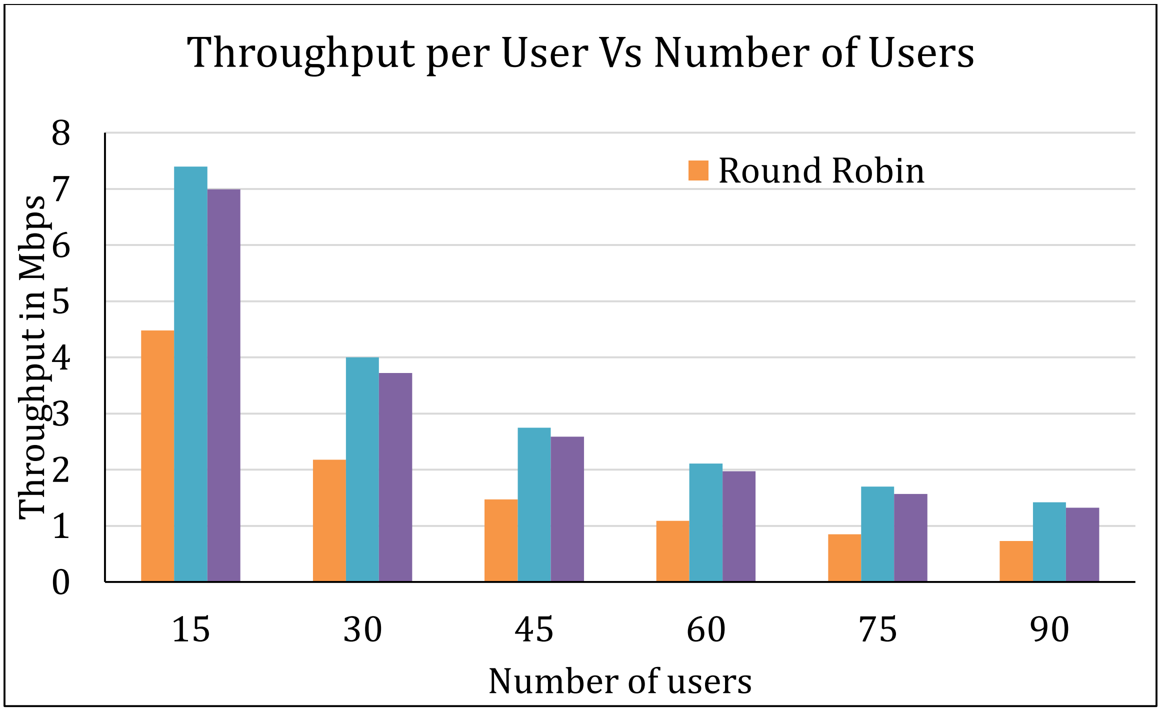


Figure 15: Average per User Throughput using different scheduling schemes

The figure 15 shows the graph indicating variation of average per user throughput with number of users for different scheduling schemes. The graph indicates that Best CQI scheduling scheme has the ability to achieve the highest throughput in a network as this scheduling scheme is channel aware. Depending on the channel conditions, the resource blocks are allocated to the users. In this scheme if the cell edge users had data to send they are not given resources because they tend to possess bad channel due to their distance from eNodeB. The Proportional Fair scheduling scheme stands next in achieving best average throughput as this scheme is channel aware. But, due to its ability to be fair enough the average throughput achieved here is little less when compared to Best CQI. The Round Robin has the least average throughput as this is channel unaware and allocates the resource blocks to all users requesting service in order.

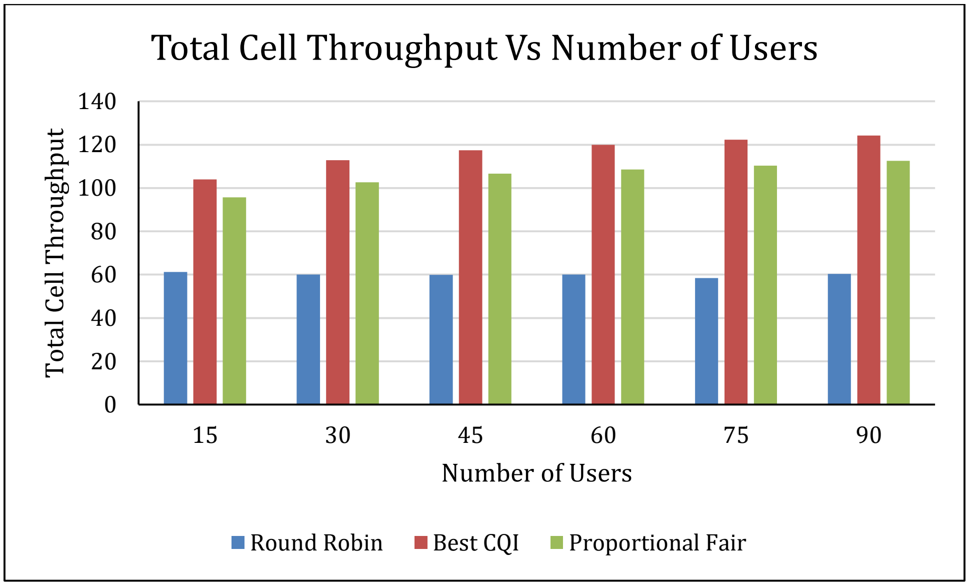


Figure 15.a: Total Cell Throughput different scheduling schemes

The figure 15 a shows the variation of the total cell throughput as number of users increase in the network. For Round Robin the total cell throughput almost remains the same as the available resource blocks is equally divided between all the users and it increases with number of users for Best CQI and Proportional Fair.

With this analysis of fairness and average user throughput between different scheduling schemes, we draw the conclusion of the best scheduling scheme for the network. If the networks requirement was to be fair with neglecting the average user throughput then Round Robin is the best scheduling scheme for that network. If the networks requirement was to achieve highest average user throughput over fairness then Best CQI scheduling scheme is the best choice for the network. Finally, if the network wanted to have optimal performance between fairness and throughput then the Proportional Fair scheduling scheme has ability to ensure both better fairness and throughput in the network.

If Proportional Fair scheduling scheme is the best then the below graphs show how better it is when compared to the Round Robin and Best CQI. The main feature of Round Robin is that it offers the network highest degree of fairness against the throughput. Though the fairness two scheduling schemes offer to the network is almost equal the Proportional Fair outwits the Round Robin in the average user throughput.

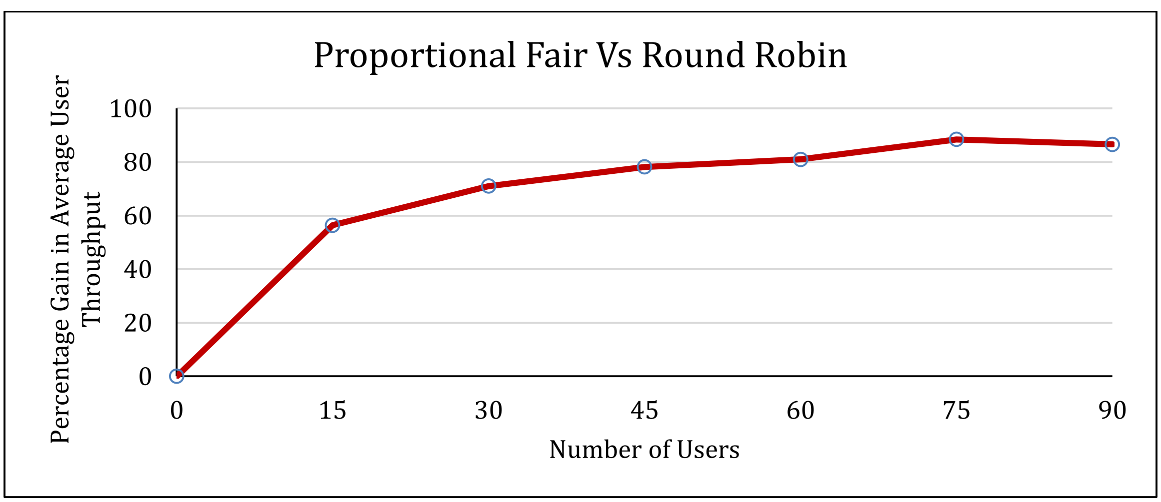


Figure 16: Comparison between Proportional Fair and Round Robin on throughput

The figure 16 shows the comparison between the Round Robin and the Proportional Fair with respect to their key component user throughput. The plot shows the graph of percentage gain in user throughput of Proportional Fair compared to Round Robin with increase in number of users. It shows that the average user throughput increase almost 100% for 90 users network using Proportional Fair with little trade off in the fairness.

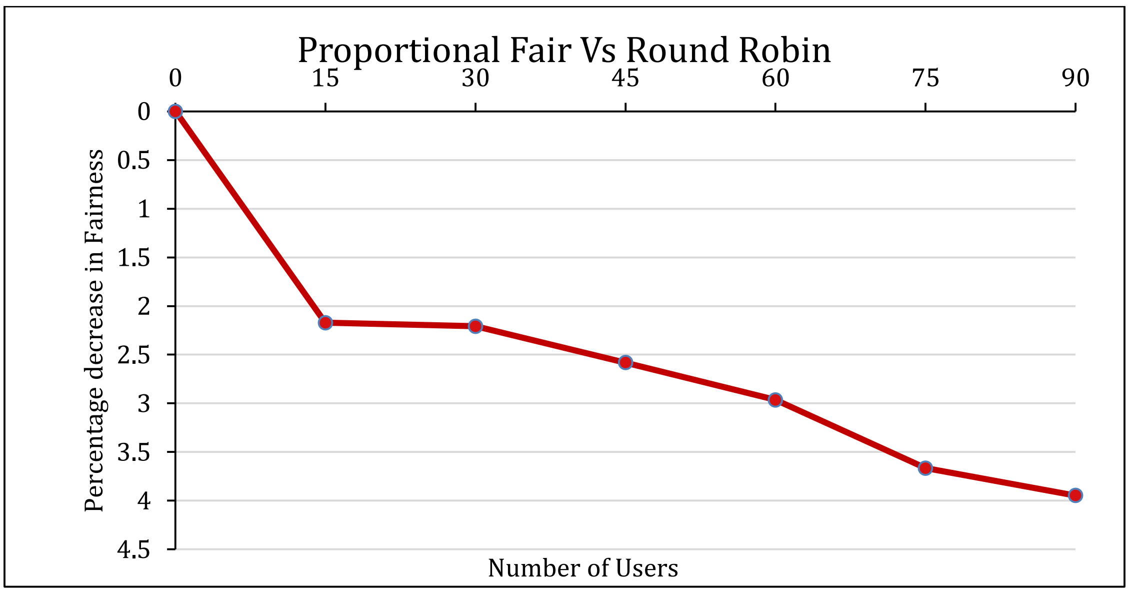


Figure 17: Comparison between Proportional Fair and Round Robin on fairness

The figure 17 shows the comparison between the Round Robin and the Proportional Fair with respect to fairness. The plot shows the graph of percentage decrease in fairness of Proportional Fair compared to Round Robin with number of users. The Proportional Fair scheduling shows gradual decrease compared to Round Robin as it is channel aware and allocates the user in terms of metrics.

The figure 18 shows the comparison between the Proportional Fair and Best CQI, but here the key component of comparison is the fairness index.

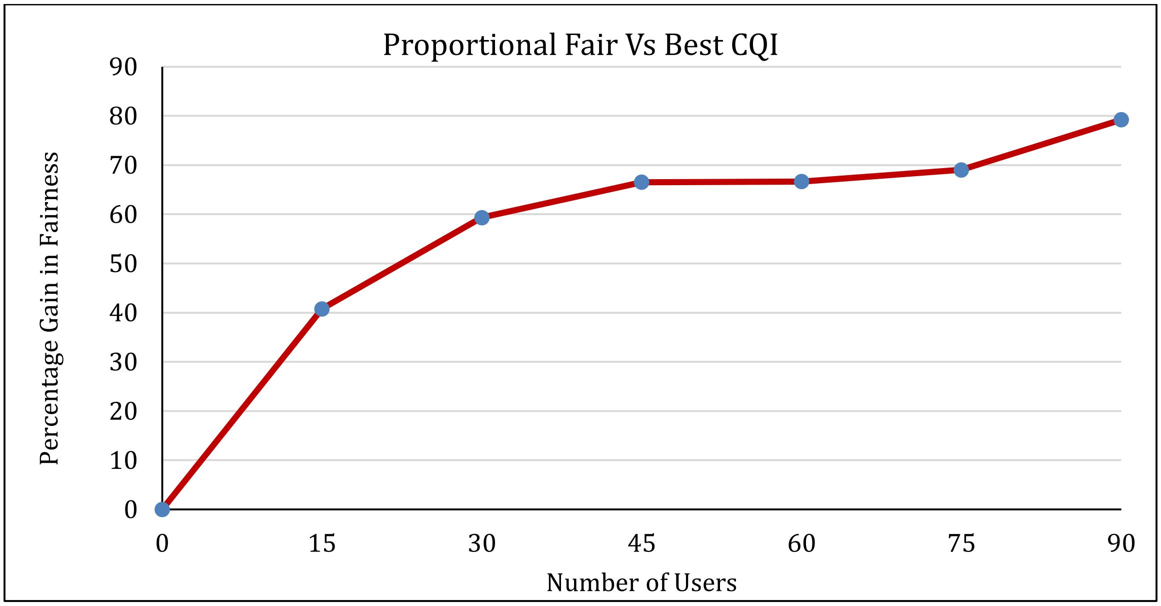


Figure 18: Comparison between Proportional Fair and Best CQI on fairness

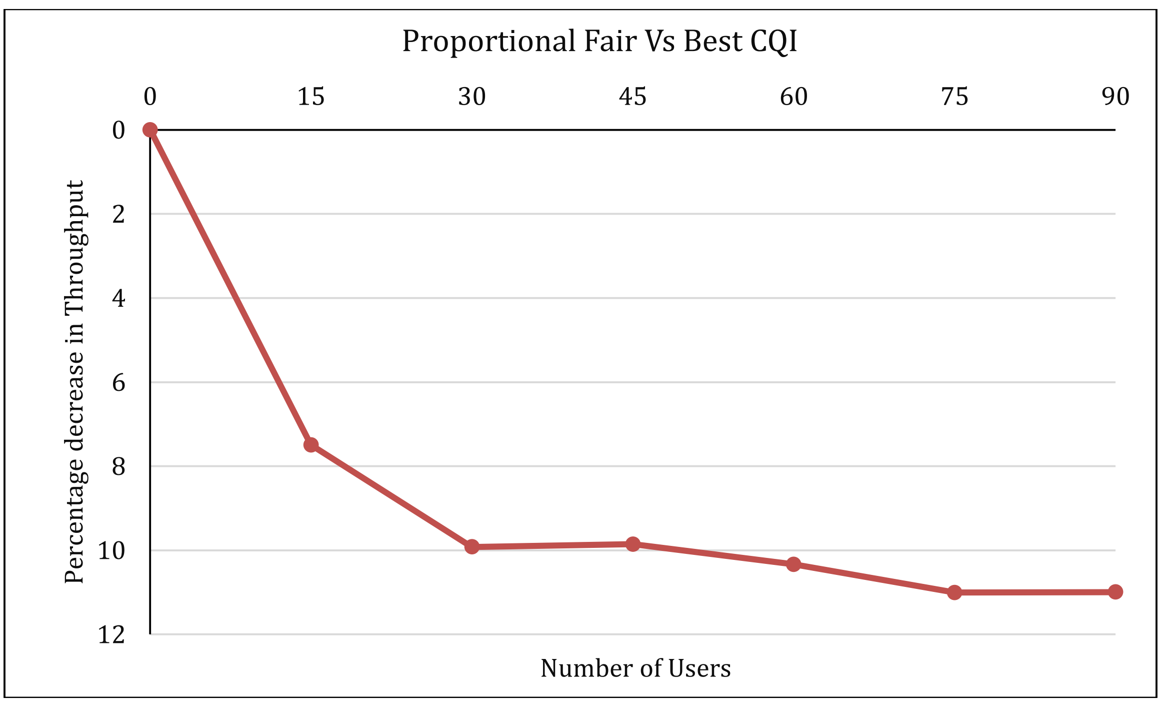


Figure 19: Comparison between Proportional Fair and Best CQI on throughput

The figure 19 highlights that the user throughput for network using Best CQI or Proportional Fair do not have much of difference. The Best CQI has higher throughput and it's about 10% more than Proportional fair for 90 user network. However, the major plus for the Proportional Fair is the much better fairness index. The figure 18 shows the percentage increase in fairness index for Proportional Fair scheme with increase in number of users. The graph shows almost 80% increase in fairness index for 90 users indicating that most of the users requesting the service are served.

Thus the Proportional Fair scheduling is the best scheduling scheme for a network requiring higher throughput with better fairness. The performance evaluation study highlights Proportional Fair scheduling scheme as the best scheduling scheme.

5.2 Performance Evaluation of Scheduling Schemes for Small Cells

With this study proving the Proportional Fair as the best, with increased small cells deployment in practice there arises a need for an additional study which proposes to see if Best CQI is better than Proportional Fair with small cells. The main motivation for this study is that, the users closer to eNodeB have better channel conditions and can achieve higher throughput using Best CQI than any scheme. The major sufferers are the cell edge users which have uneven channel conditions due to their distance and interference from neighboring cells. If small cells are deployed in these regions then all the cell edge users have good channel conditions too and can achieve higher throughput with certain degree of fairness. Is it really efficient to have Best CQI with small cells or use Proportional Fair? This section focuses on this idea.

To evaluate this idea we design the network as shown in the figure. The network shows three macro cells with 30 users per sector, same as the earlier 90 user distribution. Additionally this cell includes the small cells placed at the edge, which enhances the channel conditions of the cell edge users. There are three small cells placed in each cell with each small cell serving an additional 10 users. There are a total of 60 users in a sector area.

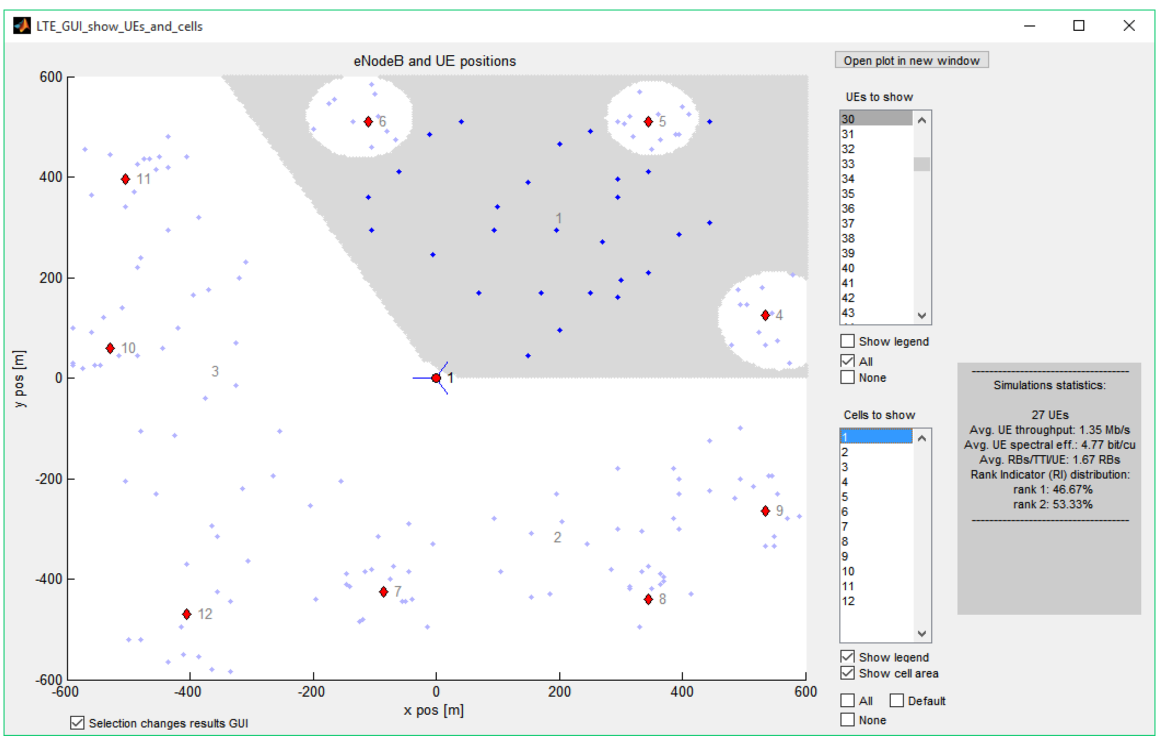


Figure 20: Network for Comparing Proportional Fair and Best CQI

The small cells are placed at the edges and the simulation is run. The values for the throughput and the fairness are recorded for two cases on this network. One uses the Proportional Fair and other Best CQI. The figures 21 and figures 22 show the comparison between the two for average user throughput.

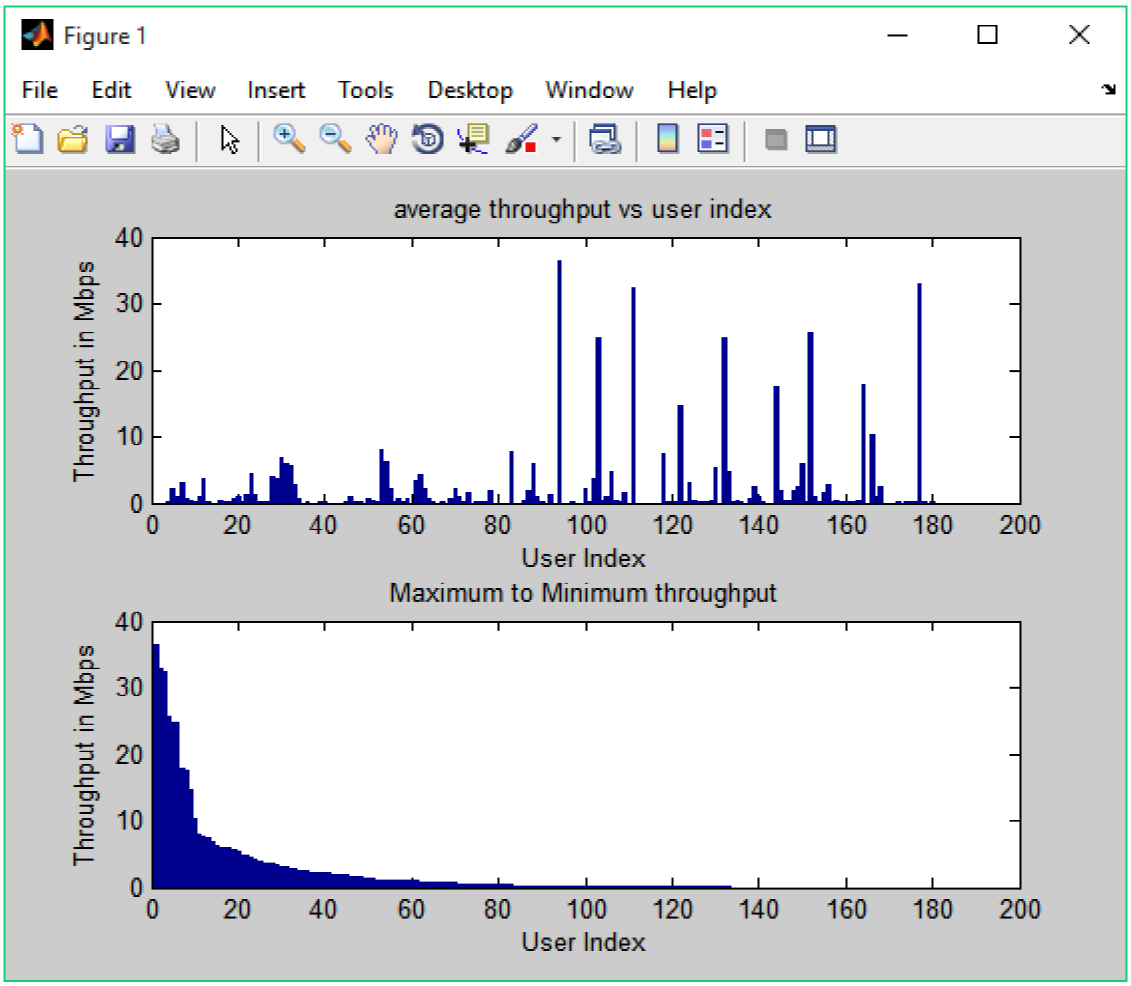


Figure 21: Average User Throughput for Best CQI

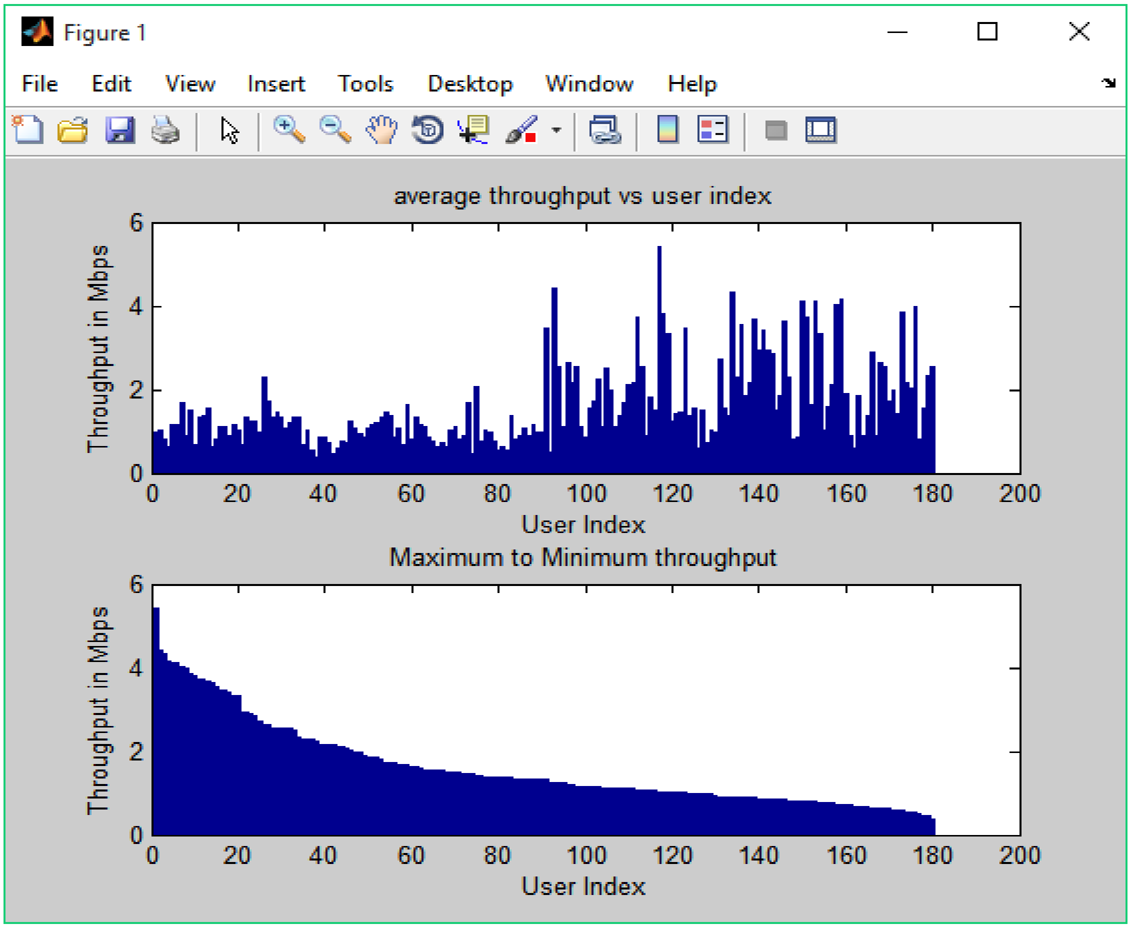


Figure 22: Average User Throughput for Proportional Fair

The figures 21 and 22 show that even though the Best CQI showed higher user throughput for certain users with addition of small cells, it still had certain users that were not served and hence having a low fairness. In contrast, even though the Proportional Fair showed lower user throughput compared to Best CQI, it had higher fairness which can be verified from the plot. The above plot shows that all the users in the network using Proportional Fair scheme were served with each user having certain throughput.

Thus the Proportional Fair scheduling scheme can be titled as the best scheduling scheme for a network because it ensures better throughput as well as fairness. However, the choice of scheduling scheme depends on the need of the network but the performance evaluation shows that the Proportional Fair scheduling scheme is better compared to the Round Robin and Best CQI for all the networks requiring optimal results.

5.3 Traffic model analysis

Having evaluated the performance of various scheduling schemes, next section highlights feature of the Vienna LTE simulator that helps in analyzing effect of different traffic models on the network. The study of traffic models not only helps us to understand network behavior for particular traffic but also help in optimization and plan the network for the bandwidth and other requirements so that the users can enjoy the better quality of service.

The Vienna LTE simulator offers a wide range of traffic models that help in modelling the real world network more efficiently. The major traffic models Vienna supports are FTP [File Transfer Protocol], HTTP [Hyper Text Transfer Protocol], VoIP [Voice over Internet Protocol], Video and Gaming. The main motivation for this study is, by surveying the region of interest for bandwidth usage at different times of the day, load on the network is estimated for every hour. Using these statistics we determine the bandwidth and network requirements for each these traffic at different time of the day to satisfy the QOS requirement. Using this data network is planned and deployed. This helps in making the network more reliable for unexpected increase in load at certain time of day. Thus in this section we do the performance evaluation of traffic models using the Vienna LTE simulator. We consider a network with 90 randomly distributed users such that all the users are in the vicinity of good coverage. For different traffic models using the Proportional Fair scheduling scheme, we obtain the average user throughput and the fairness index when only certain type of traffic circulates over the entire network and evaluate the performance.

Figure 23 shows the network under study. The Vienna LTE offers two scheduling schemes to evaluate the traffic models, they are Round Robin and Proportional Fair scheduling schemes. We run the simulation for various traffic models and obtain the graph comparing the fairness and average user throughput for all the traffic models and define the design strategy to optimize the network.

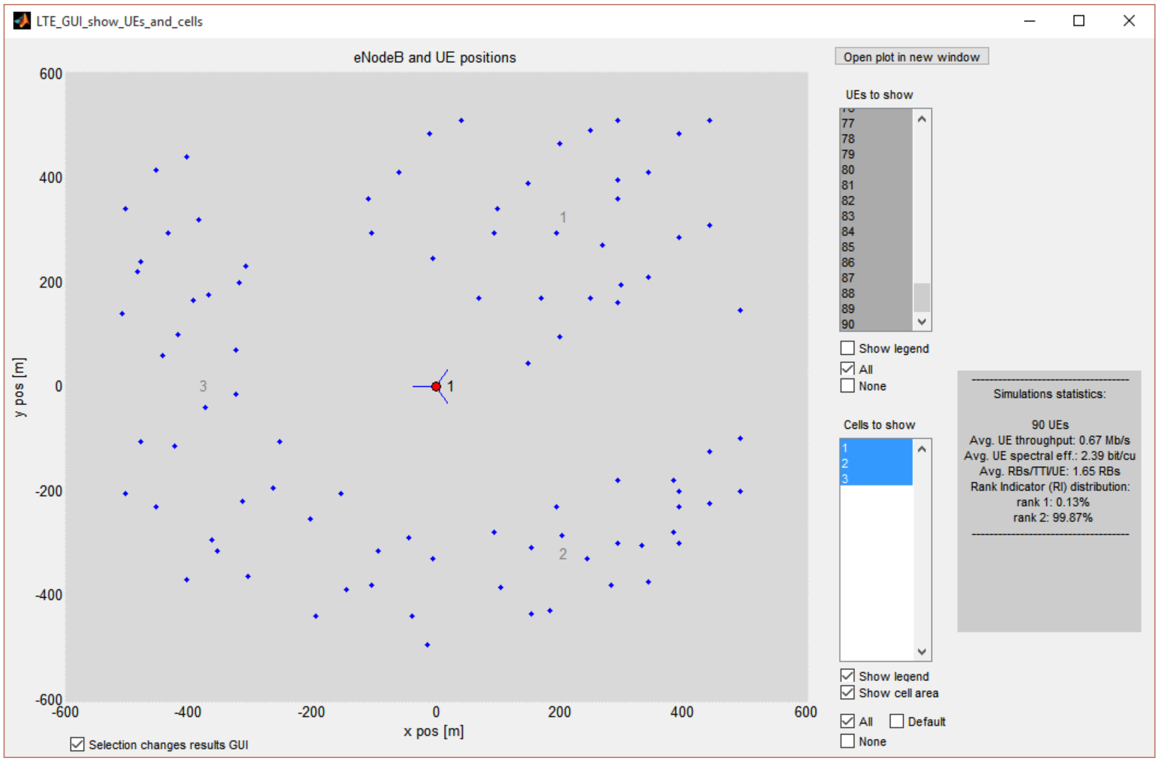


Figure 23: Network under study with 90 users

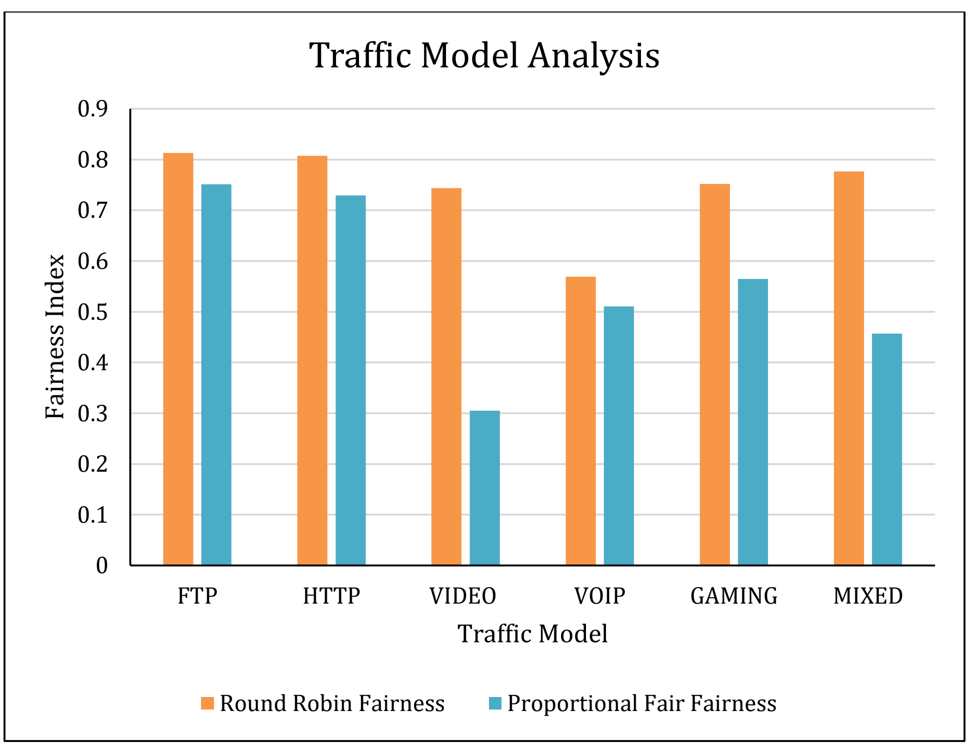


Figure 24: Fairness comparison between PF and RR for different Traffic models

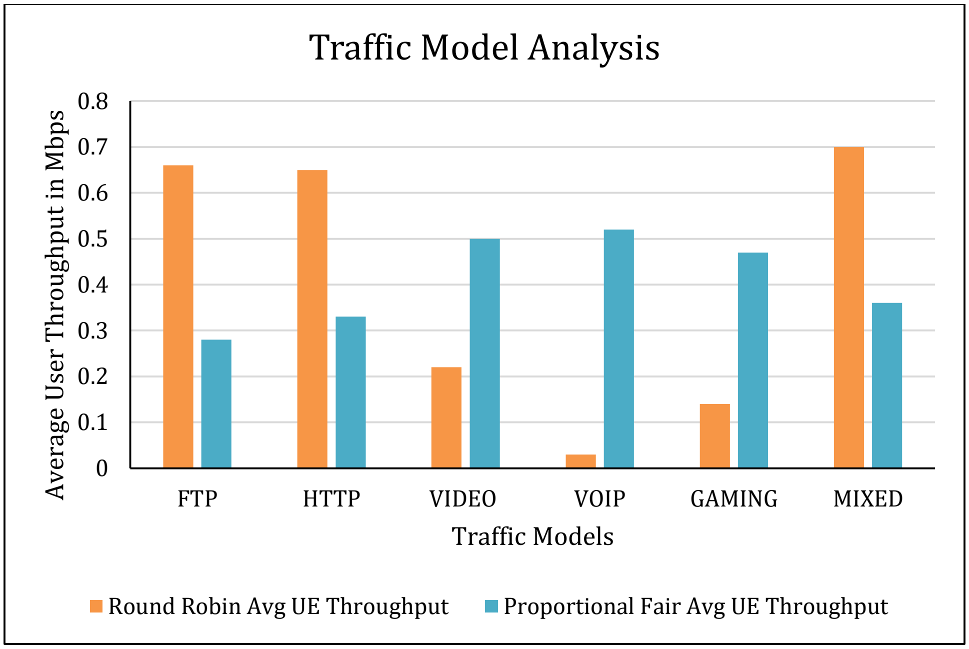


Figure 25: Throughput comparison between PF and RR for different Traffic models

The figures 24 and 25 show results for the throughput and fairness for the network under study using the Round Robin and Proportional Fair scheduling scheme. The fairness plot show that, the Round Robin has a better fairness for all the traffic models. Even though Proportional Fair performs better for FTP and HTTP, the fairness for the video, gaming and all the traffic in equal proportion called "Mixed" is low compared to Round Robin. The plot of average user throughput shows that the high bandwidth applications such as video, VoIP and gaming models perform well on Proportional Fair scheduling scheme but the other traffic models have a better user throughput using Round Robin. If each of these traffic models were equally distributed over network then Round Robin scheduling scheme performs better than Proportional Fair.

Since the Proportional Fair scheduling scheme is the most widely used scheduling scheme and its performance towards VoIP, video and gaming traffic models is low, due to increased use of these high bandwidth traffic, in this section we consider planning the network by deploying the small cells at the cell edge and see if they can take care of those users flooding the macro network with these type of traffic and effectively increase the overall cell throughput. The figure 26 shows the network under consideration.

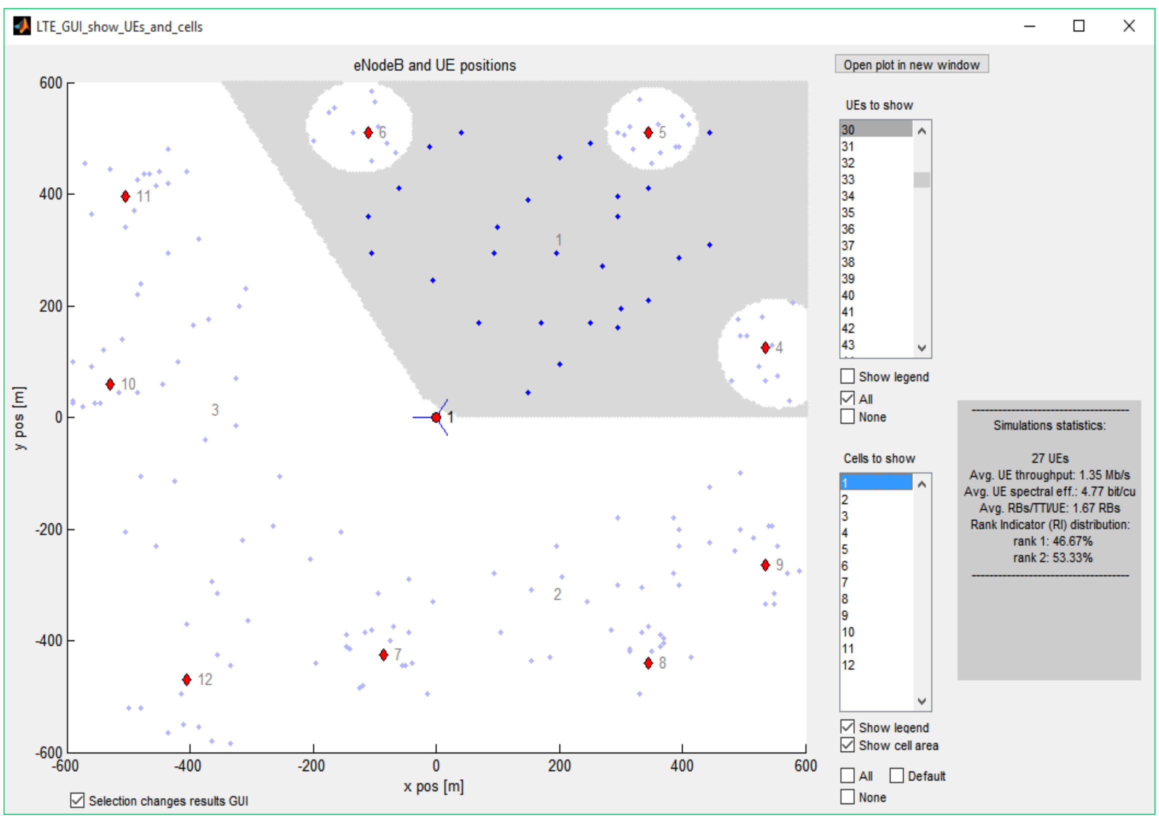


Figure 26: Network for demonstrating the traffic planning

The network consists of a macro cell with 3 sectors with 30 users in each sector. To this macro cell, three small cells are placed along the edge and each cell serving 10 users making a total of 60 users per sector. The small cells are designed to serve 80% of users having the video, gaming or VoIP traffic and 20% of FTP and HTTP users and with the macro users serving all of them in equal proportions. Firstly the throughput and fairness is obtained for the entire network having mixed traffic i.e. FTP, HTTP, VoIP, Video and Gaming traffic models in equal proportions. Then the traffic models are altered in such a way that femtocells experience 80%of users with VoIP, Video or gaming traffic and obtain the throughput and fairness index. Figures 27 and 28 show the comparison between the two cases.

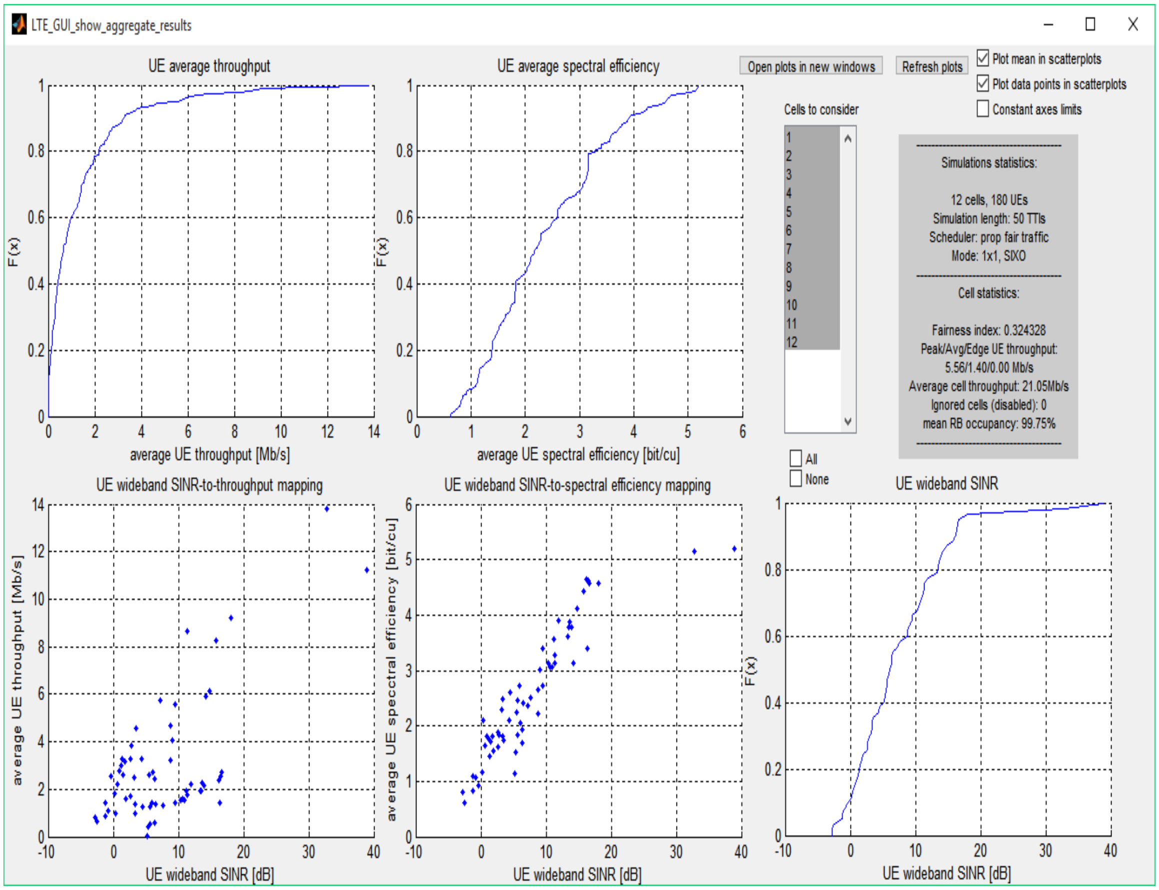


Figure 27: Results for network with equal portions of all traffic

The figure 27 shows that users experience an average throughput of 1.4 Mbps and fairness index of 0.32. Though it has very low fairness index the network shows a decent average throughput per user as the number of users considered is 180. The figure 28 is the plot generated when the Macro network users have FTP, HTTP, VoIP, Video and Gaming traffic in equal proportions and femtocells have only the VoIP, Video and Gaming traffic.

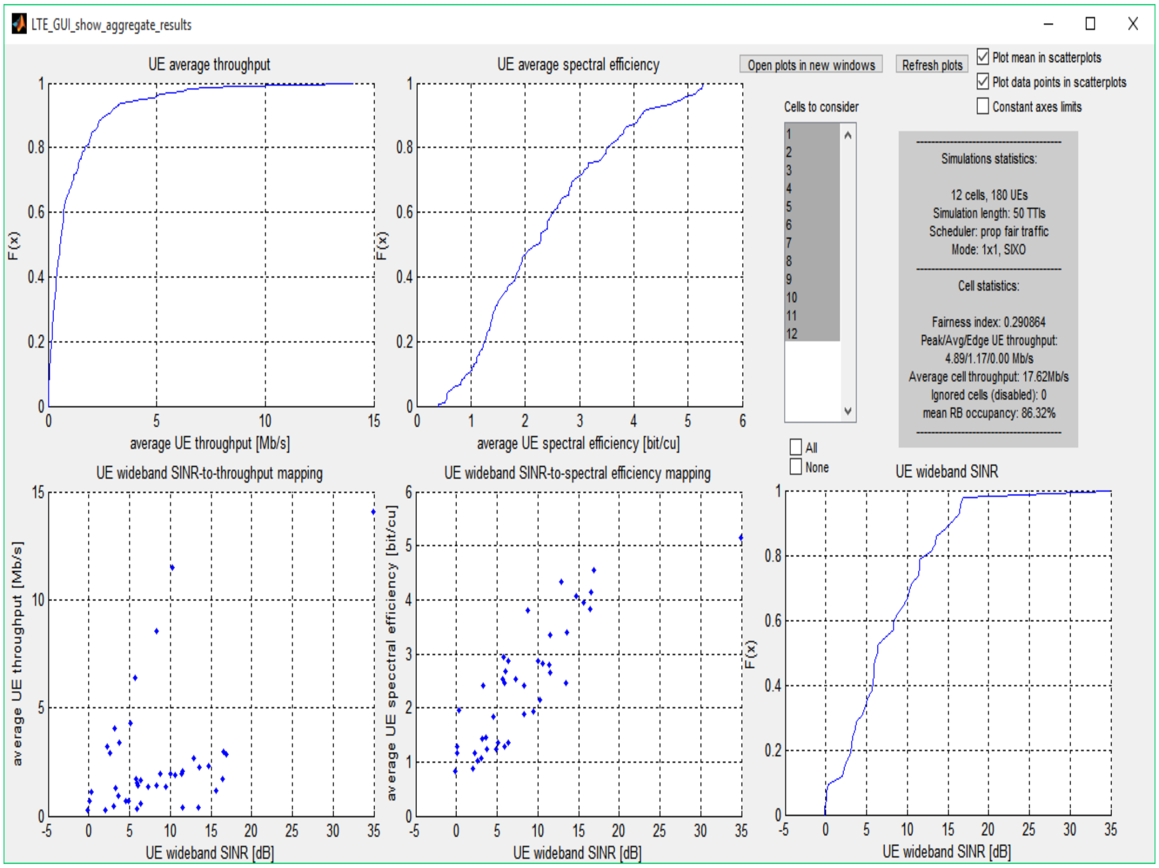


Figure 28: Results for network with femtocell serving high bandwidth traffic

From figure 28 we can see that, when femtocells were serving only the high bandwidth traffic, the fairness index, total cell throughput and average user throughput for the network drops indicating that most of the users required more resource blocks to achieve better throughput and hence better quality of service.

This highlights the need for technologies that can increase the throughput under these circumstances. However, LTE has been able to provide efficient solution to these problems. LTE can operate on wide range of bandwidth ranging from 1.4 MHz to 20 MHz and also it supports MIMO [Multiple Input Multiple Output] feature that aid in increasing the total throughput as well as per user throughput and contribute to better quality of service.

In this section we show how higher bandwidth and MIMO feature helps in increasing the throughput of the system. The figure 29 shows comparison between fairness indexes of the network simulations when different bandwidth was used along with MIMO. The figure 29 show that the fairness index decreases when the femtocells start serving only the VoIP, video and gaming traffic. To compensate for this we try increasing the system bandwidth and implementing MIMO as well. But even with increase in bandwidth the fairness index drops showing that even though more resource blocks are made available, the Proportional Fair scheduling scheme allocates them only to users having high metric value and thus the fairness index drops down as the bandwidth increases.

The simulations were run for 5000 TTI and compared with the results obtained for 50 TTI. It was found that the results were of same order.

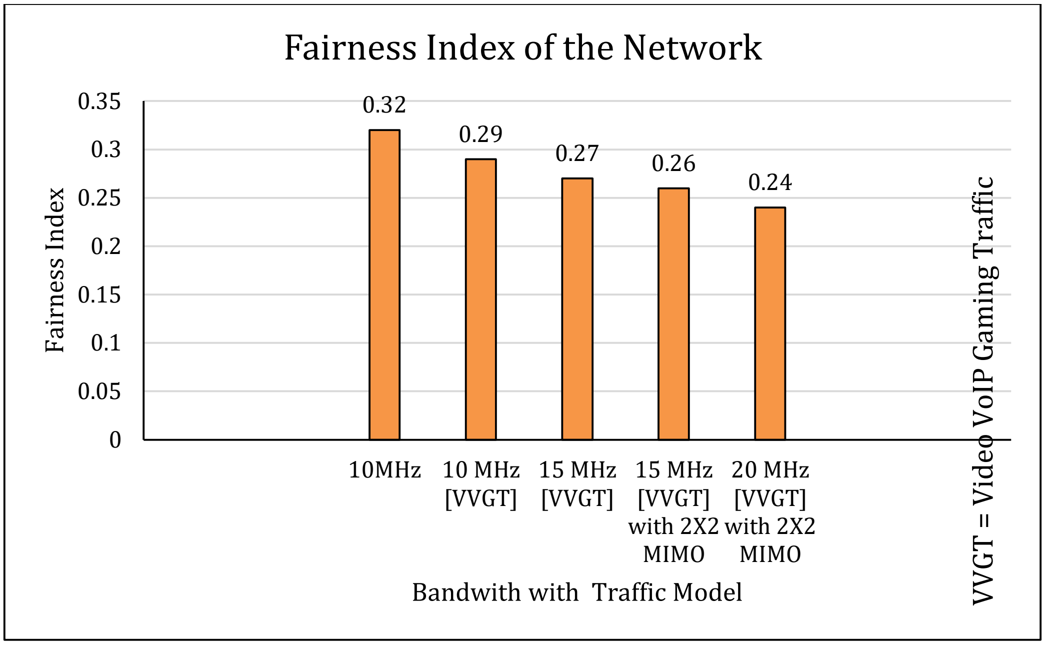


Figure 29: Fairness index for network with femtocells serving high bandwidth traffic

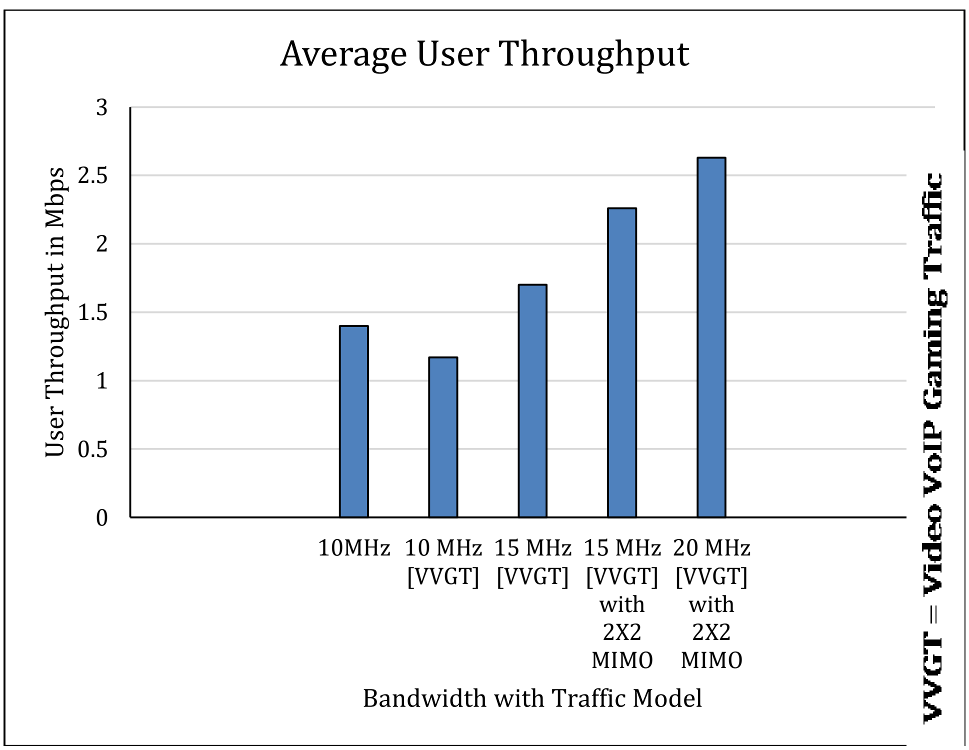


Figure 30: User Throughput for network with femtocell serving high bandwidth traffic

The figure 30 shows the variation of the average user throughput with respect to the bandwidth and type of traffic used. Initially the throughput is compared with network having system bandwidth of 10 MHz and equally distributed traffic to same system bandwidth but now femtocells serve only the VoIP, video and gaming traffic. The plot shows that the throughput decreases by this traffic categorization. To compensate for this we try increasing the system bandwidth and implementing MIMO feature of LTE simultaneously and we see that this network transformation increases the throughput thus proving the need for high bandwidth for networks having users who flood the network with applications such as video streaming, gaming and so on.

5.4 Performance Evaluation of Femtocells

Due to increase in use of high bandwidth applications, the future networks must be planned and deployed in such a way that they are able to sustain the growth of network efficiently. Though the 3GPP LTE has been able to mitigate most of the challenges, in recent days to support the growth of network, the deployment of femtocells has taken its own stand. In this section we highlight the importance of femtocell by comparing the performance with the macro cell. The figure shows the macro network with 20 users in each sector. All the users are assumed to be greedy i.e. every user has data to transmit every instant of time. The simulation is run and results for the network are recorded.

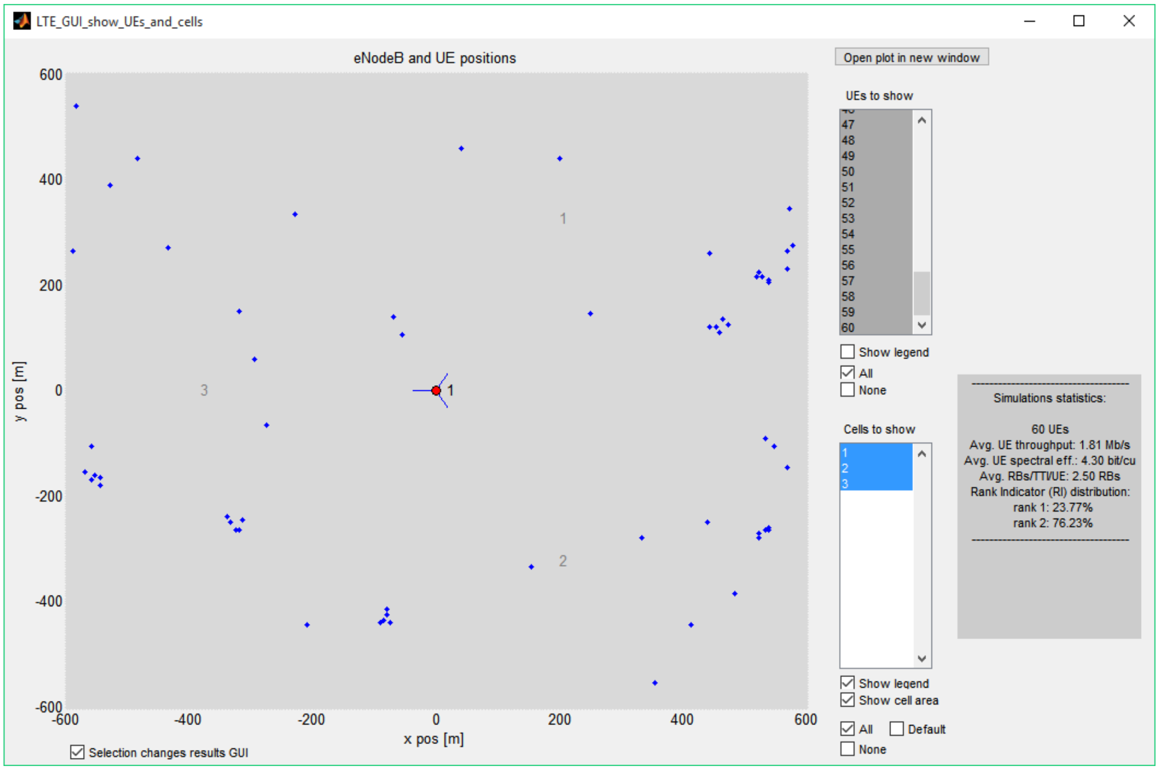


Figure 31: Macro cell network with 60 users

The figure 31 displays a macro cell network under study. It consists of 60 users in total with 20 users in each sector. The users are distributed in such a way that they show user densification at certain places indicating large organization or malls. For this network, simulation is run and the results are obtained. The motivation for this simulation is to show need for femtocells over large organizations or malls where number of users are more and contribute significantly to the traffic of the macro cell during certain period of the day. The figure 32 and 33 show the networks response for the simulation.

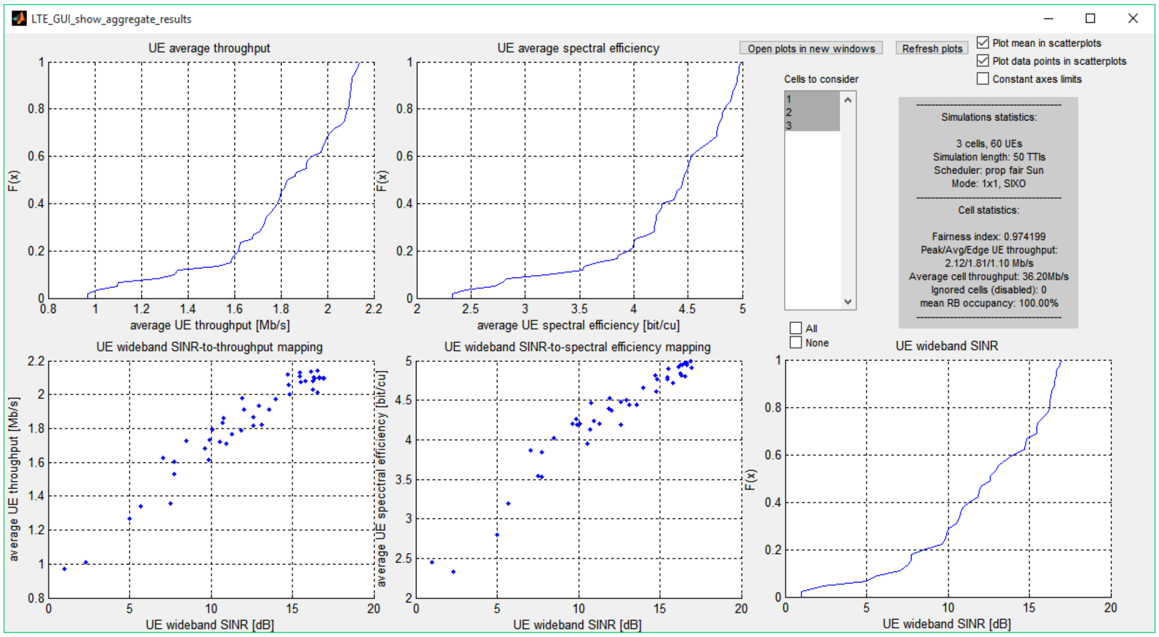


Figure 32: Simulation results for Macro only network

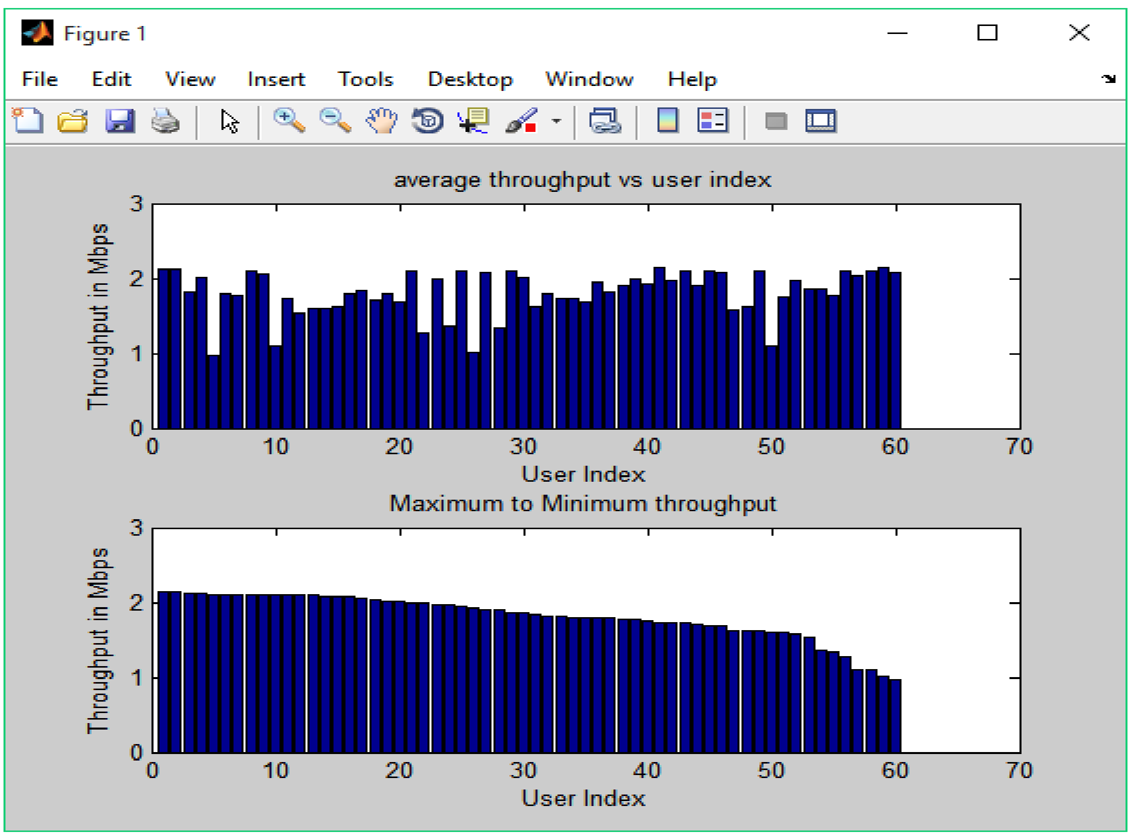


Figure 33: Average User Throughput for each user

The simulation results show that each user enjoys an average throughput of 1.81 Mbps with a fairness index of 0.97 by using the Proportional Fair scheduling scheme. The upper subplot of figure 33 indicates the average user throughput for each user and the lower subplot shows throughput arranged from maximum to minimum. Now for the same network we demonstrate how the deployment of femtocells can increase the throughput in places where the users are densely populated. Figure 34 shows the network with the femtocells. The total number of users still remain 60.

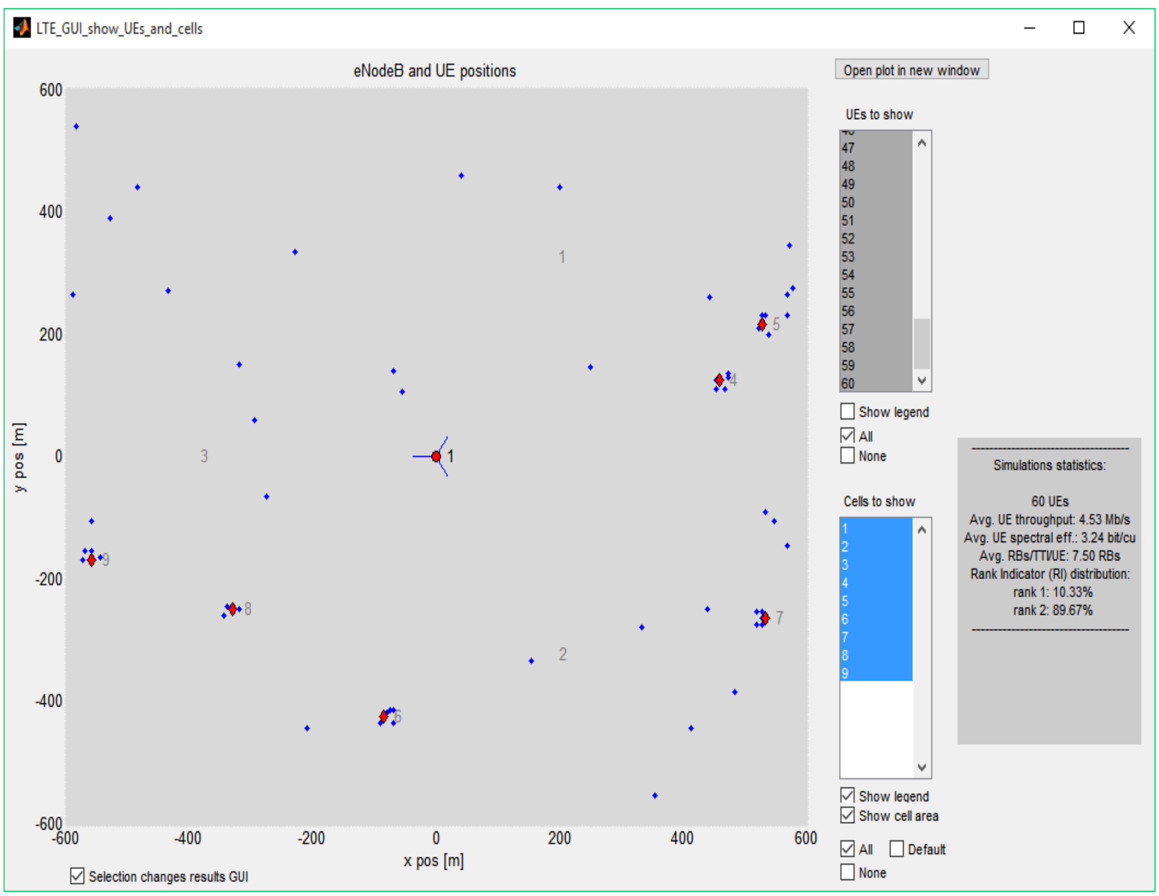


Figure 34: Macro cell network with femtocells

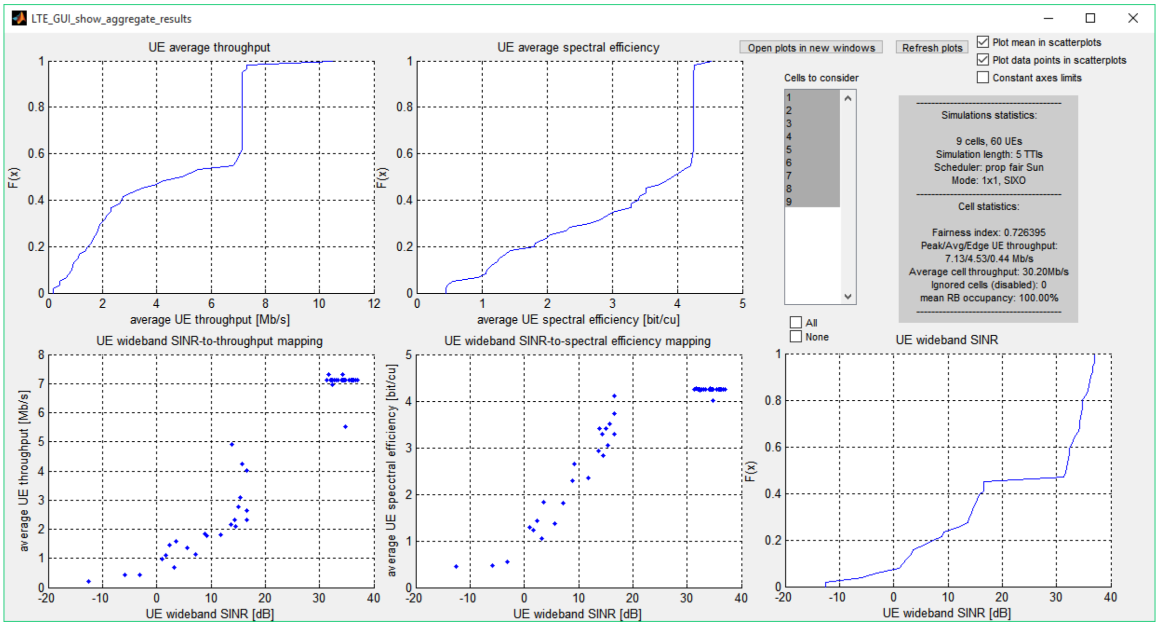


Figure 35: Simulation results for Macro only network

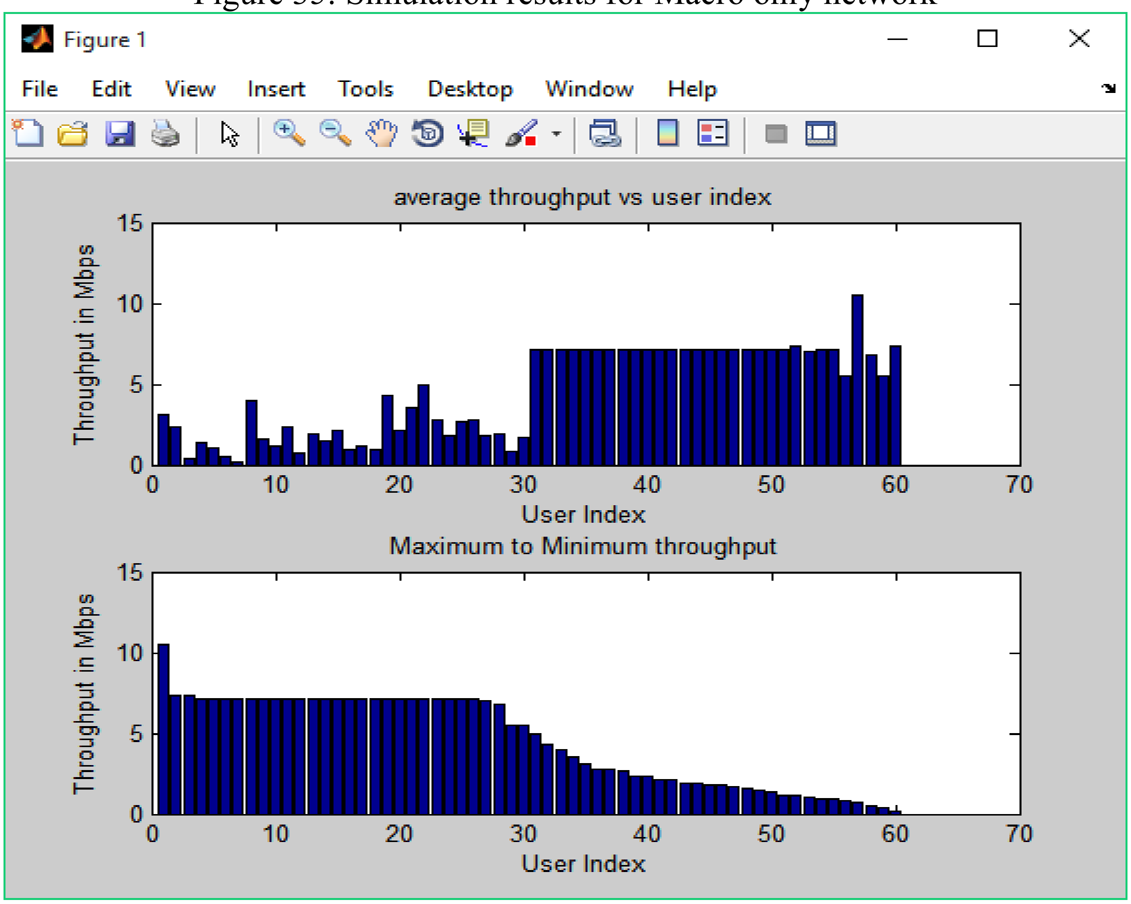


Figure 36: Average User Throughput for each user

The Figure 31 and 32 show the simulation results for the network with femtocells. Now we see that the deployment of femtocells in the densely populated area proved to be a plus. The users under the femtocells show a throughput of 7.13 Mbps which averaged about 1.75 when they were served by macro cell alone. The average user throughput for the entire network increased from 1.81 Mbps to 4.53 Mbps thus showing an improvement in total cell throughput.

CHAPTER 6

CONCLUSION

In the current fast paced environment, with growing technology and population, the communication networks have grown in an unpredictable way. This is backed by a constant growth of high bandwidth applications that enhance the user experience. With this evolution of the networks there exists a need for efficient management of spectrum by analyzing the existing network traffic. To satisfy all these needs in this project we demonstrate how 4G LTE has been able to mitigate most of the challenges with the help of a 4G LTE Network Simulator that helps us to analyze the performance of the network and assist in achieving reliable communication. The 4G LTE simulator used in this project is the Vienna LTE Simulator. The main advantage of this simulator is that it is an open source simulator having various capabilities that help us to simulate the real world environment and thus helping in optimizing the existing network or plan the future network predicting its evolution before actual deployment of the network. To demonstrate the capabilities of this simulator we had few studies in this project.

Firstly we studied the performance of various scheduling schemes in a network as scheduling schemes play a major role in avoiding the network congestion due to heavy data traffic with increase in number of users. Results indicated that the Proportional Fair scheduling algorithm performs the best with increase in number of users in a network with trade-off between the fairness and throughput. We then evaluate the scheduling schemes for various traffic models which helps in understanding the network behavior for different types of traffic. MIMO is another technique that provides the transmission diversity and thus enhancing the reliability of communications which is demonstrated using Vienna LTE simulator. Lastly with the help of Vienna LTE simulator we demonstrate how deployment of femtocells can change the network by helping in coverage as well as cell capacity. We deploy the femtocells at cell edge and also at areas where we have network densification and show how this idea of femtocells will be next generation savior.

Thus in this project we understand various features of LTE using Vienna LTE Simulator as an effective 4G LTE Simulator that can model the real world network aiding in performance analysis and ensure reliable communication. The main features of Vienna LTE simulator are ease of availability for researchers as it is and open source and graphical interface to depict the network making it not lesser than any other commercially available simulator. With only few capabilities of LTE being highlighted in this project, there are lot of others that can be achieved and learned with the help of this simulator. Thus using Vienna LTE Simulator to analyze the real world networks not only enhances the efficiency of the network but also brings down the cost of implementation for the service provider and offer reliable communication for the users.

6.1 Future Work

This project highlighted the importance of Vienna LTE Simulator and how to operate the simulator with shedding lights on the simulator capabilities with respect to performance evaluation of various scheduling schemes, Femtocells and its uses and MIMO. As a future scope of expansion, the first best thought that arises in our mind is to use Vienna LTE Simulator as a future asset to realize the 5G communication ideas.

- To further enhance the scheduling schemes, with first responders in mind, Vienna LTE simulator can be used to demonstrate the idea of group scheduling with adding the ideas of priority and latency.
- The researchers can work on the idea of Millimeter wave communications and Massive MIMO that are assumed to be key for next generation 5G Communications.
- The Femtocells have evolved as the solution for increasing the coverage and cell capacity, the next idea is to work on how many femtocells and defining the positions in network in order to have high cell throughput before the actual deployment

- Studying the handover issues in Intra and inter-Macro cell, between Macro cells - Femtocells and finally between Intra – Femtocells.
- Simulate the idea of new network that has many femtocells within the macro cells but the femtocells are in ideal/stand-by mode and are activated when the traffic in that area increases over a previously determined threshold.

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VITA

Naveen Narasimhaiah was born on July 5th, 1990 in Bengaluru, Karnataka, India. Being born in the "Silicon City", Naveen was fortunate to witness one of the best educational practices. He attended Cordial High School, Karnataka, India and finished his matriculation in 2006. With passion for Engineering he received his Bachelor's degree in Electronics and Communications Engineering from Dr.Ambedkar Institute of Technology, Karnataka, India in 2012.

Fueled by the thoughts of practical learning he wanted to pursue master's degree in his field of interest. As a dream come true, in 2013, Naveen was given admission for Master of Science in Electrical Engineering department at University of Missouri - Kansas City, Kansas City, MO. He always stood among the top 5% of the class and was awarded the Dean's International Scholarship Award for his academic success. With his major being Telecommunications, Naveen is expecting to graduate in December 2015.

Upon completion of degree, he plans to work as a Telecom Engineer at one of the major telecom service provider.