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PERFORMANCE EVALUATION OF THE LTE-ADVANCED FEMTOCELLS

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MSc. THESIS
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This thesis is dedicated to the soul of my father "Ali THABET" may Allah forgive to him and grant him his highest paradise (Ameen). I miss him every day, but I am glad to do something that for sure would make him so happy and proud if he was alive.

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LIST OF SYMBOLS

fc	Carrier frequency
R	Distance between BS and UEs
h_{BS}	Hight of the Base station
$L_{p[In]}$	Indoor path loss
D	Equal or smaller than indoor area radius
n	Indoor path loss exponent
$L_{p[InWL]}$	Indoor path loss for wall losses
IR	Indoor area radius
$L_{p[Out]}$	Outdoor path loss
R	Distance between transmitter and reciever, but grater than IR
J(t)	Fairness index
R_i	Throughput of the user (i)
R_x	Total received power of the RB that assigns to each UE
I	Interference received power for all interfering RBs
σ^2	Thermal noise power
P_T	Transmitted power of RB
L_p	Macroscopic path loss
G_T	Transmitter antenna gain
G_R	Receiver antenna gain
R_{RB}	Interfering Received power allocation for RB
D	Thermal noise density
N_f	UE receiver noise figure
R	Average UE Throughput
α	Sum of total bits
β	Number of the TTI that assigned for the UE
γ	Length of TTI
C	Cell capacity
B	Bandwidth
ρ	Cyclic prefix ratio
ε	Reference symbol ratio
φ	Synchronize symbol ratio
K	Number of RBs
J	Bandwidth of RB
X	Cyclic prefix length
Y	Length of the symbol
Z	Cyclic prefix length samples

Fs	Sampling frequency
FFT points	Number of Fast Fourier Transform points
R	Number of Reference symbols
H	Number of symbols
S	Number of subcarriers per RB
V	Number of transmitting antennas
P	Sub-frame size of the symbol
M	Number of symbols in each sub frame and by using cyclic prefix
S	Sub-carriers per RB

LIST OF ABBREVIATIONS

ACM	Adaptive Modulation and Coding
BS	Base Station
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CP	Cyclic prefix
DL	Downlink
DSL	Digital Subscriber Line
eICIC	Inter Cell Interference Coordination
EPC	Evolved Packet Core
E-UTRAN	Evolved Universal Telecommunication Radio Access Network
FAP	Femto Access Point
FDD	Frequency Division Duplex
FMC	Fixed Mobile Convergence
FUE	Femtocells User Equipment
4G	Fourth Generation of Mobile Communication
GPS	Global Position System
GSG	Closed Subscriber Group
GSM	Global System for Mobile
HeNB	Home Enhanced Node Base Station
HetNets	Heterogeneous Networks
HMS	Home eNB Management System
HNB	Home Node Base Station
HSDPA	High Speed Downlink Packet Access
HSDPA	High Speed Uplink Packet Access
HSPA	High Speed Packet Access
HSPA	High Speed Packet Access
HSPA+	High Speed Packet Access plus
HSS	Home Subscriber Server
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MAC	Medium Access Control
MCL	Minimum Coupling Loss
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MUE	Macrocell User Equipment
NLOS	None Line Of Sight

OFDM	Orthogonal Frequency Division Multiple
OFDMA	Orthogonal Frequency Division Multiple Access
PAPR	Peak to Average Power Ratio
PCRF	Policy and Charging Rules Function
PDN-GW	Packet Data Network Gateway
PL	Path Loss
QPSK	Quadrature Phase Shift Keying
64QAM	64Quadrature Amplitude Modulation
RHH	Remote Radio Head
SAE	System Architecture Evolution
SC- FDMA	Single Carrier Frequency Division Multiple Access
SeGW	Security Gateway
S-GW	Serving Gateway
SINR	Signal to Interference plus Noise Ratio
SON	Self Organizing Network
2G	Second Generation of Mobile Communication
TS36.942	Technical specification 36.942
3G	Third Generation of Mobile Communication
3GPP	Third Generation Partnership Project
3GPPTU	3GPP Telecommunications Union
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications system
USIM	Universal Subscriber Identity Module
WCDMA	Wideband Code Division Multiplexing Access
WL	Wall Losses
Wi-Fi	Wireless Fidelity

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ABSTRACT

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MSc. Thesis

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Nowadays, the cellular communications traffics have been significantly increased. Most of these traffics occur in indoor environments. The communications in indoor environments face problems such as weak quality of signals, and low capacity therefore required to deploy a number of home base stations in indoor environments. Femtocells base stations consider one of these solutions that used to enhance coverage and capacity in indoor environments. In this thesis, we will talk about performance evaluation of Femtocells overlaid with existing Macrocells deployment and compare it with only Macrocells deployment. Along with these evaluations, we have compared between the performance of the network for two Femtocell access modes, Open Subscriber Group (OSG) and Close Subscriber Group (CSG). Also, in our thesis we have compared the performance of the network system by using three well known scheduling schemes Round Robin, Best CQI, and Proportional Fair Sun in the case of without femtoBSs deployment. Moreover, we have compared between Best CQI, and Proportional Fair Sun, in case of using femtoBSs deployment. To prove the best scheduling scheme that ensure throughput and fairness in the same time.

Key words: LTE-Advanced, Femtocells, Macrocells, performance metrics evaluation, scheduling Schemes

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ÖZET

İLERİ DÜZEY LTE FEMTO HÜCRELERİN PERFORMANS DEĞERLENDİRMESİ

Omar Ali THABET

Elektronik ve Haberleşme Mühendisi
Yüksek Lisans Tezi

Tez Danışmanı: Assist. Prof. Dr. Aktül KAVAS

Günümüzde hücresel iletişim trafiği önemli derecede artmıştır. Bu trafiğin çoğu, kapalı ortamda gerçekleşmektedir.Kapalı ortamdaki iletişim sinyallerde düşük kalite ve kapasite gibi sorunlar ile karşı karşıya olduğundan kapalı ortamlarda bir dizi ana üs istasyonunun kurulması gerekir.Femtocell baz istasyonu; kapalı ortamlarda kapsama ve kapasiteyi arttırmak için kullanılan bu çözümlerden birini göz önünde bulunduruyor . Bu tezde mevcut makro hücrelerin yerleştirilmesi ile örtüşen femtosellerin performans değerlendirmesinden bahsedip; sadece makro hücrelerin yerleştirilmesi ile karşılaştıracağız.Bu evrimlerle birlikte, Açık Abone Grubu ve Kapalı Abone Grubu gibi iki Femtocel erişim modu için şebekenin performansını karşılaştırdık. Tezimizde de, ağ sisteminin performansını, üç iyi bilinen planlama şemasını kullanarak, FemtoBss dağıtımı olmadan karşılaştırdık: Round Robin, Best CQI ve Proprtional Fair Sun. Femto Bss dağıtımında Best CQI ve Proportional Fair Sun arasında bir karşılaştırma yaptık. Bu karşılaştırma ile en iyi planlama payını sağlamak aynı zamanda verimlilik ve adaleti sağlamaya çalıştık.

Anahtar Kelimeler: Gelişmiş LTE, Femto Hücreler, Makro Hücreler, Performans Ölçümleri Değerlendirmesi

YILDIZ TEKNİK ÜNİVERSİTESİ FEN BİLİMLERİ ENSTİTÜSÜ

CHAPTER 1

INTRODUCTION

1.1 Literature Review

The basic idea of our work is the performance evaluation of Femtocells deployment. Therefore, we will talk in this history review about the history of Femtocells. The idea of home base station has been introduced for the first time by Bell Labs of Alcatel-Lucent in 1999, and then in 2002 Motorola has announced 3G include home base station. However, in 2005 the concept of home base station begun to get a wider acceptance, in 2006 the term of Femtocell had first introduced. In the beginning of 2007, several companies demonstrated the term of Femtocell at the third Global System Mobile (3GSM) World Congress Barcelona, with operators have announced trials of Femtocells [1].

In the middle of 2007 established Forum to provide and support Femtocell standardization and work on the deploying Femtocells in the world and this forum called FemtoForum. In the end of 2008 the forum became including more than 100 telecom mobile operators, vendors and content providers to get starting. In that time 3rd Generation Partnership Project (3GPP) Release 8, has been introduced Home NodeB (HNB), and Home enhanced NodeB (HeNB) were introduced, and had became a mainstream wireless access technology [1].

In 2010, significant numbers of Femtocells have deployed in the world. Then LTE networks included Macrocells for outdoor and Femtocells for indoor environments and continued roll out of Femtocells, because it is proved as promising technology for enterprise and houses applications with improving capacity and performance of whole network [2]. Nowadays, Femtocells provided with new features such as having the ability of self-optimization and auto configuration. These features made Femtocells deployed by the end user in plug and play manner. Also Femtocells have the ability to be integrated with existing Macrocells networks, this helps to deploy in exponentially way.

1.2 Objective of the Thesis

The first purpose of this work is proving the positive impact of Femtocells deployment on the performance of the mobile network system such as enhancing the coverage and capacity of the network. The second purpose is comparing two Femtocells access mode such as Open subscriber Group (OSG) and Close Subscriber Group (CSG) to prove the best mode in improving the performance of whole the network system than the other. The third purpose is comparing the network performance by using three well known scheduling schemes such as Round Robin, Best CQI, and Proportional Fair Sun in the case of without Femtocells deployment. While in the case of Femtocells deployment we have compared between Best CQI, and Proportional Fair Sun. To check out the best scheme that ensures the high throughput and fairness for the small coverage area.

1.3 Hypothesis

We have used Vienna LTE-Advanced Downlink System Level Simulator in our work. Generally, our work consists of two parts. In the first part, we assumed there are two scenarios. The first scenario is deploying one eNodeB with three sector created three Macrocells and deploying different UEs in the eNodeB such as 15, 30, 45, 60, 75, and 90UE randomly in each Macrocell like the real-life distribution. While in the second scenario we have deployed randomly two and four Femtocells in each Macrocell respectively. After that, we have compared the performance of Femtocells overlaid with existing of Macrocells deployment, with the performance of only Macrocells deployment. After that we have compared the network performance of two Femtocells access mode . Finally, we have compared the performance of the network system by using three well known scheduling schemes such as Round Robin, Best CQI, and Proportional Fair Sun in the case of only Macrocells deployment. And between Best CQI, and Proportional Fair Sun schemes in the case of Femtocells deployment.

CHAPTER 2

LTE-ADVANCED OVERVIEW

2.1 Overview of 3G Releases of Cellular Mobile Communication

Indeed, the Universal Mobile Telecommunications System (UMTS) is a Third Generation (3G) of cellular mobile system based on Second Generation (2G) of mobile communications. The Wideband Code Division Multiplexing Access (WCDMA) technology is an air interface technology that used in 3G, where the data of user multiplied by high speed chip rate of 3.84Mcps, to get on a code division multiplexed output. The specific frequency bands originally defined by the UMTS standard are 1885–2025 MHz from the User Equipment (UE)-to-Base Station (BS) (uplink), while 2110–2200 MHz from BS-to-UE (downlink). The specifications of 3G developed by 3GPP organization, that is launched 3G commercially for the first time in Japan in 2001, and its maximum data rate was 2Mbps. The radio interface of UMTS is architecturally similar to GSM network, even though there are clear differences, which made UMTS radio interface unique [3].

After 3G, 3GPP introduced several releases such as High Speed Downlink Packet Access (HSDPA), High Speed Uplink Packet Access (HSUPA), and Evolved High Speed Packet Access plus (HSPA+). All these releases use WCDMA radio access that are used in 3G UMTS. UMTS was succeeded in High Speed Packet Access (HSPA), which is a new release introduced by 3GPP to provide high data rate compared to the data rate of 3G. HSPA is a combination of HSDPA and HSUPA, which introduces a higher downlink throughput with HSDPA, providing theoretical peak downlink data rate about (14.4 Mbps) compared to theoretical data rate limit of 2 Mbps for 3G. While HSUPA in the uplink provides theoretical peak uplink data rate of 5.7 Mbps. HSPA+ was also enhancing the data rates over previous HSPA with theoretical data rate extending up to 84 Mbps in downlink and 22 Mbps in uplink [4].

2.2 LTE Overview

The demands for high data rates increased, due to the new services that introduced by manufacturers of UE and the exponentially growth for traffics. 3GPP has introduced the Long Term Evolution (LTE) technology as Release-8, to satisfy these demands. LTE is a standard of wireless mobile communication systems and completely started in 2009. LTE considered as the basic of the Fourth Generation (4G) mobile networks, according to introducing a new radio access technologies such as orthogonal frequency division multiplexing Access (OFDMA) for downlink (DL) and Single Carrier-FDMA (SC-FDMA) for uplink (UL). These technologies have made LTE distinct from the previous 3G or previous releases to be classified as a new generation in the cellular mobile networks that called 4G. Release-8, in 2010, provided commercially several features [5] such as:

1. Commercially maximum data rate about 150Mbps by using two antennas at the transmitter and two antennas at the receiver, this called 2x2 Multiple-input and multiple-output antennas (2x2 MIMO);
2. Flexible bandwidths ranging from (1.4 to 20 MHz);
3. Flat architecture network,
4. 4x4MIMO; and
5. Provided low latency.

Theoretically, Release-8 provided maximum data rate up to 300Mbps, by using 4x4 MIMO, but practically that data rate cannot be reached [6].

2.3 LTE-Advanced (LTE-A)

The traffics have been increased and LTE was not efficient to fulfill that much of traffics. Therefore, 3GPP introduced Release-10. Release-10 or called LTE-Advanced. LTE-A is a standard of wireless mobile communication system and depends on the same radio access technologies of LTE such as OFDMA for DL and SC-FDMA for UL. LTE-A provided new features assisted in increasing the data rate and capacity. Some of LTE-A features are [6]:

1. Higher MIMO antenna up to 8x8 MIMO, which means eight antennas in DL and eight antennas in UL; and 8x4MIMO;
2. Heterogeneous Network (HetNet) which enhances the Inter Cell Interference Coordination (eICIC), to reduces the interference among the cells; and
3. Carrier Aggregation (CA) that extends the bandwidth of the system up to 100MHz to achieve high data rate.

Release-10, launched commercially for first time by using CA in 2013. LTE-A commercially achieved data rate up to 450Mbps during 2015 by using 3-CA as (20MHz+20MHz+20MHz). As expected, in the next few years, LTE-A is going to push the commercially data rate up to 1Gbps with 100MHz bandwidth. Figure 2.1 illustrates the commercial data rates of LTE-A [6].

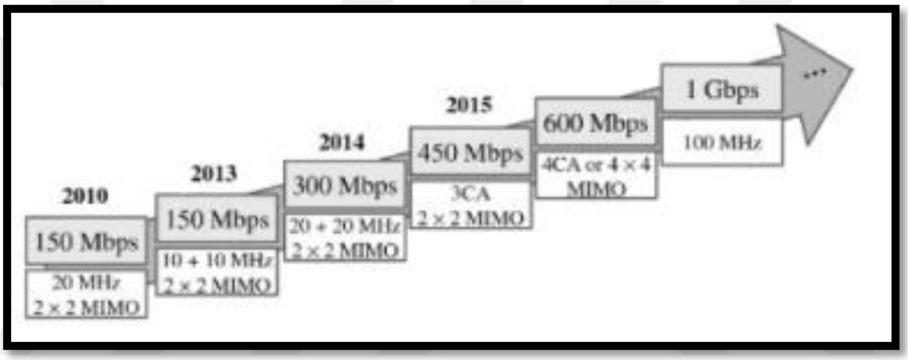

Figure 2. 1 Commercial data rates from LTE and LTE-A [6].

2.4 LTE-A Spectrum

In LTE-A, the need for higher spectrum increases to achieve high data rates and capacity. As shown in Figure 2.2, the spectrum of LTE that used in European and some Asian markets. The spectrum of LTE that used starts from 700MHz to 2600MHz. Because of the high traffics in the urban area, Macrocells (large area) used 3.5GHz spectrum. The small cells (small area) can also use 3.5GHz spectrum and unlicensed spectrum like 5GHz [6]. As a result, of all the previous roughly speech, our analysis in this research based on 2.6GHz.

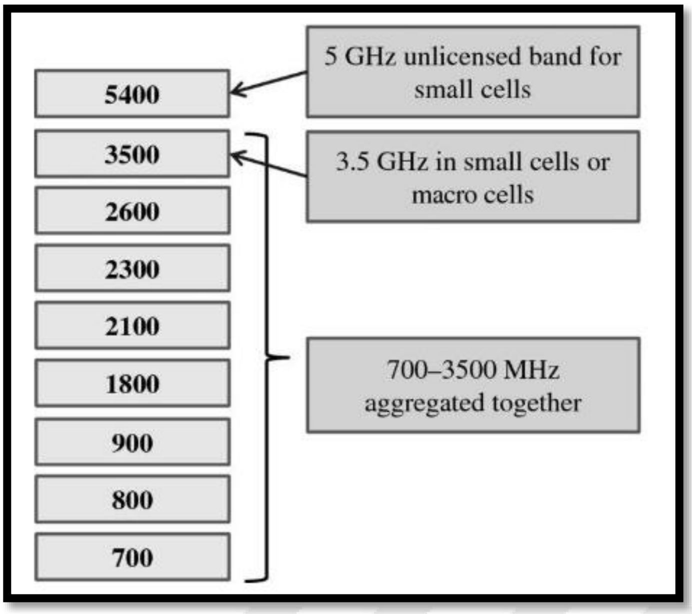

Figure 2. 2 LTE spectrum that used in European and some Asian markets [6].

2.5 LTE-Advanced Network Architecture

The LTE is an evolution consist of radio access and the non-radio access. With the radio access evolving through the Evolved Universal Telecommunication Radio Access Network (E-UTRAN). So, the radio access is the developing of LTE physical layer, but the non-radio access classified under the name of the System Architecture Evolution (SAE). SAE is the evolution of the network architecture of the LTE and includes Enhanced Packet Core (EPC). Figure 2.5 demonstrates the general architecture for LTE and the main components of the LTE system architecture are explained below [7].

1. Evolved Packet Core (EPC)

2. User Equipment (UE)

3. Evolved-UMTS Terrestrial Radio Access Radio Access Network (E-UTRAN)

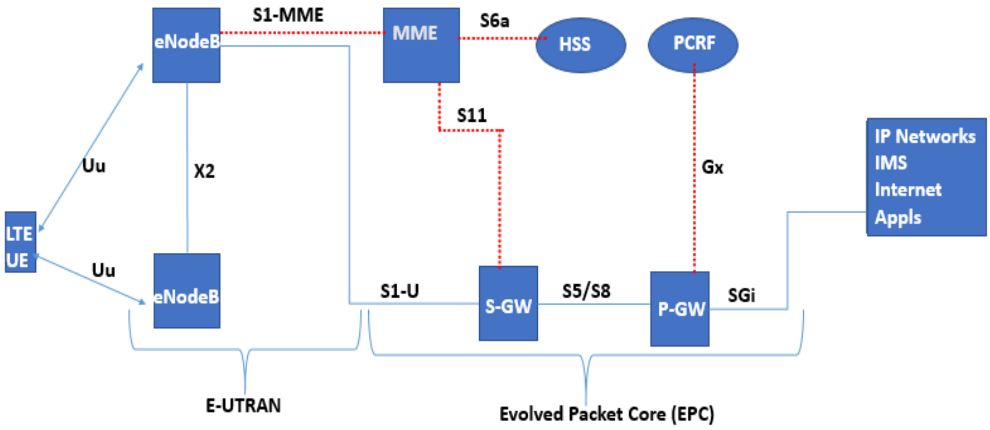

Figure 2. 3 LTE general architecture [7]

1. Evolved Packet Core (EPC)

The EPC provides access to the packet switched domain without provide accessing to the circuit switched domain. So EPC consist of several nodes some of which are:

A-Mobility Management Entity (MME);

B-Serving Gateway (S-GW);

C-Packet Data Network Gateway (PDN Gateway or P-GW);

D-Policy and Charging Rules Function (PCRF); and

F-Home Subscriber Server (HSS).

A-MME: - One of the important elements in the EPC, as it terminates, is the control plane signaling from the user. The functions of MME are mobility management, authentication, security and retrieval of subscription information from the HSS.

B-SGW: - is the main packet routing and forwarding node in EPC. It also forms an important role of mobility in inter-eNB, and inter-frequency handover. Charging based on Quality of Service (QoS) for instance, and packet marking and other functions within this node.

C- PDN Gateway or P-GW: - it is acting as the entry and exit point for the UE data traffic, to provide connectivity to external PDNs for the UE.

D-PCRF: - is responsible for imposing different operator policies on the network such as guaranteed QoS, maximum bit rate provisioned for a user. PCRF communicates with the PDN-GW in enforcing these policies for different users in the LTE network.

F- HSS: - is the master database contains all the subscription information of the user along with the subscription for various services that are offered by the operator. It is also consist of the authentication center which, stores all the keys required for ensuring the encryption and integrity of the data in the network.

2. User Equipment ((UE):- is the device that a consumer use it for data oriented communication or voice oriented. This device could be a handheld device or a wireless data card or a modem. Each user is provided with Universal Subscriber Identity Module (USIM). USIM identifies the UE from other UEs and holds the authentication and security keys related operations. There are several categories of UE introduced in LTE releases. Category of UE is varied in the supporting of data rates because of these data rates depend on the specification of UE, if it is work on the higher order modulation or higher MIMO system.

3. Evolved-UMTS Terrestrial Radio Access Network (E-UTRAN)

E-UTRAN consist of the Enhanced-Base stations (E-NodeBs), which are interconnected to each other's by using X2 interface (logical interface) and connected to the core network elements by S1-interface (S1 is a logical interface). The E-NodeBs are responsible of scheduling and allocation of the radio resources for the users in the LTE network. The E-NodeB terminates the control plane signaling messages as well as the user plane data with the EPC over the S1 interface. Control plane deals with the signaling and control functions, while user plane deals with actual user data transmission.

2.6 LTE Heterogeneous Networks (HetNets)

HetNets are deploying a different number of low-power nodes such as (Micro cell, Pico cell, Remote Radio Head (RHH), Relay, and Femtocell) with existing of high power node like (Macrocell), as depicted in Figure 2.6, these types of cells are defined by maximum output transmitted power and the minimum coupling loss (MCL). MCL refers to the minimum path loss between the BS antenna and UE antenna and refers to the type of BS installation. So in the case of high MCL, the UE cannot be so close to the BS which is typical for the high-mounted Macrocell antennas. But in the case of low MCL, the UE can be so close to the BS antenna such as in the Femtocells. Deployment of these low-power nodes considered one of the most promising and cost-effective solutions to handle the increasing of wireless data traffic. HetNet helps in supporting a flexible and effective way to remove the coverage holes in Macrocells and enhance the system capacity. So, HetNets are considered as the major performance improvement enabler in LTE-Advanced [8].

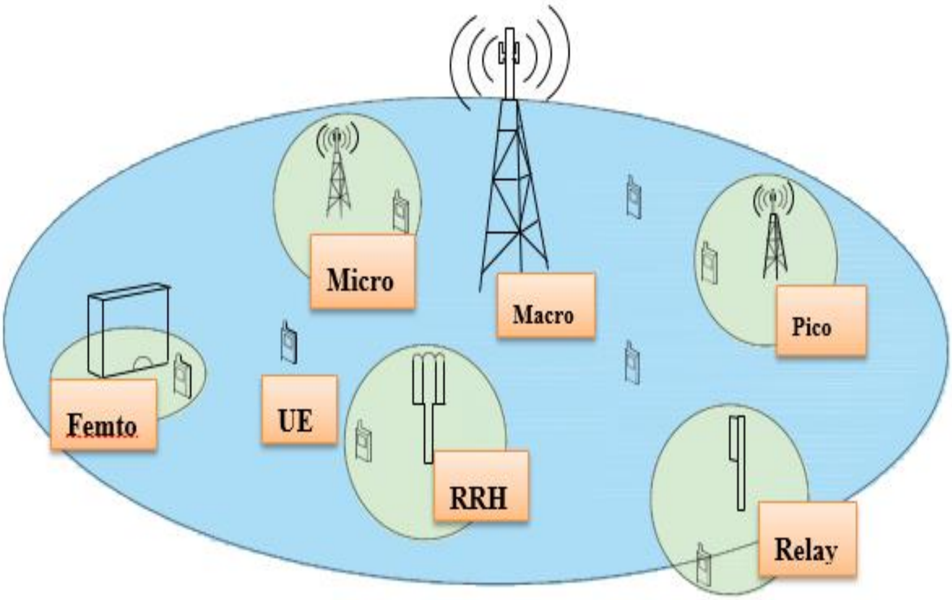

Figure 2. 4 Deployment of HetNet with different low-powers nodes

As illustrated in Figure 2.6, these low-power nodes cannot be only deployed by the operators like the Macrocells. But, it can be deployed by the users. Table 2.1 demonstrates a simple comparison between Macrocells and low-power nodes.

Table 2. 1 Comparison between Macrocells and Smallcells [6] and [8].

Type of node	Max Transmit power in watt	Cell size	Placement	Access
Macro-cell	100W	(1-30)km	Outdoors	Open to all UEs
Micro-cell	6W	400m-2km	Outdoors	Open to all UEs
Pico-cell	0.25W	< 300m	Indoor or outdoor	Open to all UEs
Femtocell	0.2 or 0.25W	< 50m	Indoors	Open/closed/hybrid
Relay	5 W	300m	Outdoors	Open to all UEs
Remote Radio Head(RRH)	5W	300m	Indoor or outdoor	Open to all UEs

There is another thing should be explained it here, Macrocells and most of these nodes are connected via S1 or X2 interface. Beside, all the benefits improving of capacity and removing the holes in the Macrocells coverage, there is a problem of interference among the Macrocells and the other nodes. But, there are several ways used to mitigate the interference.

2.7 LTE Radio Access Technology

The legacy technologies like UMTS uses WCDMA as the multiple access technique while GSM uses the Time Division Multiple Access (TDMA) approach of multiple access with the frequency division multiplexing. All of these technologies had their set of pros and cons. Most of access methods in the legacy technologies imposed the limitation on coverage and capacity of the system. With the requirements of 3GPP specified for LTE, the change in the access technology was felt and thus the technology directed towards using OFDMA, in DL direction, whereas SC-FDMA used for UL. These technologies stayed depended in LTE-A also [9].

A-OFDMA: - is a multiple access technique that consists on assigning a subset of multiple orthogonal carriers to individual users. OFDMA has many advantages: it is robust to multipath fading and interference, offers opportunities to exploit multi-user diversity, can be easily adapted to different bandwidths, and also, it is very simple to implement.

B-SC-FDMA: - on the other hand, the SC-FDMA transmission scheme is very similar to OFDMA, with the main difference being the inclusion of a Discrete Fourier Transform (DFT) pre-coding. This ensures a lower Peak to Average Power Ratio (PAPR) which helps to save the UE battery energy. While keeping some of the most important features of OFDMA like the multipath interference robustness and the frequency domain orthogonality among intra-cell users. More detailed information about the LTE multiple access technologies and transmission schemes can be found in [9].

2.8 Multiple Input Multiple Output (MIMO) Antennas Technology of LTE-A

MIMO is multiple antennas at both the transmitter and receiver that used to provide higher data rates without needing to additional time-frequency resources. Figure 2.11 as an example to show the MIMO configuration system. MIMO considered one of the new features in the first of LTE Release. LTE-A supports higher MIMO such as 8x8 MIMO and 8x4 MIMO. The increasing of MIMO performance has achieved by using different techniques that exploit the spatial domain of the radio channel. The technique that will be depended in this research is spatial multiplexing, that has used to transmit parallel different data streams, and therefore, peak data rate increase linearly. In our research we have used 4x2 MIMO Closed Loop Spatial Multiplexing (CLSM) [11]. There are two types of spatial multiplexing. The first type is Open Loop Spatial Multiplexing (OLSM), and the second type is CLSM. The difference in OLSM there is no feedback from the UE in spite of the Rank Indicator (RI), sent from the UE. RI transmitted from UE to BS to determine the number of spatial layers. While CLSM in general is similar to OLSM, but it has feedback incorporated to close the loop. So, in CLSM the precoding can be applied at the base station before transmission [10].

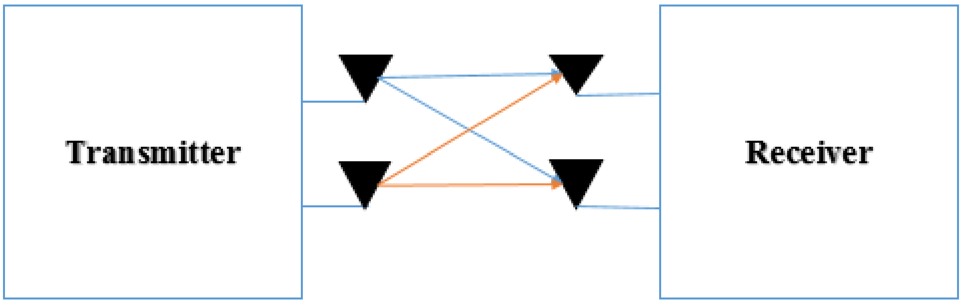

Figure 2. 5 Example on the 2x2 MIMO configuration system

2.9 LTE-A Frame Structure and Resource Allocation

We can demonstrate the idea behind resource allocation is that whenever the UE requests service, based on various network parameters like channel quality, Reference Signal Received Power (RSRP), and priority. RSRP is a measurement of the received power level in an LTE cell network. RSRP is the average power received from a single reference signal resource element. There are three metrics such as QoS requirement; size of the buffer, and channel quality that reported by the user. If the per Resource Block (RB) metric for a specific user is higher than, any others requesting the service, then that UE enjoys the benefit of being allocated [11]. In order to understand resource allocation, it is very necessary to understand how the available bandwidth divided into resource blocks. Wide range of flexible bandwidth considers one of the important features of LTE [12]. LTE Bandwidth consist of number of frames. Figure 2.7, shows the LTE frame structure for UL and DL. The duration of one frame in LTE system is 10ms with each frame is divided into 10 sub-frames. Each sub-frame with duration of 1ms. So each subframe is further divided into two time slots. Each timeslot with duration of 0.5ms. Each time slot consists of either 7 or 6 Orthogonal Frequency Division Multiple (OFDM) symbols depending on the type of Cyclic Prefix (CP) employed [13].

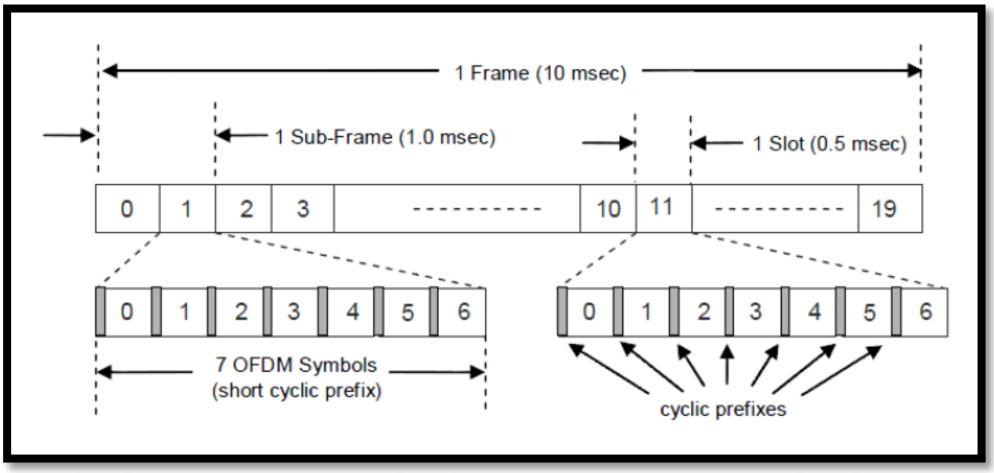

Figure 2. 6 LTE Frame Structure with 7 OFDM symbols per time slot [13].

CP is a copy of the last portion of the symbol data which is inserted in the beginning of the same data symbol during the guard interval as shown in the Figure 2.8. LTE utilized two kinds of CP, called by Normal CP consist of 7OFDM symbol and Extended CP consist of 6 OFDM symbols. So we have used normal cyclic prefix in our work.

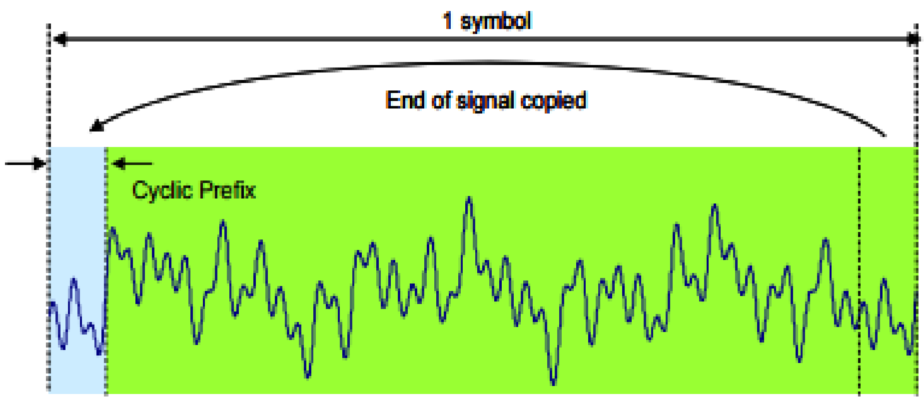

Figure 2. 7 The generating of Cyclic Prefix [11]

In the case of Frequency Division Duplex (FDD), all sub frames are assigned either for DL or for UL transmission as shown in Figure 2.8. The blue arrow represents DL transmission and the black arrow represents UL transmission. So we have used FDD in our work [13].

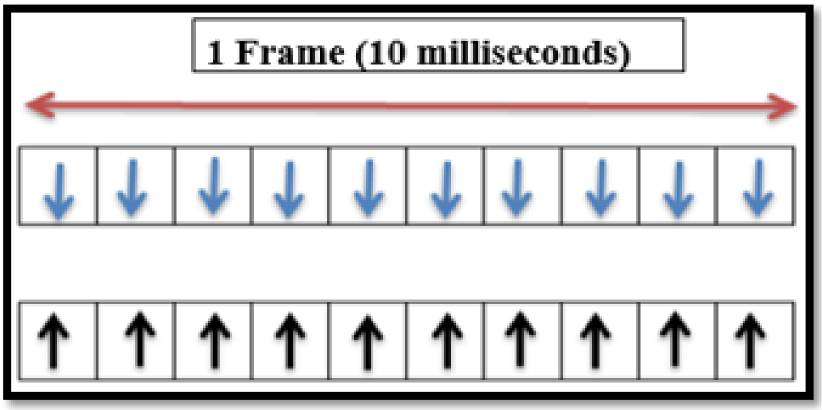

Figure 2. 8 Configurations for LTE FDD in the Uplink-Downlink

LTE uses OFDM as one of the key technologies. In OFDM, the whole transmission bandwidth is being divided into subcarriers. The physical layer of LTE consist of 12 subcarriers which are classified as one RB. The RB has duration of 1 time slot. Within one RB there are 12x7 or 12x6 resource elements as depicted in Figure 2.9. A RB is the smallest element allocated to a user. Table 2.2, shows number of RBs, that available in different bandwidths. The mathematical calculation explained in Appendix A.

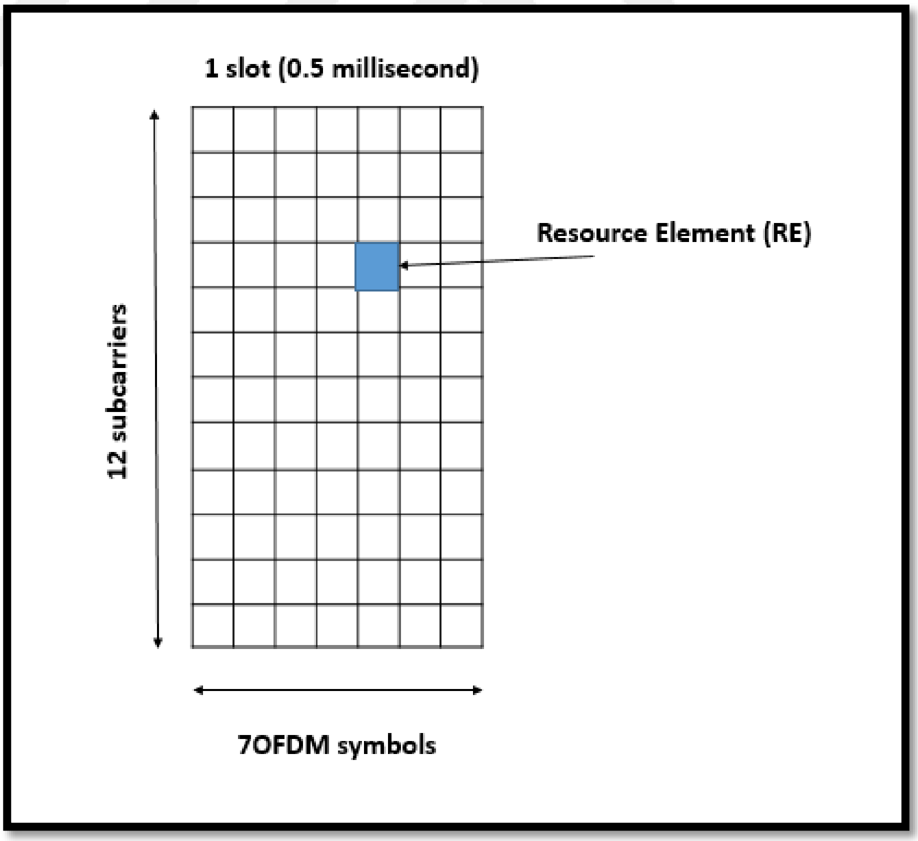

Figure 2. 9 LTE Resource Block

Table 2. 2 Bandwidth vs Number of Resource Blocks

Bandwidth in MHz	1.4	3	5	10	15	20
No of RBs	6	15	25	50	75	100

The understanding of needing to RBs and the parameters that impact on the resource allocation. The next thing should be studied is how these resource blocks are allocated to each user. Based on the type of service and performance requirement, we have different scheduling schemes that allocate resource blocks to users. So, we have explained three well known scheduling schemes and these schemes are examined in this work.

2.9.1 Scheduling

Scheduling is a process of distributing available resources among the users who need service in such a way that QoS has 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. More broadly, the scheduling schemes has classified into two groups [14].

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

We have explained the scheduling schemes such as Round Robin, Best CQI and Proportional Fair Sun scheduling schemes, due to we are going to compare among these schemes in our work in the case of with and without Femtocells deployment.

1] Round Robin scheduling scheme is a channel unaware technique in which resources have allocated in order of service requested by the user. This scheduling scheme ensures the fairness among users and does not take the channel quality into consideration thus resulting in lower user throughput [15]. Figure 2.10, shows the flow chart of the Round Robin scheduling scheme [16].

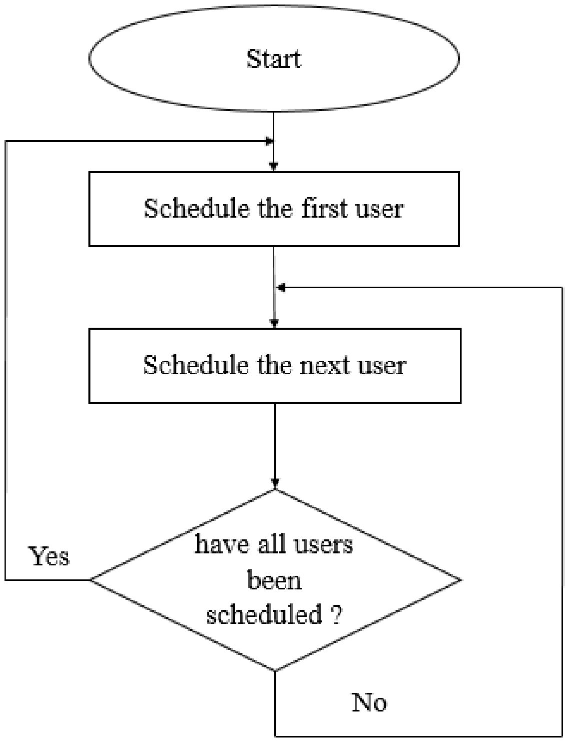

Figure 2. 10 Flowchart of Round Robin scheduling scheme [16]

2] Best Channel Quality Indicator (Best CQI) scheduling scheme is a channel aware technique that allocates resources to the users based on channel conditions. All users report their channel quality to the eNodeB by sending back a value in response to reference signal, which has sent by eNodeB. As the name indicates, users with best channel quality have higher Channel Quality Indicator (CQI) value and they have assigned resources. Since it depends only on channel conditions, it achieves higher network throughput but at the cost of fairness. Figure 2.11, depicts the flow chart of Best CQI scheduling scheme [16].

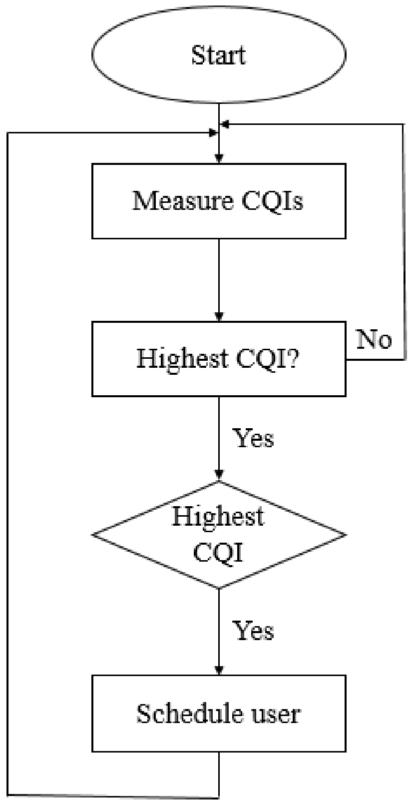

Figure 2. 11 Flow chart of Best CQI scheduling scheme [16]

3] Proportional Fair scheduling scheme is a channel aware scheduling scheme that has developed to overcome drawbacks of Round Robin and Best CQI. It provides fairness in allocation as well as higher throughput and it is the most used scheduling scheme [17]. Figure 2.12, shows the flow chart of Proportional Fair scheduling scheme. As depicted in Figure 2.12, at the beginning of the scheduling process, the BS compares the CQI from different terminals and selects the user with the highest CQI. If there is more than one terminal with the highest CQI, a random one has picked by the scheduler. In the first time slot, the terminals with higher CQI are scheduled. In the second time slot, the terminals have scheduled periodically in turn. At the end of the second slot period, the process begins again. Thus, in the first slot of the second sub-frame, the terminal with the higher CQI has selected and in the second time slot, the terminals have assigned the RBs in turn [16].

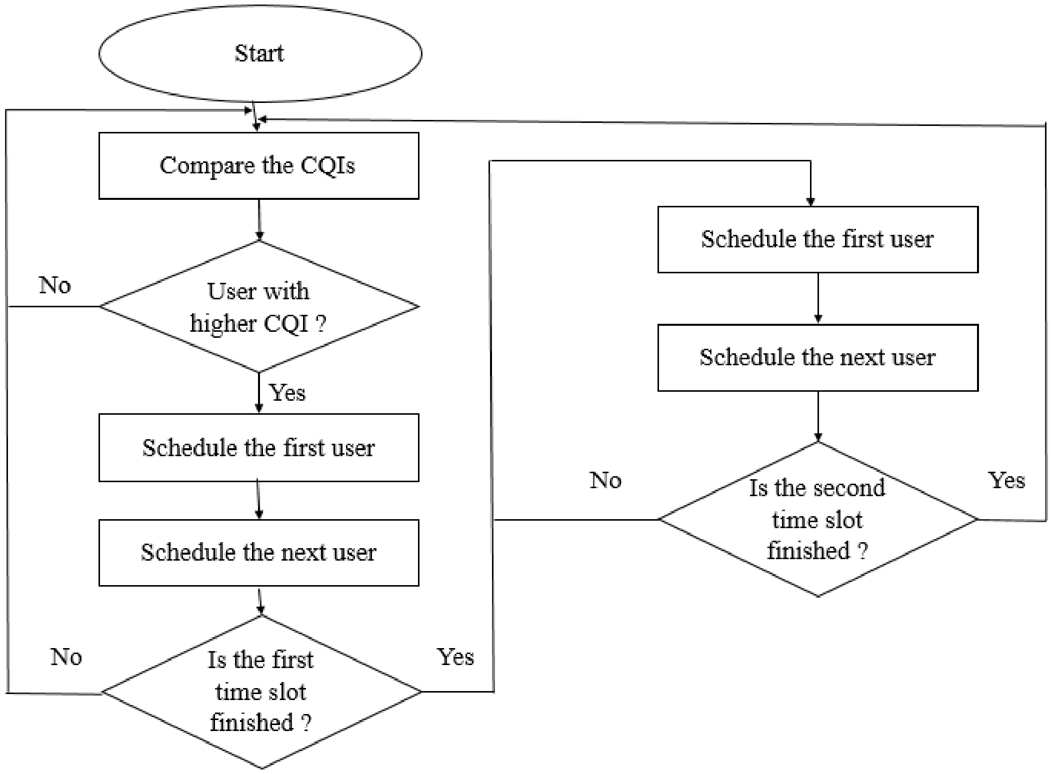

Figure 2. 12 Flowchart of the Proportional Fair scheduling scheme [16]

CHAPTER 3

FEMTOCELL TECHNOLOGY

3.1 Introduction

Due to the exponentially growth of traffics and the increasing demand for high data rates. We need to deploy additional nodes in the geographical area. That kind of solutions requests high capital expenditure. To solve these problems, a new approach has been designed which involves transforming the existing macro network into a heterogeneous network by deploying low transmit power base stations, called small cells along with the existing of Macrocells deployment. The Femtocell is a class of small cells, which are beneficial because they not only increase the capacity and coverage of the network and also have low implementation cost.

3.2 Femtocell Definition

Femtocell or called Femto Access Point (FAP) and also called HeNB, is a small size, low output power cellular base station and operate in the same license spectrum of operator network [1]. The number of HeNB can be very high compared to operators for example; number of Femtocells is 10–20 times more than the number of macro base stations. Typically, it is designed for using in homes or small business, which means is located in indoor environments. Femtocell installs by the subscribers without need to operators network. The key idea behind Femtocell deployment is to improve coverage and the capacity of the cellular mobile network with existing Macrocell [6]. Table 3.1 illustrates the specifications of Femtocell.

Table 3. 1 Some of 3G Femto access point specification [6]

Output power	Max (100 or 200) mW
Carrier frequency	Share the same operator spectrum (2.6GHz) as setting in our work
Peak data rate	For HSDPA 21 Mbps but for HSUPA 5.76 Mbps
Power consumption	<13.5W
Volume	Volume 1.38 liters
Temperature range	0°C to +40°C
Maximum capacity	Up to 16simultanous users
Cell size coverage	Less than 50meter
Option for integrated Wi-Fi	No
Synchronization	Network time protocol or over the air from macro downlink
Power feed	Power over Ethernet (PoE+) or AC/DC adapter
Backhaul	Ethernet over copper
Self-organization network (SON)	YES
Weight	505 g

3.3 Why is Femtocell Important?

Femtocells very important for the following reasons [2]:

1. Femtocell can provide indoor coverage for places where it is difficult for Macrocell to cover it;

2. Femtocell assists in offloading from Macrocell and enhances the Macrocell capacity;

3. Addition of Femtocells can enhance the total network capacity in significant way by reusing radio spectrum;

4. due to the exponential demand for higher data rates;

5. The using of Femtocell greener than Macrocell

6. Femtocell provides an ideal solution for Fixed Mobile Convergence (FMC);

7. Femtocells can provide significant power saving to UEs; and

8. Femtocell plays an important role in mobile broadband and ubiquitous communication.

3.4 Working of Femtocell

The working of Femtocells are illustrating in the Figure 3.1, but the six steps that mentioned below are explains the Femtocells working but in briefly [18].

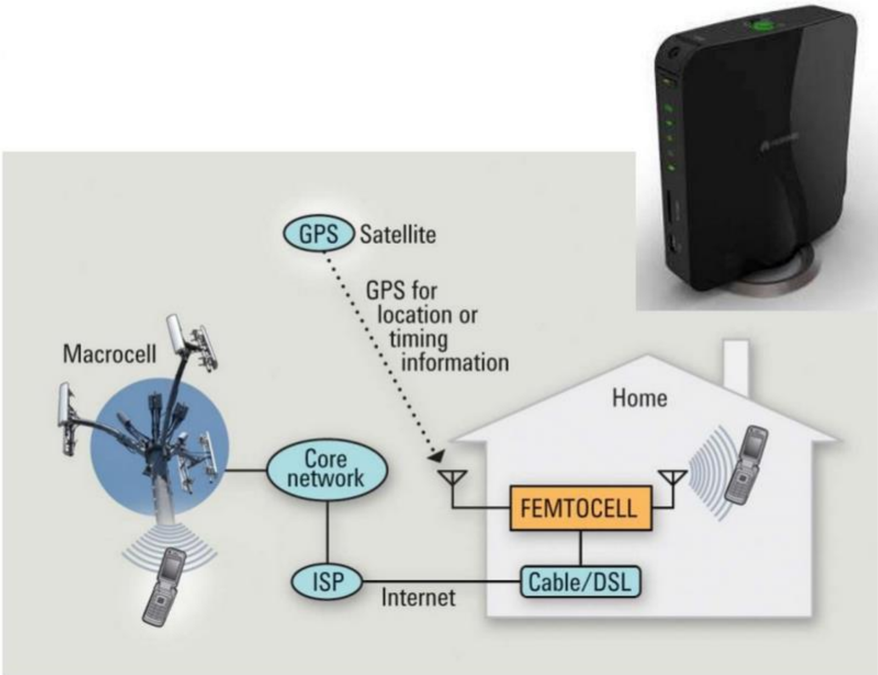

Figure 3. 1 General working of Femtocell [20]

1- Femtocell is installed in the home and connected to power and standard broadband IP connection, typically connects to Digital Subscriber Line (DSL), through into the mobile operators core network.

2- Usually, Femtocell provided with Global Position System (GPS) receiver due to the accessing to GPS is required to set up Femtocell. GPS allows the operator to tailor operating parameters to location and enables the operator to disable service if the base station is moved;

3- Data services, voice calls, and text messages are supported by the same systems;

4-Femtocells operate at very low radiation power levels as mentioned in Table 3.1 and typically have a range less than 50 meters;

5-When users walk outside or out of range, calls are automatically handed over to the external mobile network; and

6-Unlike Wi-Fi access points, Femtocells operate by using licensed spectrum and thus must be supplied and operated in conjunction with the mobile operator.

3.5 Femtocells Deployment

Femtocells are assumed to be self-deployed by users instead of operators and typically deployed in an uncontrolled manner. Uncontrolled deployment means that, Femtocell installed out of the controlling of operators. So, that need to be located in suitable place to avoid the interference of Femtocell with neighboring Femtocell. Femtocells have the capability of automatic configuration as they are regarded as consumer electronics in order to generate minimum interference to outdoor Macrocells and neighboring Femtocells. The automatic configuration considered as the key of successful Femtocells deployment. Automatic configuration achieved by two processes [1], [6], and [19].

- The sensing process in which the Femtocells sense the radio surrounding environment for assessment
- The auto-tuning process in which the Femtocell set up its configuration parameters such as DL transmitting power and sub-channel allocation.

The Femtocell deployment can also be divided based on the capacity as well.

- Home Femtocells, which are capable of supporting 2-6 simultaneous users.
- Enterprise Femtocells that are capable of supporting 8-16 users.

3.6 Femtocell Access Control Strategies

There are three access control modes in which a Femtocell could be operated: Opened, Closed and Hybrid. The explanation of these modes is shown below [20].

A. Open Access mode: Every user can access the Femtocell in this mode and benefit from its services and this mode deployed in public places such as Coffee shops.

B. Closed Access mode: In this mode, a specific number of users can get access to Femtocell, therefore, called Closed Subscriber Group (CSG), and the owner only can decide which user is able to access, this mode deployed in the houses.

C. Hybrid Access mode: allows the particular outside users to access a Femtocell home base station and the access conditions grant by the operator after receive request from the owner of Femtocell and this mode deployed in small business.

3.7 Advantages and disadvantages of Femtocell

Advantages of Femtocell can be divided into types such as operator and subscriber advantages [21].

3.7.1 Femtocell Advantages

A. Operators advantages

- Offloading traffic from Macrocells and hence less Macrocell sites are needed.
- Improving service quality and wideband data services and hence more revenues.
- Providing coverage for places where Macrocell implementation is very difficult.

B. Subscribers advantages

- Excellent network coverage when there is no existing signal or poor coverage.
- Gathering all voice, video and high speed data services in one consumer electronics device.
- To get a benefit from all services that are introduced.
- Saving Femtocell User Equipment (FUE) power, because of the path loss to indoor HeNB is much smaller than the path loss to outdoor Macrocell. [18].

3.7.2 Femtocell Disadvantages

- Specific number of users can access, have limited connection.
- Neighboring subscribers may or may not be allowed to connect to them.
- Trouble shooting is difficult, because of the service providers are depending on the broadband services which are beyond control therefore trouble shooting is difficult.

3.8 LTE Femtocell or Home eNB (HeNB) Architecture

The basics architectural aspects of HeNBs are based on the same concepts that applicable to all kinds of LTE cells. The architecture of the network that including HeNBs designed to be flexible and scalable with respect to the number of HeNBs, especially, if the network consists of a large number of HeNBs, HeNB Gateway (HeNB GW). So the deployment of HeNB GW can optionally manage the HeNBs from the perspective of the Evolved Packet Core (EPC) [6]. The capacity of HeNB GW can be up to thousands of HeNBs, and these HeNB GW can be deployed on the Control plane (HeNB GW CP) only, or can be deployed on the User plane (HeNB GW UP) also [22]. Figure 3.2 illustrates all the network architecture parts of HeNB such as HeNB, HeNB-GW, security gateway (SeGW), and HeNB management system (HeNB-MS) as explained below

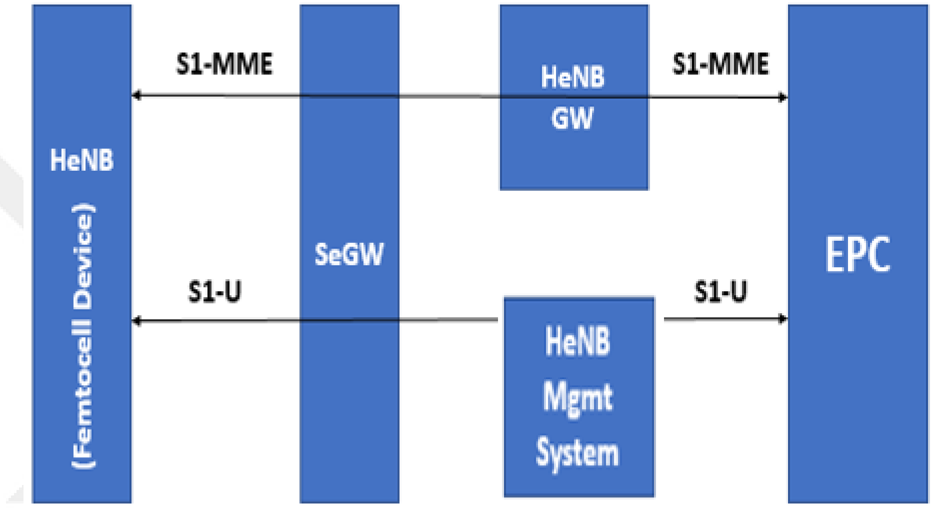

Figure 3. 2 LTE Femtocell logical architecture [6]

1-HeNB: - Performs the same function of Macrocell eNodeB that mentioned in Section 2.5, but it is better for smaller coverage deployment than Macrocell eNodeB, such as homes or small business offices. HeNB is connected to the MME by S1-MME that provides the control functions for idle mode UE accessibility and active mode UE handover. The HeNB is connected to the S-GW by S1-U interface [6].

2- S1 interface:- An interface between the HeNB-GW and the core network; between the HeNB and the core network; between the HeNB and the HeNB-GW; and between the eNB and the core network. So S1-MME is a reference point for the control-plane protocol between HeNB and MME. While S1-U is an interface user plane [7].

3- Security Gateway (SeGW):- provides a secure communication link between the HeNB and the EPC. Also SeGW provides protection against security threats and network attacks that may occur when mobile traffic is exposed to the public access network. SeGW is a logical entity that comes, in some cases, as an integrated solution within a HeNB-GW, while in other cases it is a separate network entity [22].

4-The HeNB GW: - is connected to the HeNB by the interface S1, and connected to the MME and S-GW by using the same interface S1. HeNB-GW appears to the MME as an eNB, and to the HeNB as an MME. HeNB-GW plays the role of a concentrator and a distributor (aggregates traffic from a large number of HNBs back into an existing core network). The HeNB GW serves as a concentrator for the control plane, specifically the S1-MME interface at transport network layer. It transports many S1 Application Protocol (S1AP) [22].

5-Home eNB Management System (HMS):- The functions of the HMS is based on the TR-069 family of standards. It enables the operators to control and manage the configuration of HeNBs. Moreover, it produces errors reports and collects different performance variance from the HeNBs. With the HMS, an operator grants access to HeNBs with additional services and applies service usage policies.

3.9 Handover of Femtocell

The handover procedure allows communication during users' movement among the network. It is important to support the UEs mobility in all current mobile systems including the Femtocell network [23] and [24]. The handover that has implemented in our work, where the Indoor Macrocell User Equipment (MUE) have served by eNodeBs unless they have authorized to access Femtocells that located in their coverage area. The FUEs unlike MUEs that can be located anywhere with Macrocell coverage area. FUEs existence is only limited to the predefined Femtocell coverage area otherwise it will handoff to Macrocell and be a MUE. However, we have explained in general and in briefly the handover procedure in Femtocell network, where contains three scenarios.

3.9.1 Hand-in procedure (Macrocell↔Femtocell)

Represents the handover scenario when the UE switch out from Macrocell eNodeB to HeNB. This scenario is a difficult procedure and quite demanding because there are hundreds of possible targets HeNBs. In hand-in procedure, the UE needs to select the best target HeNB so the optimal handover decision policy is so critical and difficult [24].

3.9.2 Hand-off procedure (Femtocell↔ Macrocell)

The handover scenario is not so complicated as the hand-in, because there is only one candidate eNodeB and UE does not need to select the optimal target cell. When the signal strength from the Macrocell is higher than the one from serving HeNB, the UE will connect to it and transmit the data packets using the target Macrocell NodeB without considering so many elements as those in the hand-in decision making phase [24].

3.9.3 Inter-HeNB procedure (Femtocell↔Femtocell)

Represents the interaction between two HeNBs, the handover from one HeNB to another HeNB in the same Macrocell network. The inter-HeNB handover is similar to hand-in procedure since in this scenario, there are still hundreds of candidates target HeNBs when UE move out of the coverage of its serving HeNB. So, in this scenario the target cell selection mechanism is necessary and appropriate selection for the efficient handover is required [24].

3.10 Interference Management in Femtocell Networks

The interference in two-tier networks has two types. The first type is co-tier interference. The second type is cross-tier interference. These two-tier interference types have illustrated in Figure 3.3. Both types of interference may occur either in the UL or DL transmission. Due to the unplanned and random deployment of Femtocells, interference can be a severe problem in two-tier networks if it is not well managed. Interference is managed via two different approaches which are interference cancelation or interference avoidance [25]. Interference cancelation aims to reduce interference at the receiver end by means of signal processing and using some prior knowledge about interfering signal. It has been found that interference cancelation is not preferred practically in two-tier networks due to require antenna array systems and signalling overhead which may not be suitable especially for DL. While interference avoidance aims to allow intelligent transmission to reduce interference as much as possible. In this Chapter, we have explained in briefly the Fractional Frequency Reuse (FFR) that used for providing interference avoidance in two-tier OFDMA Femtocell networks and also FFR used in our simulator. So, below we have mentioned the scenarios of the interference that occur in two- tier network [26].

1. Macrocell UE Femtocell BS
2. Macrocell BS Femtocell UE
3. Femtocell UE Macrocell BS
4. Femtocell BS Macrocell UE

Cross-Tier

5. Femtocell ‘A’ UE Femtocell ‘B’ BS
6. Femtocell ‘A’ BS Femtocell ‘B’ UE

Co-Tier

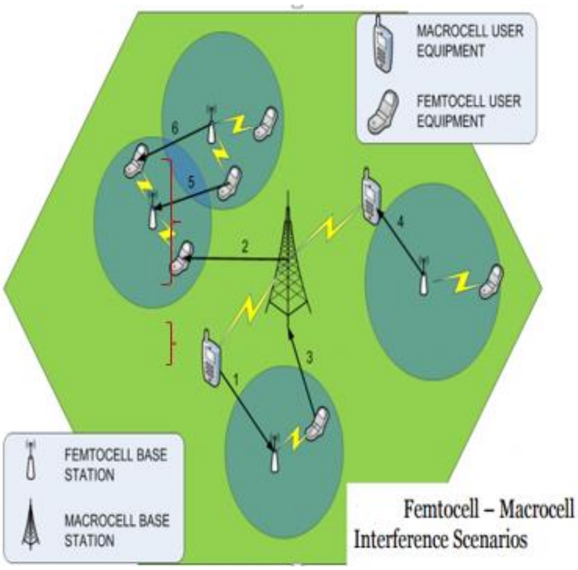

Figure 3. 3 Femtocell-Macro cell interference Scenario [26].

3.10.1 Fractional Frequency Reuse (FFR)

The concept of Fractional Frequency Reuse (FFR) depends on dividing the Macrocell into center region and edge region. Different reuse factors are used at each region mainly to enhance cell edge performance. FFR has two types; dynamic and static. The first type is the dynamic FFR. The dynamic is an adaptive FFR scheme as explained in [25] to mitigate cross-tier interference in DL. Resource partitioning process is varied in both time and frequency (dynamic) and the allocation process depends on the density of Femtocells and the location of each one (center or edge). If the Femtocells are in a dense scenario in center region, Femtocells use orthogonal sub-channels to minimize interference otherwise they use arbitrarily sub-channel. The second type is static FFR scheme as explained in [26] to mitigate cross-tier interference in co-channel allocation scenario. Femtocells sense the spectrum during turn on to discard operation on sub-bands with largest received signal strength to enhance the Signal to Interference and Noise Ratio (SINR) of MUEs and overall network throughput. Another static FFR scheme as explained in [26] to reduce the cross-tier interference in DL. This scheme divides Macrocell into center zone with reuse factor of 1 (Reuse-1 and this is only implemented in our simulator) and edge zone with reuse factor of 3 (Reuse-3). The spectrum is divided into two parts; one of them is assigned for center region while the other is divided equally among the Macrocells. The Femtocells at each sub-area of the Macrocell use the sub-bands that are not used by Macrocell operation at this sub-area.

3.10.1.1 Reuse-1 Scheme

We study the Reuse-1 scheme in our work because of Vienna Simulator based on this scheme. The universal reuse scheme (or Reuse-1) assigns the entire frequency resources to be reused by all Macrocells and Femtocells existing in the system. The main advantage of Reuse-1 scheme is the possibility of using all available frequency resources and hence increasing the spectral efficiency of scarce bandwidth. This usually help in generating very high interference in the system. Since all Macrocells and Femtocells share the same bandwidth at the same time to provide service for their attached UEs, the amount of inter-cell interference ICI becomes very high especially for small-sized Macrocells. The Reuse-1 scheme also results in a coverage problem due to poor SINR for those MUEs far from their serving BSs at the edge of Macrocell due to the interfering transmission of nearby Macrocells [27]. Reuse-1 scheme also results in a severe problem for indoor MUEs that are very near to active transmitting Femtocells. In the Figure 3.4, we describe the operation of Reuse-1 scheme where all Macrocells use the entire frequency bandwidth at the same time slots with reference transmission power PM. The Femtocells also applies the concept of Reuse-1 such that they use the same entire frequency bandwidth simultaneously with Macrocells but with limited transmission power PF.

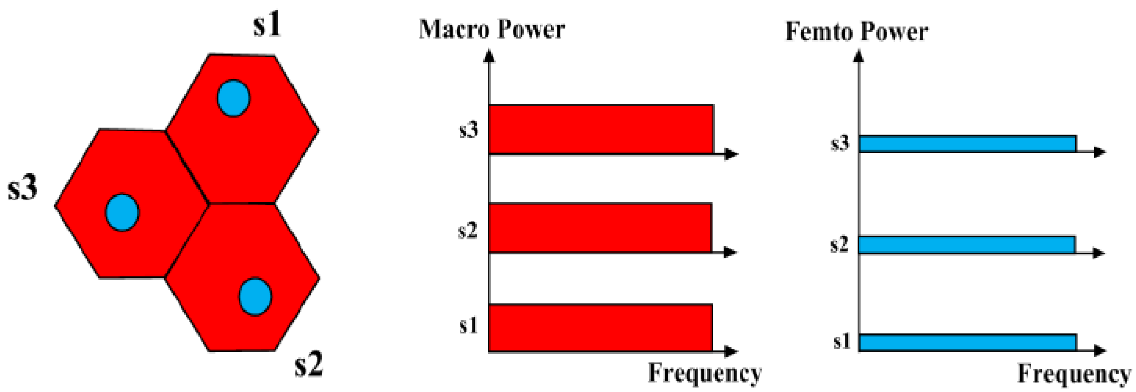

Figure 3. 4 Reuse-1 Scheme [27]

CHAPTER 4

SYSTEM ANALYSIS

4.1 Introduction

In this Chapter, we provide a full description and analysis of LTE Femtocell system that are applied in our work. We start firstly by giving an overview of the Vienna LTE Simulator that used as a powerful LTE System Level Simulator (SLS) [28]. We then describe the LTE cellular system Layout and the indoor model. We also describe the propagation of path loss models that used between BSs and UEs and we have explained the performance fairness. Finally, we provide an explanation for SINR and average UE throughput and cell capacity analysis for DL between BSs and UEs.

4.2 Vienna LTE-A System Level Simulator

The Vienna LTE Simulator is an open source MATLAB-based simulator, developed by Institute of Telecommunications of Vienna University of Technology, Austria [28]. 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, standardization of LTE, and in the implementation process of equipment manufacturers, simulations are necessary to test and optimize algorithms and procedures. 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 Media Access Control (MAC) and network layer [system level].

There are two types of Vienna LTE Simulator of simulators: The first type is Link Level Simulator, assist in investigation of channel estimation, modeling of channel encoding and decoding, MIMO gains, and Adaptive Modulation and Coding (ACM). While the second type is, System Level Simulator and this have used in our work, assist in resource allocation and scheduling, mobility and interference management and network planning optimization.

The core part of the System Level Simulator divided into link measurement model and link performance model as shown in Figure 4.1. Link measurement model used to abstract the measured link quality that used for link adaptation and resource allocation based on SINR as a metric. The aim of this step is to reduce run-time computational complexity by pre-generating and store the results of these heavy computations to reuse during the simulation time. While the link performance model is used to determine throughput and error rates at a reduced complexity [29].

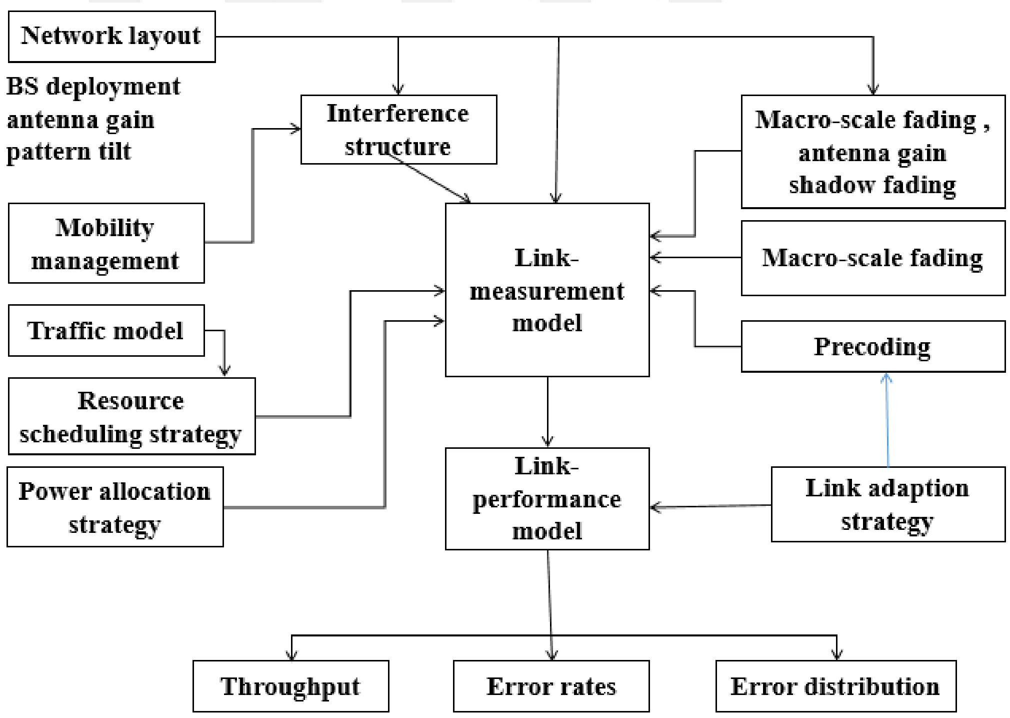

Figure 4. 1 Schematic block diagram of the LTE system level simulator [29]

The simulator flow follows the pseudo-code below. The simulation has performed by defining a Region of Interest (ROI) in which the eNodeBs and UEs have positioned. The simulation length measured by Transmission Time Intervals (TTIs). It is only in this area where UE movement and transmission of the Downlink Shared Channel (DLSCH) are simulated [30].

For each simulated TTI **do**

Move UEs

If UE outside ROI **then**

Reallocate UE randomly in ROI

For each eNodeB **do**

Receive UE feedback after a given feedback delay schedule users.

For each UE **do**

1- Channel state → link quality model → SINR

2- SINR, MCS → link Model → BLER

3- Send UE feedback

Where,"→" represents the data flow in and out of the simulator link abstraction model

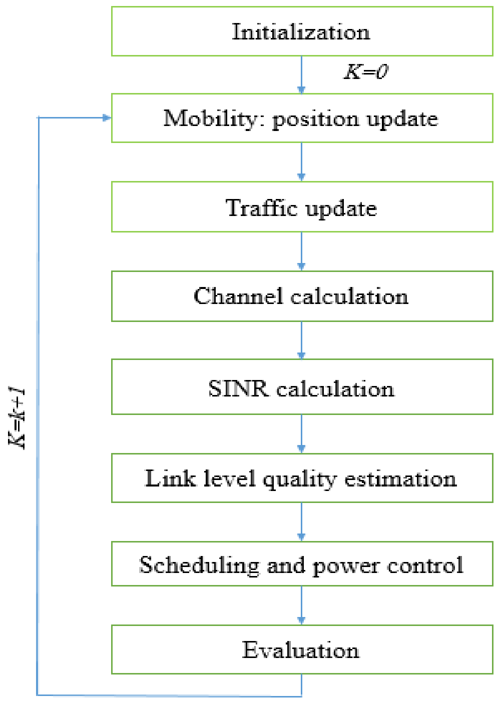

Figure 4. 2 LTE-A Vienna simulator flowchart [31]

Figure 4.2, shows the simulation flow chart. The Vienna Simulator continuously simulates the temporal development of cells by calculating densely spaced snapshots k, where k = one TTI. Within each snapshot (TTI), the position of the MUE, changes and the traffic situation have updated. After that, the channels between each Femto/Macro UE and each Femto/Macro BS are newly calculated and scheduling has performed for each snapshot (TTI).

1. In the initialization, all the parameters remain constant during the whole simulation as set. The following parameters can be set:

- Number of Macro BS / number of eNodeB;
- Inter-site distance;
- Number of macro UEs per Macro cell (changes due to mobility, but total number of macro UEs stays constant);
- Velocity of UEs;
- Number of transmit and receive antennas;
- Femtocell scenario;
- Number of Femtocell per Macrocell;
- Bandwidth;
- Carrier frequency;
- Scheduling algorithm.

2. Update position: The locations and direction of movement of UEs have updated for each TTI. In this part, new UEs have generated if necessary.

3. Traffic update: The communication traffic in the network has updated on each TTI. Traffic models can be grouped in the service types 'best effort packet transmission and real time transmission'. The best effort packet service type includes File Transfer Protocol (FTP) and HTTP, while real time services include streaming, VoIP and gaming.

4. Channel calculation: calculate the path loss for indoor and outdoor environments UEs.

5. Measure SINR for UEs: The link performance has evaluated by using Block Error Ratio (BLER) or throughput. In this work, we focus on the throughput performance.

6. Link Level Quality Estimation: Link adaptation techniques significantly increase user throughput by providing efficient ways to maximize spectral efficiency. The chosen link quality measure has evaluated per subcarrier. Based on the Signal to Interference and Noise Ratio (SINR), the UE computes the feedback (PMI, RI, and CQI), which is employed for link adaptation at the eNodeB.

7. Scheduling is a process of distributing available resources among the users who need service in such a way that 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. We have discussed in (Section 2.9.1), the three well know scheduling scheme. These, scheduling scheme is specified in the first part of initialization to which one use. The scheduling algorithm assigns resources to users in order to optimize the performance of the system (e.g., in terms of throughput) based on feedback.

8. End: If the simulation time have reached, it will stop. Otherwise go back to Step 2 and transmit another frame.

4.3 System Model

4.3.1 Cellular Layout

The cellular layout of Vienna System Level Simulator is composed of 7 eNodeBs. Each eNodeB consists of three Macro cells, which have used to provide service for MUEs that attached to these Macro cell. The BSs in LTE cellular systems have called evolved NodeB (eNodeB) in 3GPP standard [34]. As we previously mentioned, each eNodeB consists of three hexagonal cells such that each hexagonal cell has provided by a different directional antenna. The beam directions of different cell antennas have separated by 120 degree from each other. MUEs have randomly distributed in the Macro-cells and can be classified into, outdoor MUEs located in free space area and indoor MUEs located inside offices, enterprises, houses ... etc. Indoor MUEs have served by ordinary eNodeBs unless they have authorized to access Femtocells that are located in indoor environment. The cellular layout of ordinary LTE cellular system as shown in Figure 4.3 [29].

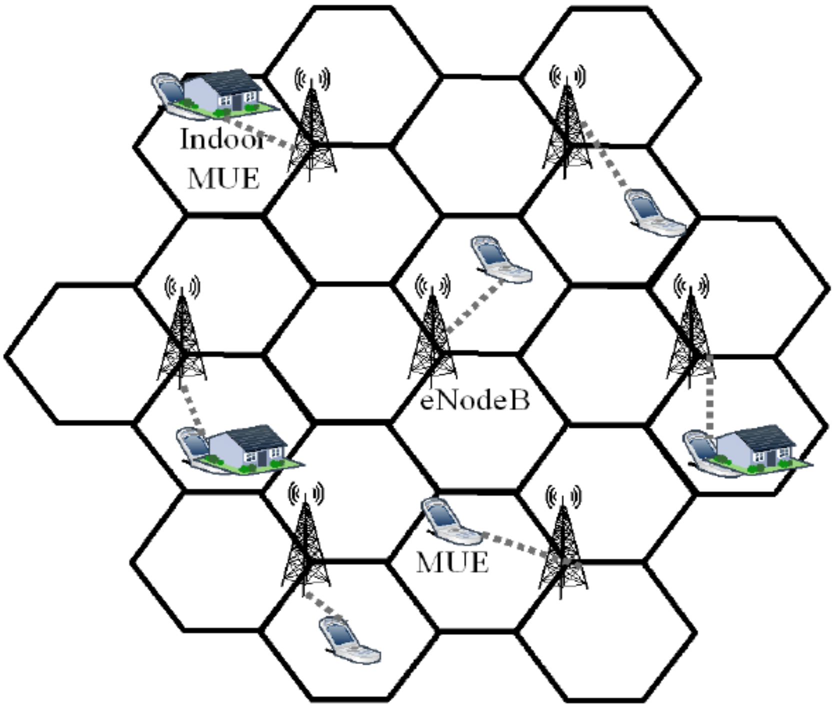

Figure 4. 3 Cellular Layout [29]

4.3.2 Modeling Indoor Area

Macro-cell Coverage area in our system model has classified into outdoor coverage area (e.g. Free Space) and indoor coverage area. The indoor coverage, in our simulator is implemented as circularly shaped buildings of radius IR = 20m and randomly distributed within each macro cell, but their footprints do not overlap with each other. Femtocells have deployed at the centers of the buildings and equipped with omnidirectional antennas. The number of active Femtocells at a time have not set to a fixed number, but set as a variable parameter to study the performance in different Femtocell deployment densities. The FUEs unlike MUEs, which can be located anywhere with Macrocell coverage area. FUEs existence is only limited to the predefined Femtocell coverage area otherwise it will handoff to Macrocell and be a MUE. Figure 4.4 shows an example of a Macrocell providing access for ordinary MUEs (outdoor and indoor) overlaid by Femtocell network providing access for only limited number of subscribed UEs (FUEs) [29].

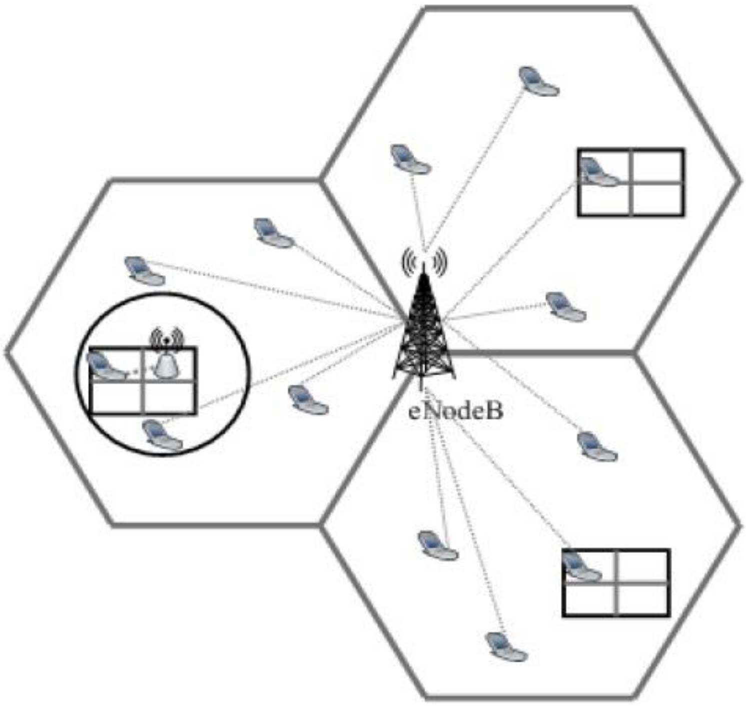

Figure 4. 4 Hybrid Macro-Femto Cellular Network

Figure 4.5 shows the cellular mobile layout for heterogeneous network (Femtocells overlaid with Macrocells). As obvious, the indoor coverage area composed from annular regions and the UEs placed in these regions. Indoor and outdoor environment have partitioned by a wall penetration loss. These walls losses assumed constant for all buildings.

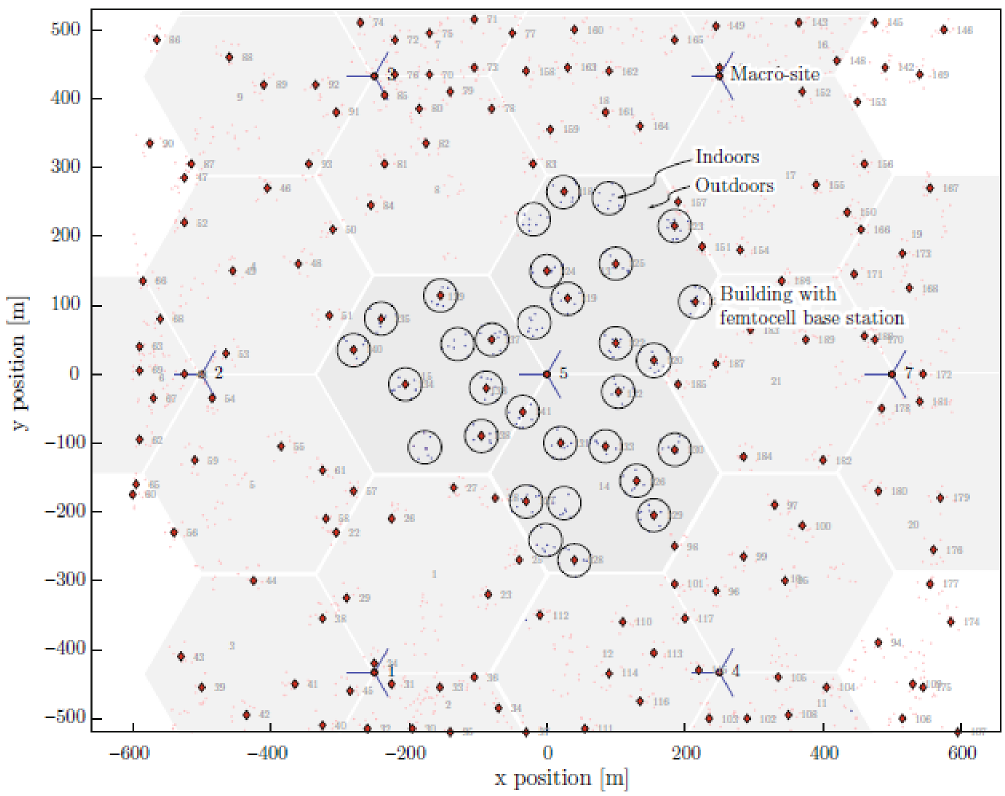

Figure 4. 5 Cellular mobile network layout for urban heterogeneous network [29]

4.4 Path loss model

The radio waves are affected during transmission between transmitter and receiver and the signal level is attenuated. So this attenuation called path loss and this path loss depends on the environment type in which the radio waves are propagated. There are several propagation models which are defined for calculating the path loss in different environments. The simulator, of our work, is implemented on two-path loss models. The first one is TS 36.942 path loss model, and used when the transmitter is eNodeB, which means for outdoor environment. While the second one is dual slop path loss model and this one used when the transmitter is Home eNodeB and for sure located in the indoor environment, as explained below.

4.4.1 Path Loss for Macrocells eNodeB

The path loss of the only Macrocells deployment scenario, in our work has been performed by using 3GPP TS 36.942 path loss model for outdoor environment (Urban), as macroscopic Pathloss model. [32]. TS 36.942, is Technical Specification provided for the future development work within 3rd GPP for E-UTRA operation primarily with respect to the radio transmission and reception including the Radio Resource

Management (RRM) aspects. Equation 4.1 illustrates the general mathematical Equation for 3GPP TS 36.942 path loss model [28] and [32], and it is used in our work to calculate path loss for outdoor environment.

$$L_{p[dB]} = 40\left(1 - 4.10^{-3}.\, h_{BS}\right)\log_{10}(R) - 18.\log_{10}(h_{BS}) + 21.\log_{10}(fc)+80 \quad (4.1)$$

Where

- fc : The carrier frequency in MHz
- h_{BS}: The BS antenna height in meters measured from average rooftop level
- R: The distance between BS and UEs in kilometers.

To calculate the path loss, where the transmitter is eNodeB, while the receiver is UE. But the UEs supposed to be in outside of the house and the pathloss has calculated by using the 3GPP TS 36.942 path loss model for urban environment. So the mathematical calculations of path loss can be measured by reducing the Equation (4.1), and substitute the values of height of BS such as (15meter) on the rooftop according to 3GPP TS 36.942 and operating frequency according to our work such as 2.6GHz. So Equation 4.1 after substitution the values of carrier frequency and height of BS became like Equation 4.2. But the distance between eNodeB and UE cannot be estimated because in our simulation we distributes several users in randomly, so the distances are different from eNodeB to each UE, but in our simulation will be calculated. The Equation 4.1 [28] can be reduce to expressed as shown in Equation 4.2.

$$L_{p[dB]} = 130.54+37.6\log_{10}R \quad (4.2)$$

Where

- R: The distance that separate eNodeB and UEs, in kilometer

4.4.2 Path Loss for Femtocells (HeNodeB)

The path loss of Femtocells occur when HeNodeB is the transmitter and UE is either in indoor or outdoor environment. So we have described the path loss of Femtocell, according to the dual slope path loss model that implemented for Femtocells overlaid with Macrocells deployment scenario in Vienna simulator. These path loss model used to calculate the path loss for the indoor and outdoor UEs. The Equations of dual slope path loss model implemented by [28]. So, Equation 4.3 describes the general indoor path loss, but it is substituted in Equation 4.4 that is include the wall losses. After that, Equation 4.4 has substituted in Equation 4.5 that is used when the UEs in outside. Finally, the Equation of path loss for dual slop model has combined the Equations 4.3 and 4.5, to obtain the finial formula of dual slop path loss model as described in Equation 4.6 [28].

$$L_{p[In]} = 38.46 + n \cdot 10\log_{10}(d) \tag{4.3}$$

Where

- $L_{p[In]}$: Indoor path loss
- n: Indoor path loss exponent
- d: equal or smaller than indoor area radius

$$L_{p[InW]} = 38.46 + n \cdot 10\log_{10}(IR) - 37.6\log(IR) \tag{4.4}$$

Where:

- $L_{p[InW]}$: Indoor path loss at wall
- IR: indoor area radius
- n: indoor path loss exponent

$$L_{p[Out]} = L_{p[InW]} + 37.6\log(R) + WL \tag{4.5}$$

Where

- $L_{p[Out]}$: Outdoor path loss
- R: Distance between transmitter and receiver, but greater than IR
- WL: Wall Losses

By combining Equation 4.3 and Equation 4.5, we obtain Equation 4.6. Equation 4.6 used to calculate the path loss for outdoor and indoor UEs.

$$L_p = L_{p[In]} + L_{p[Out]} \tag{4.6}$$

Where, empirically the relation between the average received power and the distance has determined by path loss exponent. The typical values for indoor path loss exponent for NLOS is (4 up to 6), and we have used 4 in our work. So, the WL setting up to 20dB and the IR setting to 20meter in our work.

4.5 Fairness Performance

Fairness has used in the network engineering to determine whether the users or the applications are receiving a fair share of system resources. Fairness is a very necessary requirement for any cellular network. Because it is not enough to have high system throughput without guarantee of fair distribution of system resources. Therefore, we have explained the fairness index that used in our work.

A- Jain's index: - Jain's index or Fairness index as mentioned in Vienna simulator, is very famous parameter that used to measure fairness [6]. The fairness index measures of how each user is being served in a network if has requested for RBs. Suppose there are number of users (N) and these users have throughput R_i. The evaluation of user throughput has calculated by Equation (4.14). So Equation 4.7 [29] used to evaluate the fairness index.

$$J(t) = \frac{\left(\sum_{i=1}^{N} R_i\right)^2}{N \cdot \sum_{i=1}^{N} R_i^2} \tag{4.7}$$

Where

- J(t) : Fairness index
- R_i : Throughput of the user (i)
- N: No of the users

The range of fairness index from J=1/N , this considered the worst case up to J=1, this considered the best case, and it is maximum when all users receive the same allocation.

4.6 Wideband SINR

In general, the wideband SINR is the ratio of the power received from the serving cell to the interference power received from other cells plus the noise. Sometimes this measure is called geometry factor due to present a great dependency with the position of the users in relation to the position of the BSs. In our simulation, we have measured the wideband SINR correspond cumulative distribution function (CDF). The CDF of the wideband SINR at an arbitrary user is a representation of the environment that an arbitrary user in the network will encounter [33]. SINR is important parameter due to the BS receives channel quality reports typically in the form of SINR measurements from the UE in the cell [6]. The purpose of SINR evaluation in our work is illustrating the positive impact of Femtocells in increasing SINR and also to compare between the signal qualities for two access modes for Femtocells. Here, we will describe the Equations that used to evaluate of UEs SINR. The SINR can be evaluated by dividing the summation of the total received power for the RBs that assigned for the UE, to the summation of interference power of RBs plus noise power. The SINR calculation is done under the following circumstances, power allocation has evaluated per-subframe (1 ms), and RB basis the fast fading trace is given for every 6 subcarriers (every 90 KHz), in order to, provide enough samples related to a worst-case-scenario channel length. Wideband SINR for the user can be calculated directly from Equation 4.8 [28]. If there is an interference, Equation 4.8 can be used [28]. The interference from others eNodeBs has ignored because of our work consist of single eNodeB.

$$\mathrm{SINR} = \frac{\sum_{RB=1}^{N} R_x}{\sum_{RB=1}^{N} I + (\frac{\sigma^2}{2})} \tag{4.8}$$

Where:

- SINR: Wideband UE SINR
- R_x: Total received power of the RB that assigns to each UE
- I: Total received power of interfering RB
- σ^2 : Thermal noise power per half RB (divided by 2), and multiplied by (2.No of RBs)
- N: Number of RBs that assigns for each UE

The power received of the RB (R_x) can be directly calculated by using Equation 4.9 [28].

$$R_x = \frac{P_T}{UE_{LP}} \tag{4.9}$$

Where, P_T is the transmitted power of RB and its combine of the signaling power and data power. UE_{LP}, represents the user macroscopic path loss. So, UE_{LP} has calculated by using Equation 4.10 [28].

$$UE_{LP} = L_p \cdot \frac{10^{WL/10}}{10^{G_T/10}} \tag{4.10}$$

Where:

- UE_{LP} : User macroscopic path loss, its linear not in dB
- L_p : path loss
- WL : Wall losses, 20dB
- G_T : Transmitting antenna gain, 15dBi

Equation 4.11, calculates the interference received power for RB (I). So, the eNodeB transmitting power divided over all the RBs [28].

$$I = \frac{R_{RB}}{UE_{LP}} \qquad (4.11)$$

Where

- I: The power received of the interfering RB;
- R_{RB}: The power allocation for the interfering RB;
- UE_{LP}: The UE macroscopic path loss.

The power allocations is the power that allocated to RB. The eNodeB transmitting power divided over all RBs. Interfering received power of RB has divided by two due to calculate for half RB. If there is no interference, Equation 4.12, has calculated the SINR [28].

$$SINR = \frac{\sum_{RB=1}^{N} R_x}{(\frac{\sigma^2}{2})} \qquad (4.12)$$

Where:

- SINR: Wideband UE SINR;
- R_x: Total received power of the RB that assigns to each UE;
- σ^2 : Thermal noise power per half RB (divided by 2), and multiplied by (number of RB multiplied by 2);
- N: Number of RBs that assigns for each UE.

The thermal noise power [W] at the receiver also considered one of the parameters that's should be taking into consideration, when we want to calculate SINR, so can be expressed in Equation 4.13 [28] to be substitute in the Equations 4.8 and 4.12.

$$\sigma^2 = \left(\frac{10^{(\frac{D}{10})}}{1000}\right). B.10^{N_f} \qquad (4.13)$$

Where

- σ^2: Thermal noise power;
- D: Thermal noise density= -174dBm/Hz;
- N_f: UE receiver noise figure= 9dB;
- B= Bandwidth.

4.7 Average and Edge User Throughput

The user throughput has defined as the summation of the total number of bits during simulated Time Transmission Interval (TTI). TTI refers to the duration of the transmission on the radio link. We have setting our simulator by using TTI=10msec. While each TTI length = 1msec. So, the edge user throughput is defined as the 5^{th} percentile point of the CDF of user throughput. The edge user throughput has defined as the fifth percentile point of CDF of user average throughput per transmission. By assuming that 95% of the users have expected to achieve a certain throughput per transmission regardless of their geographical location in the cell. So average UE throughput has evaluated by using Equation 4.14, [28].

$$R = \frac{\alpha}{\beta . \gamma} \tag{4.14}$$

Where

- R: Average UE Throughput (Mbps)
- α: Sum of total bits
- β: Number of the TTI that assigned for the UE,
- γ: Length of TTI=1msec

4.8 Cell Capacity Analysis

The definition of capacity in LTE became express on how much the system can have throughput in the cell. We assume in our work that different number of MUE is connected to each Macrocell at a time such that this MUE is capable of using all available frequency resources assigned to this Macrocell. The same is assumed for Femtocells; the FUEs is connected to each Femtocell at a time such that this FUE is capable of using all available frequency resources assigned to its associated Femtocell. The evaluation of the average cell capacity based on the system settings and SINR for the target cell. The cell capacity can measured by integrate over all of the ROI (sum) such as apply correction factors for used bandwidth, Cyclic Prefix and reference and synchronize symbols. Equation 4.15, [28] used to calculate cell capacity.

$$C = B . \rho . \varepsilon . \varphi . \log_2(1+SINR) \tag{4.15}$$

Where:

- C: Cell capacity;
- B: Bandwidth;
- ρ: Cyclic prefix ratio;
- ε: Reference symbol ratio;
- φ: Synchronize symbol ratio;
- SINR: SINR of whole ROI.

To evaluate cell capacity, we should substitute the Equations 4.16, 4.17, 4.18, 19 and 4.20 in Equation 4.15 [28].

$$B = K \cdot J \quad (4.16)$$

Where

- K: No of RB in the bandwidth= 100RBs, for 20MHz that used in our work;
- J: Bandwidth of RB = 180Hz.

$$\rho = 1 - \left(\frac{X}{Y}\right) \quad (4.17)$$

Where

- X: Cyclic prefix length;
- Y: Length of the symbol.

So, the cyclic prefix length has evaluated by this expression, $X = Z / F_s$

- Z: Cyclic prefix length samples = 144; for the normal cyclic prefix;
- Fs: Sampling frequency, where15 KHz* FFT points;
- FFT points: No of Fast Fourier Transform points = 2048, for 20MHz.

While, the length of the symbol can be calculated by using below expression.

Y=length of TTI/(No of symbol . 2)

- Length of TTI= 1msec;
- No of the symbol=7 for cyclic prefix

Why it is multiplied by two because of the sub-frame length = 2slots.

Reference symbol ratio has calculated by using Equation 4.18 [28].

$$\varepsilon = 1 - \left(\frac{R}{H \cdot S \cdot V}\right) \quad (4.18)$$

Where

- R: No of Reference symbol, where R = 12; when V =4;
- H: No of symbol

- S: Number of subcarriers per RB = 12;
- V: Number of transmitting antenna = 4

Reference symbol ratio can be defined as the ratio of reference symbols divided by the total number of symbols in the subframe.

The synchronize symbol ratio has calculated by using equation 4.19 [28].

$$\varphi = 1 - \left(\frac{72}{5 \cdot P}\right) \tag{4.19}$$

Where

- P: Sub-frame size of the symbol

$$P = M \cdot (2 \cdot S) \cdot K$$

Where

- M: No of symbol in each sub frame and by using cyclic prefix=14;
- S: Sub-carriers per RB =12;
- K: No of RBs, multiplied by two due to for sub frame

Synchronization signal has been broadcasting twice during every radio frame and both transmissions are identical. In the case of FDD, mapped to 72 active subcarriers (6 resource blocks), centered around the DC (frequency axis), subcarrier in slot 0 (sub-frame 0) and slot 10 (sub-frame 5). Synchronization signal used to achieve sub-frame, slot and symbol synchronization in the time domain; identify the center of the channel bandwidth in the frequency domain; and deduce a pointer towards 1 of 3 Physical layer Cell Identities (PCI). PCI are organized into 168 groups of 3, so the synchronization signal identifies the position of the PCI within the group but does not identify the group itself. The evaluation of SINR should be for whole ROI, which means the SINR, has calculated for all sectors [28].

$$SINR = \frac{R_X}{\sum_{B=1}^{N} I + \sigma^2 - R_X} \tag{4.20}$$

Where

- SINR: Linear SINR for ROI;
- R_x: Received powers from the target cell (W);
- I: Received powers from three cells (W), where B refers number of cells;
- σ^2: Thermal noise power (W).

If the total number of eNodeBs greater than macrocells eNodeB, which means there are femtocells with existing of macrocells, and should be taken into account. To evaluate the SINR, we should substitute Equation 4.21 in Equation 4.20 and the power received from the target cell, also the power received from the others cells.

$$\sigma^2 = \left(\frac{10^{(\frac{D}{10})}}{1000}\right) . \ B.10^{N_f} \tag{4.21}$$

Where

- σ^2: Thermal noise power
- D: Thermal noise density= -174dBm/Hz
- N_f: UE receiver noise figure= 9dB
- B= No of RB * Bandwidth of RB

That's procedure is used to evaluate cell throughput, which will be used later in Chapter 5 for calculating our evaluation metrics for measuring system performance.

CHAPTER 5

SIMULATION RESULTS

5.1 Introduction

We have investigated and evaluated the performance for downlink cellular mobile network by using LTE-A downlink system level simulator. In general, this chapter consist of two scenarios. The first scenario consists of only Macrocells deployment while the second scenario consist of Femtocells overlaid with Macrocells deployment. So, in this chapter we have proved the positive impact of Femtocells deployment on the network performance. Then we compared the performance of Femtocells in the case of OSG and CSG access mode. After that we have compared the performance of the network in the both scenarios by using three well known scheduling schemes (Round Robin, Best CQI, and Proportional Fair Sun) to prove the best scheduler scheme in producing better throughput and fairness.

5.2 The First Part of Thesis

5.2.1 Only Macrocells Deployment Scenario

We have deployed only Macrocells as shown in Figure 5.1 and this deployment according to the system model in the Section 4.3. So, this scenario consists of one eNodeB and this eNodeB creates three Macrocells. Our simulator in this scenario have setting up based on the parameters in Table 5.1. We have investigated the performance of the network by increasing the number of MUE per eNodeB such as 15, 30, 45, 60, 75, and 90. So we have evaluated in this scenario the average and edge UE throughput; cell throughput, and signal quality. As mentioned in Table 5.1, we have used the Proportional Fair Sun scheduling scheme due to has less complexity and it is better than other scheduling algorithms due to provide an excellent relationship between system throughput and fairness of users as we are going to prove it in the second part of thesis.

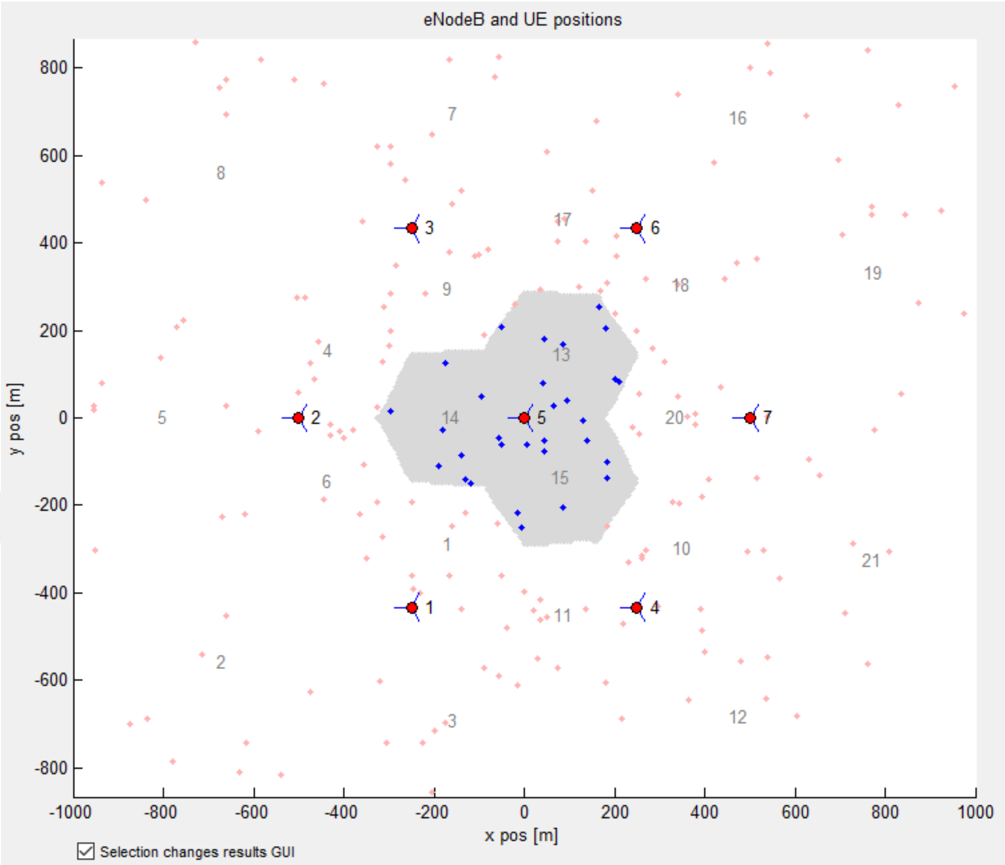

Figure 5. 1 Only Macrocells deployment Scenario by (Vienna simulator)

Table 5. 1 Input Parameters of the Simulation

Parameters	Value
	eNodeB
Transmit Power	49dBm
Carrier frequency	2.6GHz
Channel Bandwidth	20MHz
Number of Resource Blocks	100RBs
MIMO antenna	4x2
Number of Sectors per eNB	3
Scheduler scheme	Proportional Fair Sun
Minimum coupling loss (MCL)	70dB

Table 5. 1 Input Parameters of the Simulation

Max Sector Antenna Gain	15dBi
Propagation path loss model	TS 36.942 path loss model
The environment	Outdoor urban environment
Transmission mode	Close loop spatial multiplexing (CLSM)
Transmission Time Interval (TTI)	10 msec
	User Equipment
Power of UE	24dBm
Antenna Pattern	Omni-directional
Antenna Gain	0 dBi
Speed of UE	5 Km/h or 1.38 m/s
Rx Noise Figure	9 dB
Thermal Noise power	-174 dBm/Hz
	Femtocells
Number of Femtocells per Macrocell	2 and 4
Number of UE attached to each Femtocell	Fixed (2)
Path loss model	Dual slop path loss model
Transmit power	23dBm
Carrier frequency	Shared same carrier frequency for eNodeB such as 2.6GHz
Minimum coupling loss (MCL)	45dB
Access mode	Open subscriber group (OSG)
Path loss model	Dual slop path loss model
Transmit power	23dBm

Table 5. 2 Average UE throughput corresponding MUE for only Macrocell deployment scenario

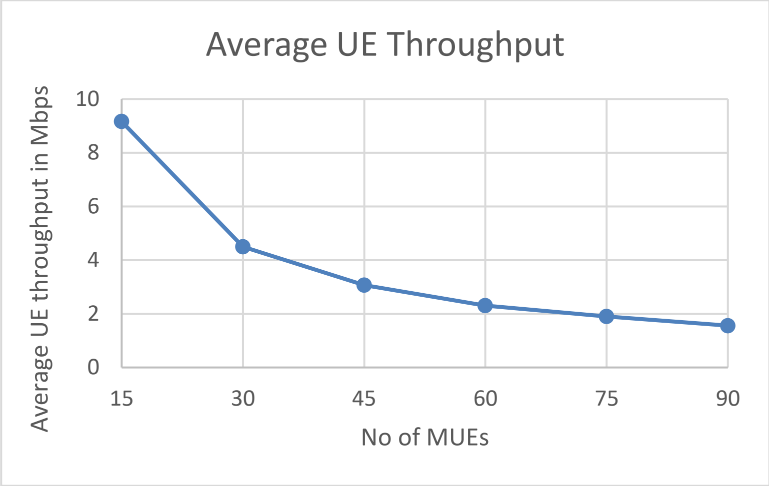

Table 5.2 shows the average UE throughput that is produced by deploying only Macrocells. As obvious the average UE throughput decreased with increasing number of MUEs as ordered 15, 30, 45, 60, 75, and 90. The average UE throughput is calculated by using Equation 4.14. Where, these Equation calculates the throughput by dividing the total number of information bits that the user successfully received divided by the total simulation time. When the multiple users are in the cell, the radio resources must have shared among the active users. As obvious the UE average throughput has reduced by increasing of MUEs, due to the resources have equally shared among active users. So, in the case of increasing of MUEs and due to random distribution of users some of users placed at the edge and cannot get a good channel, as a result of that the order modulation will be decreased, so the number of bits will decreased, finally this also impact on the average throughput of user and get decreasing with increasing number of MUEs. Table 5.5, shows the values of the average UE throughput, get decreased from 9.16Mbps up to 1.56Mbps.

Table 5. 3 Edge UE throughput corresponding MUEs for only Macrocells deployment scenario

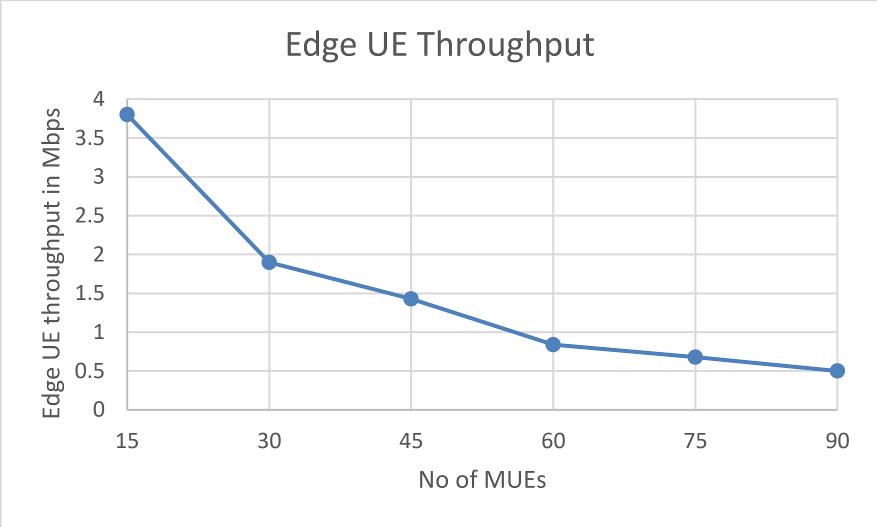

Table 5.3, shows the edge user throughput corresponding to increasing the MUEs in the case of deploying only Macrocells. The edge user throughput has defined as the fifth percentile point of CDF of average UE throughput per transmission by assuming that 95% of the users have expected to achieve a certain throughput per transmission regardless of their geographical location in the cell as explained in (Section 4.7). As obvious the edge user throughput has decreased with increasing of MUEs because of the path loss at the edge of cell will increase. As a result, the signal quality of edge UE has decreased. So, the edge UE will send feedback to cell about the poor signal, and the cell will reduce the order of modulation to minimum order. For example, Quadrature Phase Shift Keying (QPSK), and thus the bits that received successfully will reduce. Finally, as we mentioned the edge UE that obtained from CDF of average UE throughput and it is the 5^{th} percentile of CDF of UE throughput. Table 5.5, shows the values of the edge UE throughput. As illustrated in Table 5.5, the values of UE edge throughput get reduced from 3.8Mbps to 0.5Mbps.

Table 5. 4 Average cell throughput corresponding MUEs for only Macrocells deployment

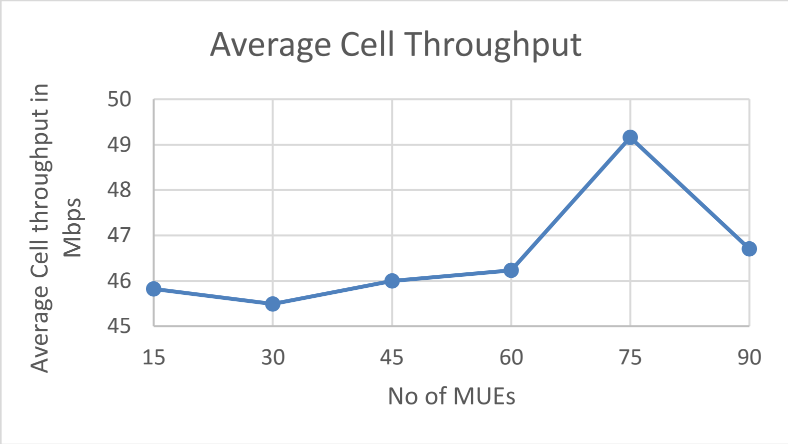

Table 5.4, shows the average cell throughput corresponding increasing of MUEs in the case of only Macrocell deployment scenario. The average cell throughput has calculated by using Equation 4.15, as mentioned in Section 4.8, the cell throughput in LTE networks means how much the system can have a throughput in the cell unlike the previous concept of the capacity in previous cellular mobile releases, which stated the capacity means the number of users. As obvious the average cell throughput almost has the same throughput according to Equation 4.15, that used to calculate cell capacity based on various system setting and SINR of the three cells. Which means SINR for all the cells is same. So, the average cell throughput between 45.49Mbps as minimum value to 49.16 as maximum value. Table 5.5, shows the values of the average cell throughput.

Table 5. 5 Results for only Macrocells deployment scenario

Number of UEs per eNodeB	Average UE throughput (Mbps)	Edge UE throughput (Mbps)	Average cell throughput (Mbps)
15	9.16	3.8	45.82
30	4.5	1.9	45.49
45	3.07	1.43	46
60	2.3	0.84	46.23
75	1.9	0.68	49.16
90	1.56	0.5	46.7

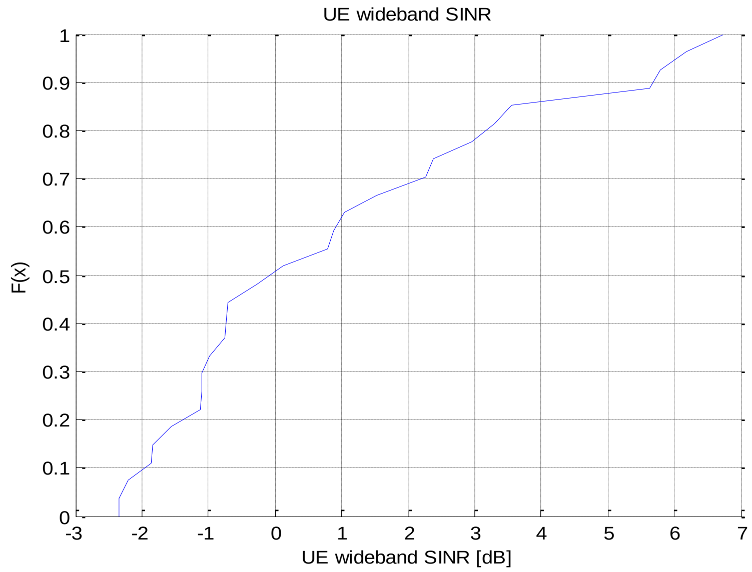

Figure 5. 2 SINR corresponding CDF for only Macrocells deployment scenario

Figure 5.2 shows the SINR corresponding CDF for the Macrocells deployment scenario. As obvious, the UE SINR values have increased with the increasing of CDF and it has calculated from Equation 4.8. First of all, the wideband SINR can be evaluated by dividing the summation of the total received power for the RBs that assigned for the user, to the summation of interfering power of RBs plus thermal noise power. Sometimes this measure called the geometry factor, since it presents a great dependency with the position of the user in relation to the position of the base stations. As illustrated the SINR starts from (-2.3dB up to +6.7dB) the negative value for SINR not means there is no connection while means the value of interference and noise more than the value of received power at the receiver. So, the SINR below -2.3 means will happen outage and the UE cannot get service. So, due to the path loss and interferences the SINR get decreased. As we mentioned the interference technique that implemented in our simulator is FFR but reuse-1, which mean assigns the entire frequency resources to be reused by all Macrocells that's why the interference value has increased, as a result of that the SINR get decreased. Finally, this figure represents the SINR in the case of deploying 90MUE.

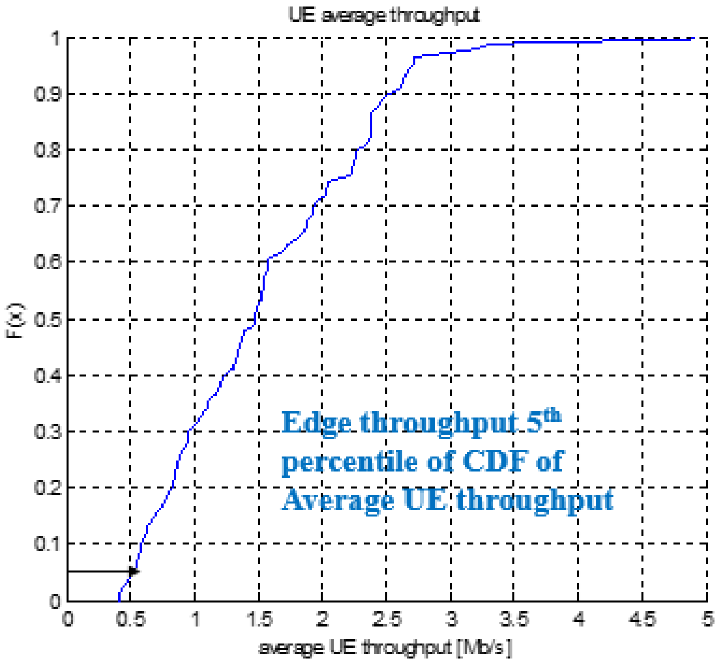

Figure 5. 3 Average UE throughput correspond CDF for only Macrocells deployment scenario

Figure 5.3, shows the Average UE throughput correspond CDF in the case of Macrocells deployment scenario and by deploying 90MUE. As obvious the purpose of that Figure 5.3 to illustrate the evaluation of edge user throughput that is defined as the 5th percentile point of CDF of user average throughput per transmission. By assuming that 95% of the users have expected to achieve a certain throughput per transmission regardless of their geographical location in the cell as explained in (Section 4.7).

5.2.2 Femtocells Overlaid with Macrocells Deployment Scenario

In this scenario, also according to the indoor system model in the Section 4.3.2, so we have deployed Femtocells overlaid with existing of Macrocells but here, we have deployed Two Femtocells and Four Femtocells as illustrated in the Figure 5.4 and Figure 5.5 respectively. We have deployed Two and Four Femtocells per each Macrocell and attach Two UEs per each Femtocell. The distribution of users and Femtocells are randomly, which means the users deployed almost like in the real life and Femtocells distribution don't overlap with each other. In this scenario, also we have evaluated the average and edge UE throughput; cell throughput and signal quality to compare these parameters with the same parameters that are measured in the only Macrocells deployment scenario to prove the positive impact of Femtocells on the network. This scenario based on the setting up in the Table 5.1. Figure 5.4 and Figure 5.5 as a sample from our simulator only to illustrate the distribution of Femtocells and UEs in the case of deploying 90MUEs.

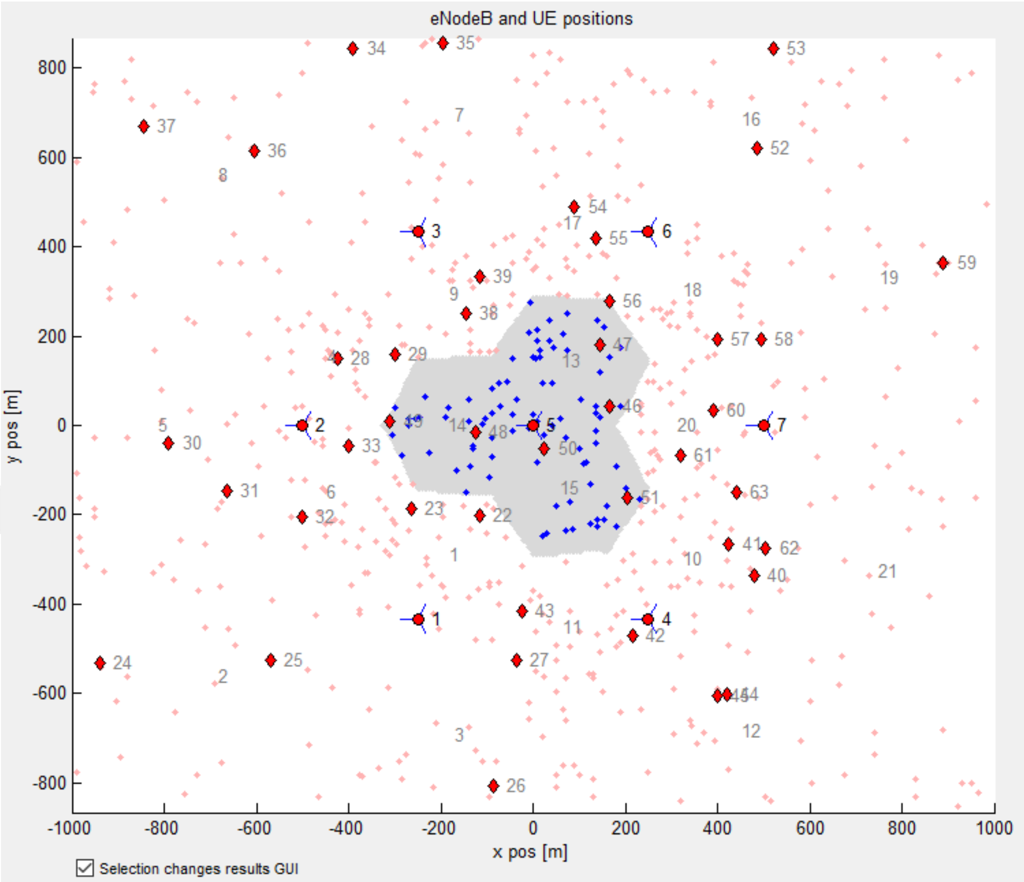

Figure 5. 4 Femtocells overlaid with Macrocells deployment scenario in the case of deploying Two Femtocells per Macrocell by (Vienna simulator)

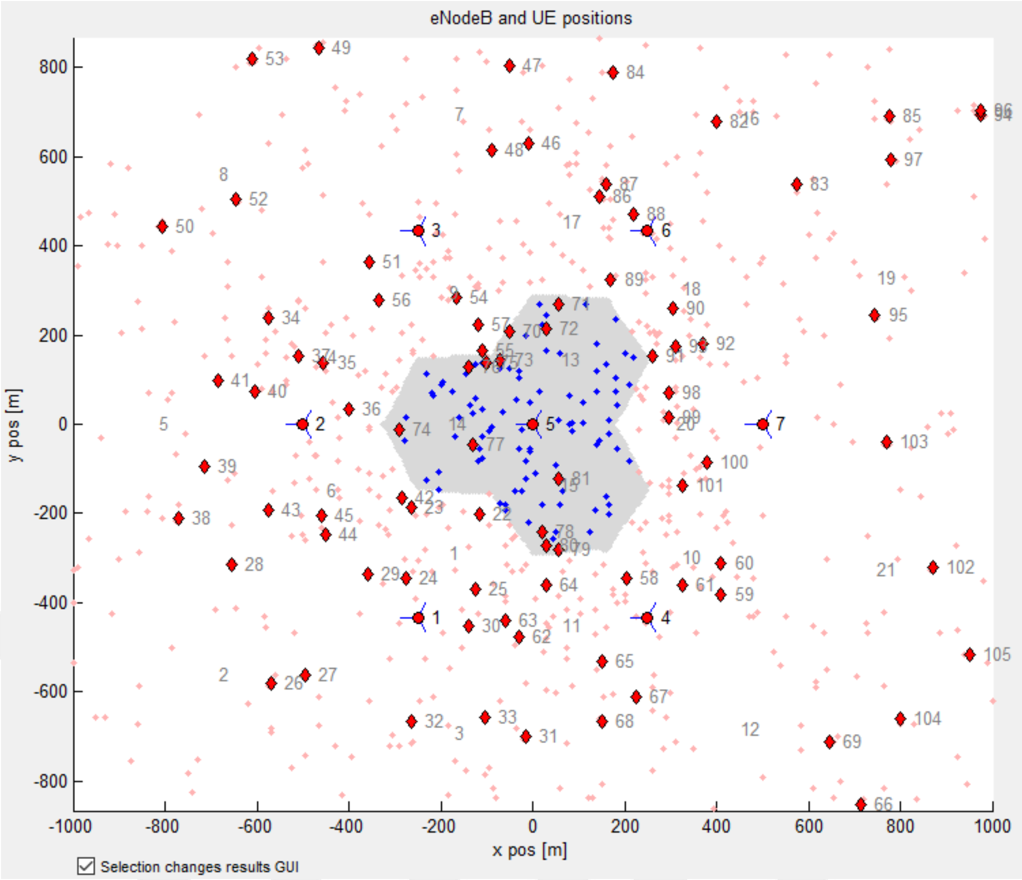

Figure 5. 5 Femtocells overlaid with Macrocells deployment scenario in the case of deploying Four Femtocells per Macrocell by (Vienna simulator)

Table 5. 6 Average UE throughput for Femtocells overlaid with Macrocells deployment scenario

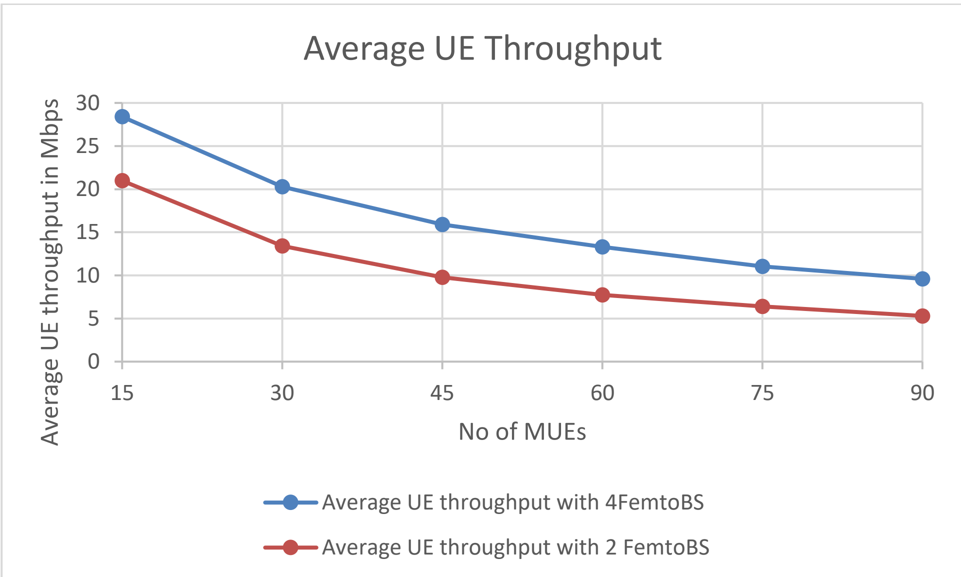

Table 5. 6, shows the average UE throughput that is produced by Femtocells overlaid with Macrocells deployment scenario. We have deployed Two and Four Femtocells

respectively. The average UE throughput has calculated according to the Equation 4.14. As obvious the Femtocells deployment have significantly enhanced the average UE throughput compared to average UE throughput that achieved by only Macrocells deployment scenario as illustrated in Table 5.2, This enhancement of Femtocells on the throughput has decreased with increasing number of MUE due to the resources are equally shared among the active users in the cell that's why increasing the number of users cause reducing in the UE's throughput. In spite of the decreasing of UE throughput in the case of deploying Femtocells, but remained keep on producing better throughput than UE throughput that achieved by only Macrocells deployment scenario. For example, at 90MUE the throughput values in the case of using 2 and 4 Femtocells are 5.3Mbps and 9.6Mbps respectively, while the UE throughput in the case of without using Femtocells deployment at 90MUE is 1.56Mbps as demonstrated in Table 5.2. The enhancement of Femtocells due to enhance the quality of signal for the UEs that are located near to Femtocells as a result of that more UE served and more data transferred. Table 5.9 and Table 5.10, show the values of the average UE throughput in the case of deploying Two and Four Femtocells respectively.

Table 5. 7 Edge UE throughput for Femtocells overlaid with Macrocells deployment scenario

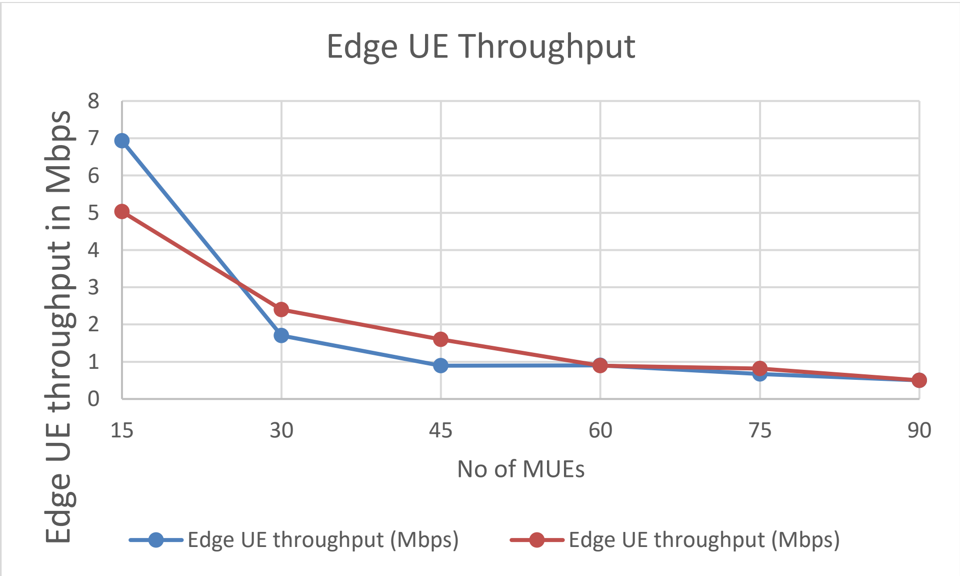

Table 5. 7, shows the edge UE throughput for Femtocells overlaid with Macrocells deployment scenario in the case of deploying Two and Four Femtocell deployment respectively. The edge UE throughput defined as the fifth percentile point of CDF of UE average throughput per transmission. Assuming that 95% of the users have expected to

achieve a certain throughput per transmission regardless of their geographical location in the cell as explained in Section 4.7. As obvious the Femtocells have improved the edge throughput of UEs but get decreased with increasing of MUEs because of the unplanned distribution of Femtocells and the interference effects on the performance of the system network also due to the worse interference mitigation technique that used in our simulator. In spite of increasing the number of Femtocells such as Four Femtocells. We obtained high throughput at 15 MUE but directly fall down with increasing of MUEs to 30MUE, that's happened due to uncontrolled deployment of Femtocells by the operator and the interference from neighboring Femtocells and from Macrocell, so that's why we have investigated the performance of Four Femtocell. So, this case can be considered the worst case, as we mentioned our simulator used the worse interference technique management, for sure, the Femtocells will enhance the edge UEs in the case of using better interference techniques. Femtocells can enhance the quality of signal for the UEs that are located close to its coverage area. Table 5.9 and Table 5.10, show the values of the edge UE throughput in the case of deploying Two and Four Femtocells respectively.

Table 5. 8 Average cell throughput for Femtocells overlaid with Macrocells deployment scenario

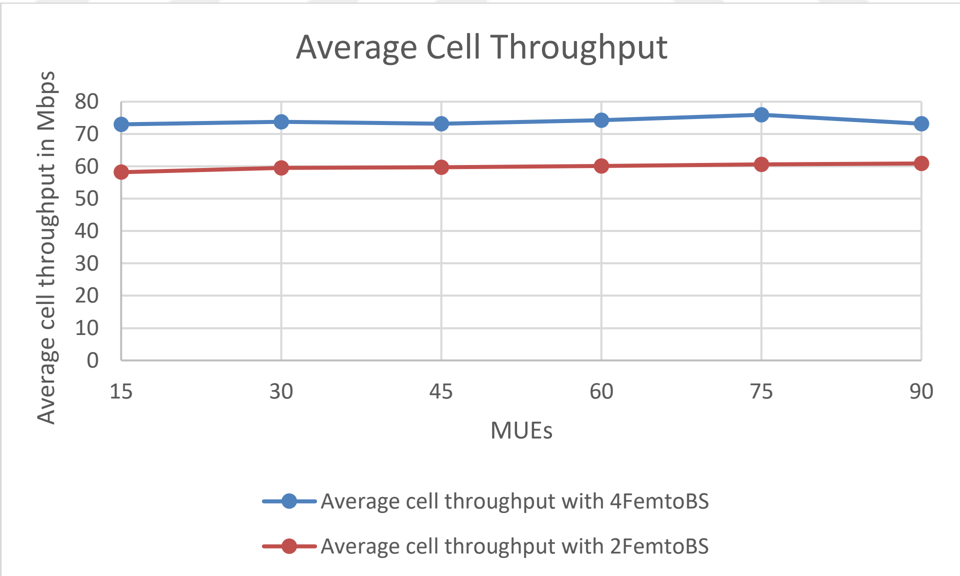

Table 5.8, illustrates the average cell throughput for Femtocells overlaid with Macrocells deployment scenario. The cell throughput has calculated by using Equation 4.15, as mentioned in Section 4.8. The cell capacity in LTE networks means how much the system can have a throughput in the cell unlike the previous concept of the capacity in previous cellular mobile releases, which stated the capacity means the number of users. As obvious the cell throughput in the case of Femtocells overlaid with Macrocells deployment

scenario better than throughput that achieved by the only Macrocells scenario as illustrated in the Table 5.4. Because of the Femtocells have enhanced the signal quality for the MUEs that positioned close to the Femtocells and grant access to these MUEs as a result of that the cell throughput has enhanced. As we observed the cell throughput almost increased by very small frictions with increasing the number of MUE but the values almost have no significant difference among these values because of throughput of the cell in our simulator depends on setting parameters and the target SINR. So, the maximum values of cell throughput by deploying 2 and 4 Femtocell is 60.9Mbps and 75.96Mbps respectively compared to the maximum value of cell throughput in the case of only Macrocells deployment scenario is 49Mbps as demonstrated in Table 5.4. Table 5.9 and Table 5.10, show the values of the average cell throughput in the case of deploying Two and Four Femtocells respectively.

Table 5. 9 Results for Femtocells overlaid with Macrocells deployment scenario by deploying Two Femtocells

No of MUEs	Average UE throughput (Mbps)	Edge UE throughput (Mbps)	Average cell throughput (Mbps)
15	20.98	5.03	58.2
30	13.4	2.4	59.53
45	9.78	1.60	59.76
60	7.73	0.89	60.15
75	6.42	0.82	60.62
90	5.3	0.5	60.9

Table 5. 10 Results for Femtocells overlaid with Macrocells scenario by deploying Four Femtocells

No of UEs per eNodeB	Average UE throughput (Mbps)	Edge UE throughput (Mbps)	Average cell throughput (Mbps)
15	28.4	6.93	73
30	20.3	1.7	73.8
45	15.9	0.89	73.2
60	13.3	0.9	74.3
75	11.05	0.67	75.96
90	9.6	0.5	73.2

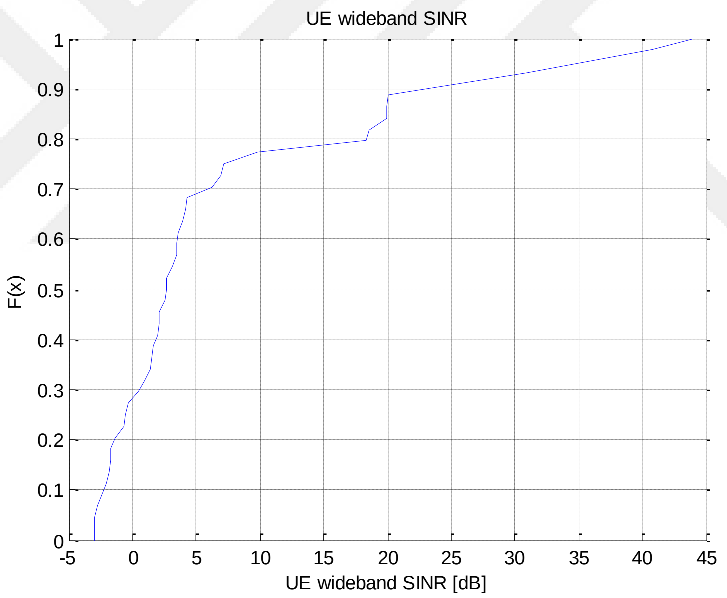

Figure 5. 6 SINR corresponding CDF for Femtocells overlaid with Macrocells deployment scenario by deploying Two Femtocells

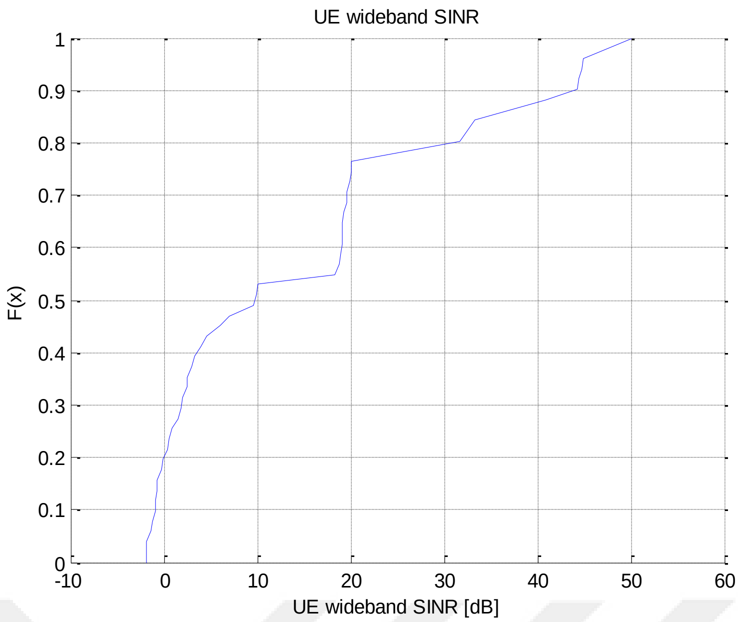

Figure 5. 7 SINR corresponding CDF for Femtocells overlaid with Macrocells deployment scenario by deploying Four Femtocells

Figure 5.6 and Figure 5.7 show us the UE SINR corresponding CDF as a sample for Femtocells overlaid with Macrocells deployment scenario results at deploying 90MUE. SINR calculated by using Equation 4.8. Firstly, SINR is the ratio of summation the total received power for the RBs that assigned for the user, to the summation of interference signals from another cells plus thermal noise power. Secondly, CDF of the wideband SINR at an arbitrary user is a representation of the environment that an arbitrary user in the network will encounter. Often, these measure is named by geometry factor due to present a great dependency with the location of the UEs in relation to the location of the BSs. As obvious the SINR have increased proportionally with increasing of CDF. So, by using 2 and 4 Femtocells have increased the SINR of UE approximately from -2.7dB to +44dB and -2.2dB to +50dB respectively. While in the case of only Macrocells deployment scenario the SINR increases from -2.3dB up to +6.5dB as illustrated in the Figure 5.2. So, the Femtocells have significantly enhanced the signal quality of the users that located in its coverage area and also the users that close to its coverage, as a result of that the SINR get enhanced compared to only Macrocells deployment scenario. So, these minimum values for SINR is threshold below these values the UEs cannot get service. The SINR can be more improved but by using better interference mitigation techniques due to the interference mitigation technique that implemented in our simulator is reuse-1 and this considers the worse technique. So, we can recognize the better value of signal quality compared to interference and noise when the SINR be close to the zero and goes towards the positive direction. Finally, we proved the Femtocells enhanced the signal quality of the network and this lead us to improve the coverage and capacity of the network.

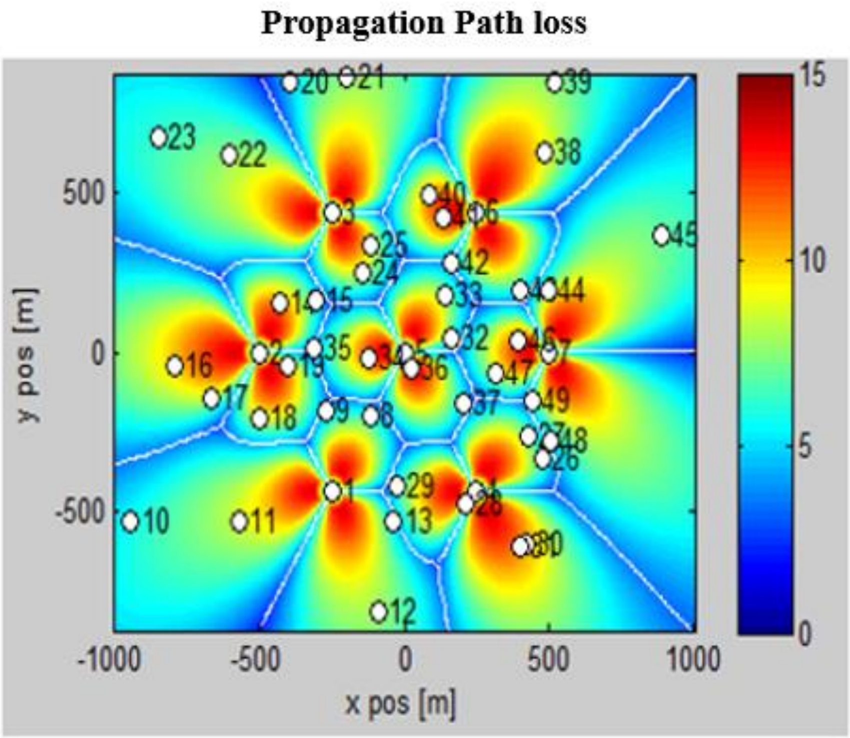

Figure 5. 8 Network layout with pathloss, 7 eNodeBs overlaid with femtocells, with different SINR values

Figure 5.8, shows the propagation path loss. As shown in the Figure, the distribution of SINR values for whole network layout, which that implemented in our simulator. As expected, and as we observe in the Figure 5.8, the high values of SINR for the users that are located closer to the eNodeB. Therefore, the excellent quality of service has assured for the users that have placed in this region. The value of SINR decreases with the increasing in the distance from eNodeB towards the edge due to increase of the path-loss and high interference from neighboring cells. To sum up, edge users experience poor SINR and hence poor quality of service that's why we have deployed Femtocells to enhance the quality of edge signal that placed inside or close to coverage area of Femtocells.

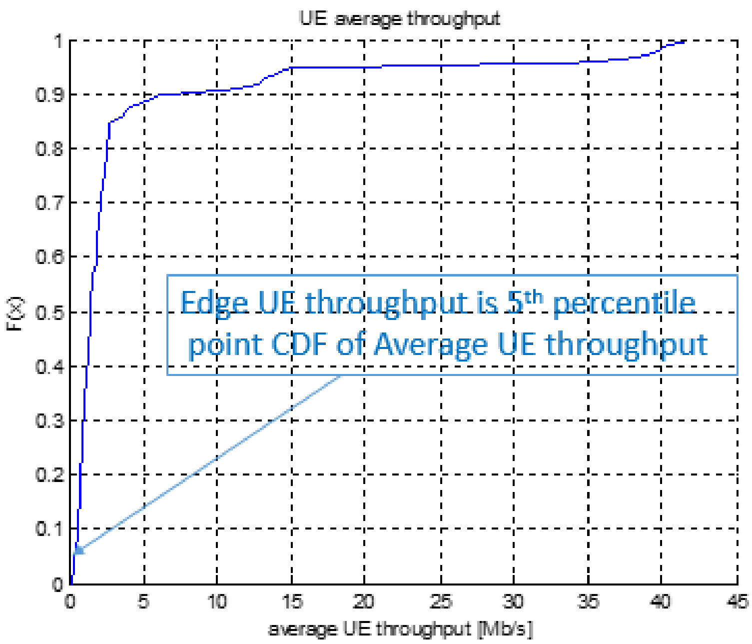

Figure 5. 9 Average UE throughput correspond CDF for Femtocells overlaid with Macrocells deployment scenario by deploying Two Femtocells

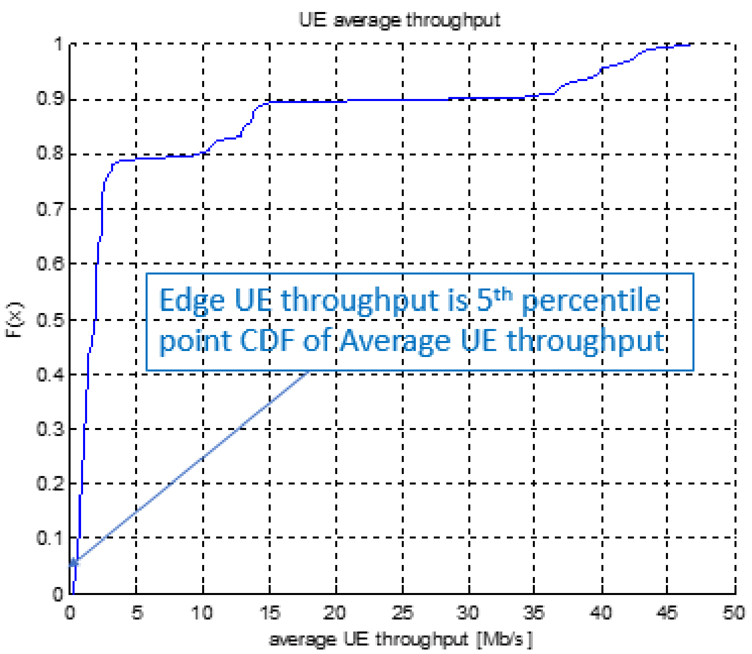

Figure 5. 10 Average UE throughput correspond CDF for Femtocells overlaid with Macrocells deployment scenario by deploying Four Femtocells

Figure 5.9 and Figure 5.10, show us the user throughput correspond CDF in the case of Femtocells overlaid with Macrocells deployment scenario by deploying, Two and Four Femtocells in the case of using 90MUEs. The main purpose of these Figures to illustrate the edge UE throughput as considered the 5th percentile point CDF of UE throughput by assuming 95% are expected to achieve a certain throughput per transmission regardless of their geographical location in the cell as explained in Section 4.6. Where, the edge UE throughput is approximately 0.5Mbps for two and four Femtocells deployment scenario as illustrated in Table 5.7, for 90 MUE.

5.2.3 Results of Investigations Femtocells OSG and CSG Access Modes

In the previous Section, we have compared the performance of Femtocells overlaid with Macrocells deployment to the only Macrocell deployment. We have proved the efficiency of Femtocells in improving the coverage and capacity of the network but by using Femtocells OSG mode. So here in this Section of thesis we have investigated the performance of network system in the case of CSG and OSG of Femtocells access mode based on Table 5.11. The purpose of this Section to let us know the best performance for the access mode strategies and also to prove the beneficial access mode for the operator. The walls that are implemented in indoor model to separate between Femtocells in indoor and outdoor MUE and also between neighboring Femtocells. The purpose of these wall to reduce the interference from neighboring Femtocells and also from outdoor MUE. So, we have investigated and compared between these access modes by increasing the FUEs such as 2, 4, 6, 8, and 10 with respect to the average/edge UE throughput, cell throughput, fairness. Also, we have compared between signal qualities for these modes.

Table 5. 11 Input Parameters of the Simulation

Parameters	Value
	eNodeB
Transmit Power	49dBm
Carrier frequency	2.6GHz
Channel Bandwidth	20MHz
MIMO antenna	4x2
Number of Sectors per eNB	3
Scheduler scheme	Proportional Fair Sun
Transmission mode	Close loop spatial multiplexing (CLSM)
Transmission Time Interval (TTI)	10 msec

Table 5. 11 Input Parameters of the Simulation

	Femtocells
Number of Femtocells per Macrocell	2
Number of UE attached to each Femtocell	2, 4, 6, 8, and 10
Path loss model	Dual slop path loss model
Transmit power	23dBm
Carrier frequency	Shared same carrier frequency for eNodeB such as 2.6GHz
Minimum coupling loss (MCL)	45dB
Access mode	Open Subscriber Group (OSG) and Close Subscriber Group (CSG)
	Femtocells
Number of Femtocells per Macrocell	2
Number of UE attached to each Femtocell	2, 4, 6, 8, and 10

Table 5. 12 Average UE throughput by using OSG and CSG Femtocell Access mode

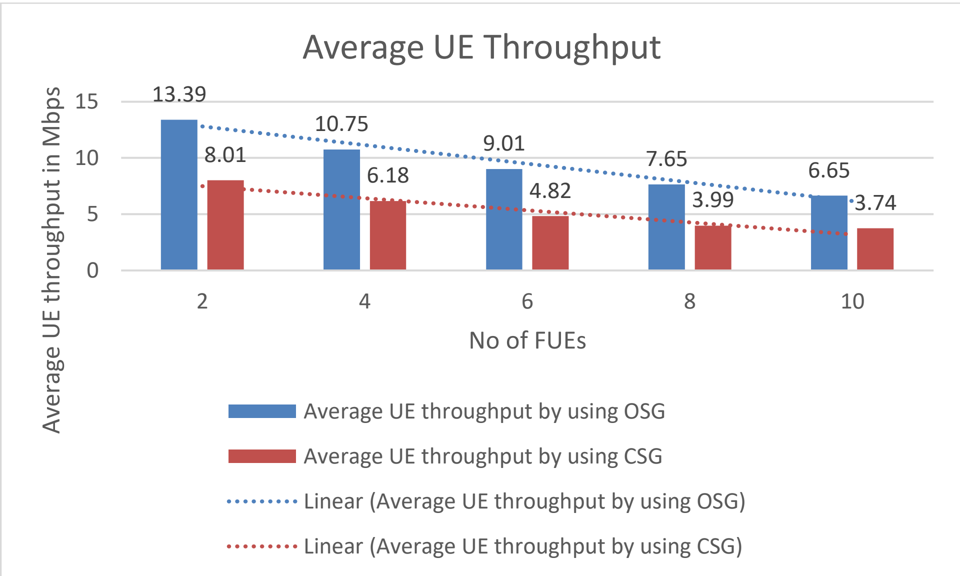

Table 5. 12, illustrates the average UE throughput in the case of Femtocell OSG and CSG access modes and evaluated by using Equation 4.14. As obvious, the OSG produces better UE throughput compared to CSG mode but the throughput has decreased gradually with

increasing number of FUE because of the radio resources must be shared among all the users. The reason of good performance for OSG mode due to the Femtocell in this mode have served the attached users and also can grants access to the indoor MUEs that are closed and inside the coverage area of Femtocells. While in the case of using, CSG mode the Femtocells only served the registered users that specified by the owner therefore the neighboring FUEs and close indoor MUEs cannot serve, and cause an interference to FUEs. Table 5.16 and Table 5.17, show the values of the average UE throughput for OSG and CSG access modes.

Table 5. 13 Edge UE throughput by using OSG and CSG Femtocell Access mode

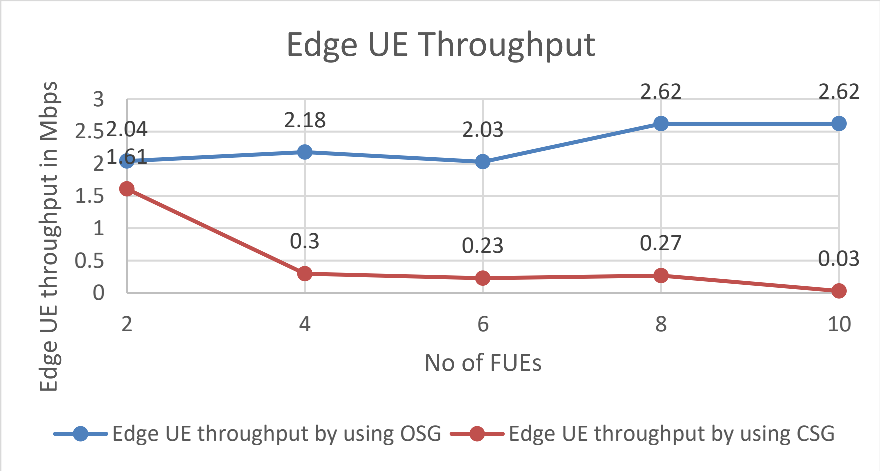

Table 5. 13 shows the edge user throughput that produced by using OSG and CSG access mode. As we observed in the case of using OSG mode the UE edge throughput better than throughput that achieved by CSG access mode. The edge throughput has increased with increasing number of FUEs in the case of using OSG access mode. While the UE edge throughput has decreased in the case of using CSG access mode because of the radio resources must be shared among all the FUEs that attached and the cell edge UEs cannot get access, also cause an interference. While the OSG access mode has served all the FUEs and the indoor MUEs and improved the edge signal quality therefore produced better edge UE throughput. Table 5.16 and Table 5.17, show the values of the edge UE throughput for OSG and CSG access modes.

Table 5. 14 Average cell throughput by using OSG and CSG Femtocell Access mode

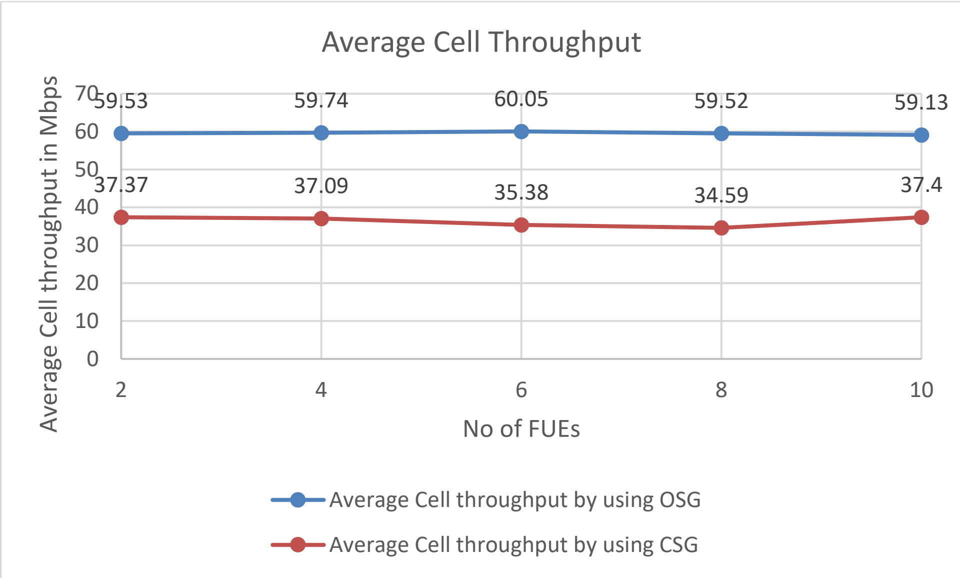

Table 5. 14 shows the Average cell throughput in the case of using OSG and CSG. The average cell throughput has evaluated by using Equation 4.15. As clear and expected the cell throughput that achieved by using OSG access mode better than throughput that achieved by CSG access mode. The reason behind the better cell throughput that achieved by OSG access mode is the enhancement for the edge users and increase the signal quality for them therefore in the OSG mode the number of users that have service more than in the case of using CSG. As we noticed, the cell throughput almost keep on the same values with small difference by fractions along with increasing of FUEs. Table 5.16 and Table 5.17, show the values of the average cell throughput for OSG and CSG access modes.

Table 5. 15 Fairness Index by using OSG and CSG Femtocell Access mode

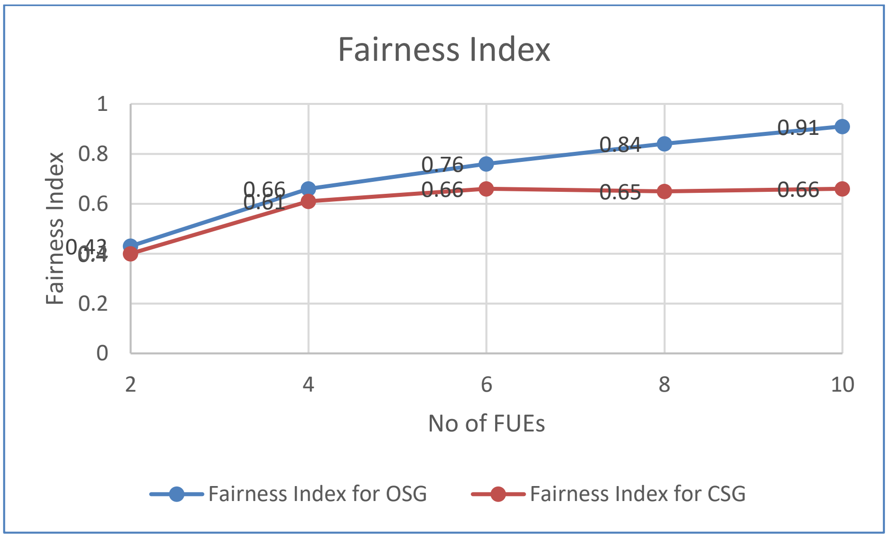

Table 5. 15 shows the fairness index in the case of OSG and CSG. We have compared between these access modes at this parameter by using Equation 4.7. As well known the fairness index is the measure of how each user is serving in a network if they have requested for RBs. So, as obvious the fairness index has increased with increasing the users but the OSG access mode has higher fairness than CSG mode. In the OSG, the fairness index increasing ascendingly with increasing the number of FUEs. While CSG also increased, and stay almost equal with increasing FUEs due to this mode do not grant access to the UEs that have not registered in the Femtocells. Table 5.16 and Table 5.17, show the values of fairness index for OSG and CSG access modes.

Table 5. 16 Results of Femtocell OSG access mode

No of UEs	Average UE throughput (Mbps)	Edge UE throughput (Mbps)	Average cell throughput (Mbps)	Fairness Index
2	13.39	2.04	59.53	0.43
4	10.75	2.18	59.74	0.66
6	9.01	2.03	60.05	0.76
8	7.65	2.62	59.52	0.84
10	6.65	2.62	59.13	0.91

Table 5. 17 Results of Femtocell CSG access mode

No of UEs per Femtocell	Average UE throughput (Mbps)	Edge UE throughput (Mbps)	Average cell throughput (Mbps)	Fairness Index
2	8.01	1.61	37.37	0.4
4	6.18	0.3	37.09	0.61
6	4.82	0.23	35.38	0.66
8	3.99	0.27	34.59	0.65
10	3.74	0.03	37.4	0.66

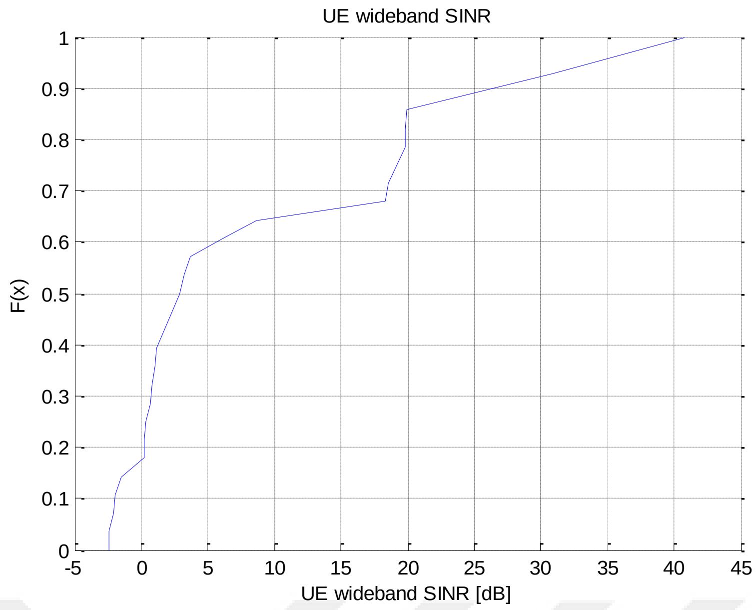

Figure 5. 11 SINR corresponding CDF by using OSG

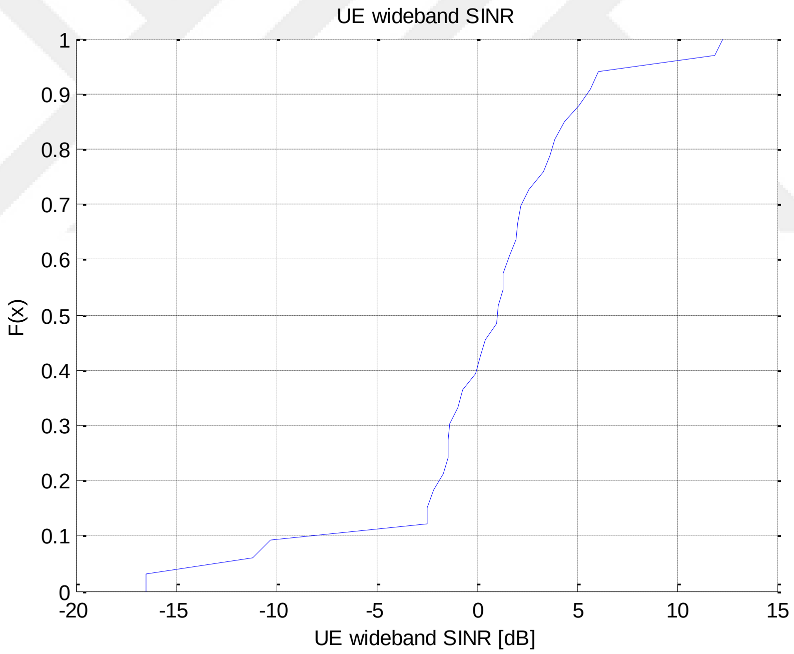

Figure 5. 12 SINR corresponding CDF by using CSG

Figure 5.11 and Figure 5.12 show the SINR corresponding CDF in the case of using OSG and CSG respectively. These SINR have evaluated by Equation 4.8. These Figures as a sample in the case of using 2FUEs in the both modes. So, as we mentioned the uncontrolled distribution for Femtocells and also the worse interference mitigation technique that implemented in our simulator have made the CSG less efficiency than OSG due the neighboring users can impact on the Femtocells in the case of CSG and cause interference. So, Figure 5.11 shows very high signal quality that obtained by OSG compared to the value of signal quality that achieved by CSG in Figure 5.12. We can notice from these Figures the interference value in the case of CSG is very high such as the SINR started almost from (-16.5dB up to +12.5dB) the values below zero means the received signal value less than interference and noise values. While the SINR value of OSG is started almost from (-2.5dB up to +40dB). As so clear from the values of SINR in the both access modes, where the OSG have enhanced the signal quality and it is less exposed to interference compared to CSG access mode.

5.3 The Second Part of Thesis

As we mentioned in the Section 4.2, where the Vienna system level simulator assists in evaluate the performance of the system, resource allocation and scheduling of the network. So, in the first part of this thesis, we have already investigated the performance of the system network by using Proportional Fair Sun scheduling scheme. Therefore, in this part of research we have compared the performance of network by using three well known scheduling such as Round Robin, Best CQI and Proportional Fair Sun. The comparison among of them by increasing the number of users with respect to average UE throughput, Fairness Index, and average cell throughput.

5.3.1 Performance Evaluation of Scheduling Schemes for Macrocells

In this Section, we compare and evaluate the performance network system by using different scheduling schemes. This study help us to realize how the resources have allocated to each user and the various factors that affect the scheduling. The role of the scheduling schemes is allocating the resource blocks to users depending on signal quality and channel conditions. We compare the three well known scheduling schemes are Round Robin, Best CQI and Proportional Fair Sun. We compared these scheduling schemes for their performance evaluation with increasing in number of users in the eNodeB such as 15, 30, 45, 60, 75 and 90 and in the case of only Macrocell deployment. The results obtained help us to decide the best scheduling scheme for a network to overcome network congestion also to demonstrate why we have used Proportional Fair Sun in the first part of this research.

Table 5. 18 Input Parameters of the Simulation

Power of eNodeB	49dBm
System Bandwidth	20MHz [100 Resource Blocks]
System Frequency	2.6 GHz
Number of Transmitter	4
Number of Receiver	2
Number of Users per eNodeB	15, 30, 45, 60, 75,90
Scheduling Algorithm	Round Robin, Best CQI, Proportional Fair
Channel Model	3GPP Typical Urban (TU)
Path loss Model	TS36942 – Urban
Transmission Time Interval (TTI)	10 msec

The network has configured according to parameters in the Table 5.18, and the simulation is running on the Vienna LTE simulator. The number of MUEs distributed randomly over Region of Interest (ROI) like in the real life, and the resulting of fairness, average user throughput and cell throughout have compared for each scheduling scheme starting from the Round Robin scheduling scheme. Figure 5.13, shows 15 randomly distributed users in the eNodeB by using Round Robin scheduling scheme this is as a sample to illustrate the distribution of users in the ROI.

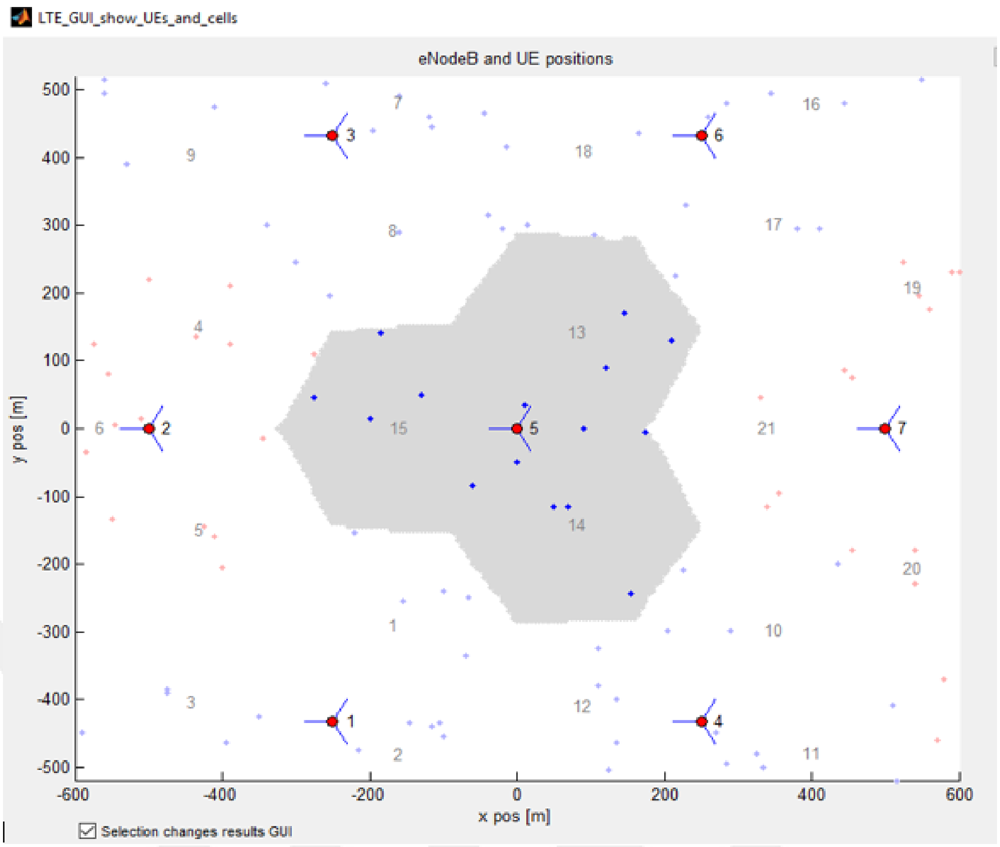

Figure 5. 13 Only Macrocells deployment scenario

For the network in Figure 5.13, simulation is running 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 shows the same. For simulation purposes, the traffic model assumed to be full buffer, meaning that all the users have a packet to send.

Table 5. 19 Fairness index of different scheduling schemes for only Macrocells deployment scenario

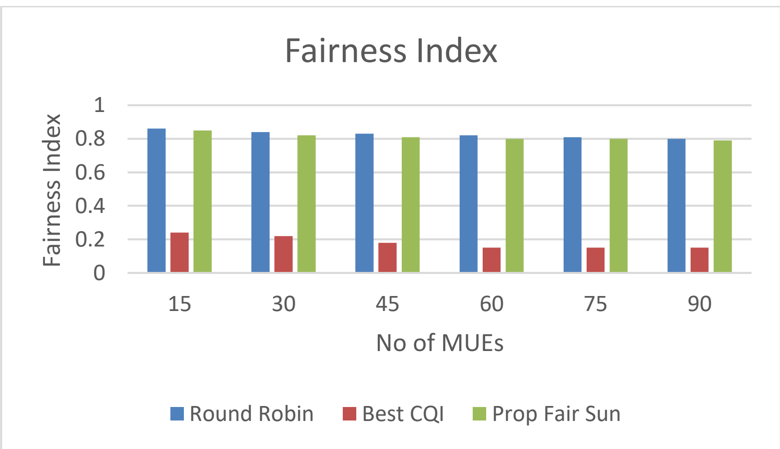

Table 5.19, shows the variation values of the fairness index for different MUEs in the case of using three scheduling schemes under study. The graph shows that the Round Robin scheduling scheme has the highest fairness index values compared to other two scheduling schemes. The fairness index is the measure of how each UE is serving in a network if they have requested for resource blocks. We also observe that fairness index changes in small fractions with increase in number of users. The Proportional Fair Sun scheduling scheme stands next to Round Robin in being fair to allocate the resources to the UEs. The Best CQI scheduling scheme has the less 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 data to send, but has not allocated resources if the channel conditions are bad. Table 5.20, shows the values of three scheduling schemes.

Table 5. 20 Results of fairness index for Round Robin, Best CQI, and Prop Fair Sun for only Macrocells deployment scenario

No of Users	Fairness index for Round Robin	Fairness index for Best CQI	Fairness index for Prop Fair Sun
15	0.86	0.24	0.85
30	0.84	0.22	0.82
45	0.83	0.18	0.81
60	0.82	0.15	0.8
75	0.81	0.15	0.8
90	0.8	0.15	0.79

Table 5. 21 Average UE Throughput by using different scheduling schemes for only Macrocells deployment scenario

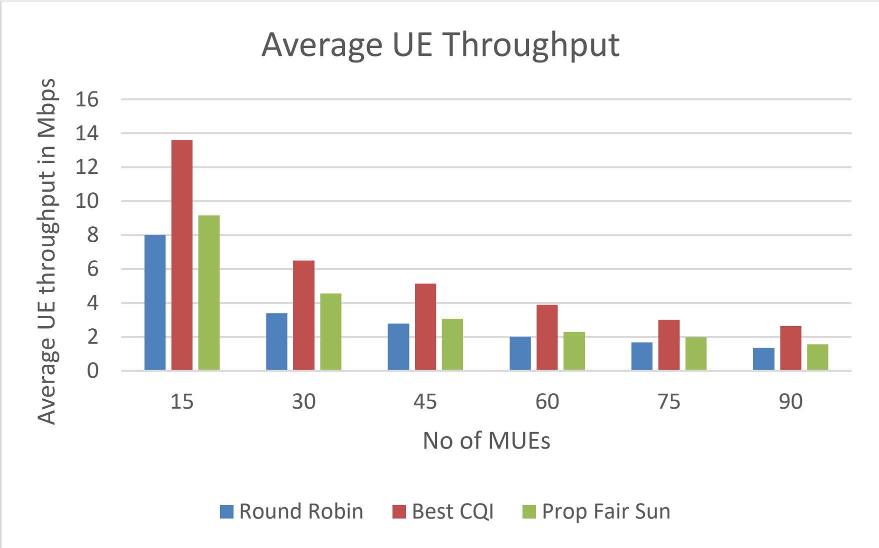

Table 5.21, shows the graph indicating variation of average user throughput with the increasing number of MUEs for different scheduling schemes. The graph indicates that Best CQI scheduling scheme has the ability to achieve the highest UE throughput in the network, as this scheduling scheme is a channel aware. Depending on the channel conditions, the resource blocks have allocated to the users. In this scheme if the cell edge users had data to send they have not given resources because they tend to possess bad channel due to their distance from eNodeB. The Proportional Fair Sun scheduling scheme stands next Best CQI in achieving best average UE throughput, as this scheme is a channel aware. But, due to its ability to be fair enough, the average UE throughput achieved here is less when compared to Best CQI. The Round Robin has the least average UE throughput, as this is a channel unaware and allocates the resource blocks to all users requesting service even if the UEs do not benefit from the service. Table 5.22, shows the values of average UE throughput for three scheduling schemes.

Table 5. 22 Results of Average UE throughput by Mbps, for Round Robin, Best CQI, and Prop Fair Sun For only Macrocells deployment scenario

No of users	Average UE throughput (Mbps) for Round Robin	Average UE throughput (Mbps) for Best CQI	Average UE throughput (Mbps) for Prop Fair Sun
15	8.01	13.6	9.16
30	3.39	6.5	4.55
45	2.78	5.15	3.07
60	2.02	3.9	2.3
75	1.68	3.02	1.97
90	1.36	2.63	1.56

Table 5. 23 Average Cell Throughput by using different scheduling schemes for only Macrocells deployment scenario

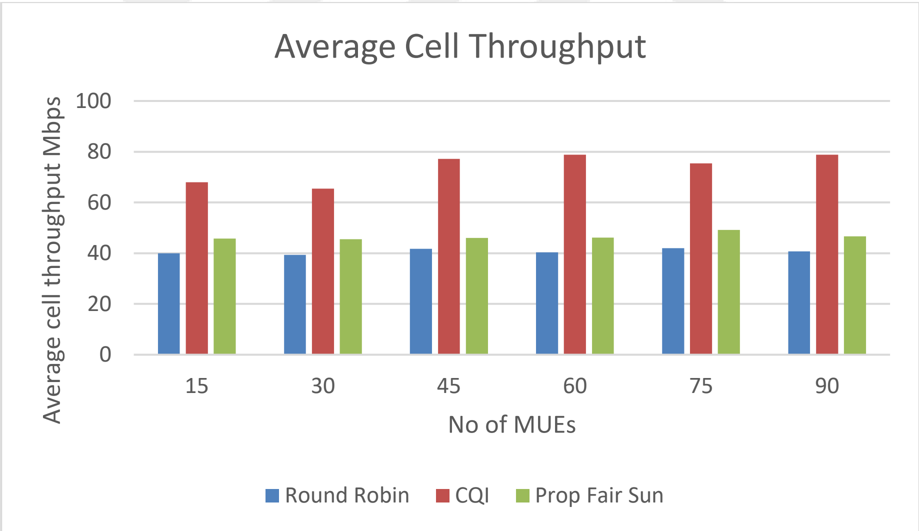

Table 5.23, shows the variation of the average cell throughput with the increasing number of MUEs in the network. For Round Robin, the total cell throughput almost remains same as the available resource blocks has equally divided between all the users. Also, Round Robin having less value of throughput in comparing with throughputs of other scheduling schemes. The cell throughput for Best CQI is the highest, but Proportional Fair Sun stand next to Best CQI and throughput most likely increase when the number of UEs get increasing.

With this analysis of fairness and average UE and cell throughput, among 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 network requirements were supposed to be achieving highest average user throughput over fairness, then Best CQI scheduling scheme is the best choice for the network. Finally, if the network requested to have optimal performance between fairness and throughput then the Proportional Fair Sun scheduling scheme has ability to ensure both better fairness and throughput in the network. So, we have proved the efficiency of Proportional Fair Sun that used in the first part of our thesis and we have proved why we have used it in our investigation. Table 5.24, shows the values of average cell throughput for three scheduling schemes

Table 5. 24 Results of Average cell throughput by Mbps, for Round Robin, Best CQI, and Prop Fair Sun For only Macrocells deployment scenario

No of users	Average cell throughput (Mbps) for Round Robin (Mbps)	Average cell throughput (Mbps) for Best CQI (Mbps)	Average cell throughput (Mbps) for Prop Fair Sun
15	40.02	67.96	45.82
30	39.3	65.45	45.49
45	41.75	77.22	46.02
60	40.4	78.85	46.2
75	42	75.46	49.16
90	40.7	78.86	46.7

5.3.2 Performance Evaluation of Scheduling Schemes for Femtocells

We proved in the Section 5.3.1, the Proportional Fair Sun, is the best one among the others scheduling schemes in the case of only Macrocells deployment. With increasing of Femtocells deployment in real life and there is arising need for an additional study, which proposes to see if Best CQI is better than Proportional Fair Sun with Femtocells deployment. So, the main motivation is that, the closer user to eNodeB or Femtocells have better channel conditions and can achieve higher throughput by using Best CQI than any other scheme. If the Femtocells have deployed, in these regions, then some edge MUE and all FUE have good channel conditions too, and can achieve higher throughput with certain degree of fairness. Is it efficient to use Best CQI with Femtocells or use Proportional Fair? This Section focuses on this idea. To evaluate this idea, we have designed the network as shown in the Figure 5.14. The network shows three Macrocells with (10) users per sector. Additionally, this cell includes the Femtocells placed randomly but almost placed at the edge of Macrocells, which enhances the channel conditions of the Macro-cell edge users. We have fixed number of femtocells at two Femto per Macro-cell but we have increased the number of FUE such as 2, 4, 6, 8, and 10. We have carried out the simulator based on Table 5.25 parameters.

Table 5. 25 Input Parameters of the simulation

Power of eNodeB	49dBm
System Bandwidth	20MHz [100 Resource Blocks]
System Frequency	2.6 GHz
Scheduling Algorithm	Best CQI and Proportional Fair
Transmission Time Interval (TTI)	10 msec
Number of MUEs per Macrocell	10 MUE
No of Femtocells	2
Transmit power	23dBm
No of UEs per Femtocell	2, 4, 6, 8,and 10
Access Mode	OSG

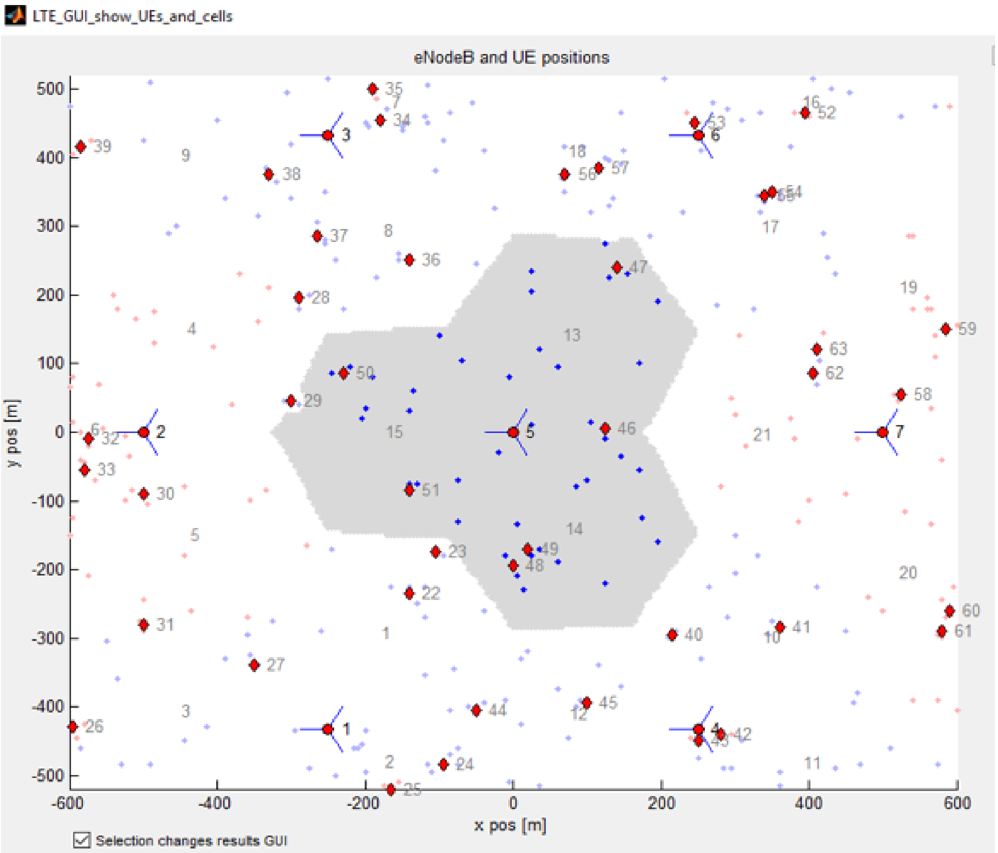

Figure 5. 14 Femtocells overlaid with Macrocells scenario

The simulation is running and set up the Femtocells to OSG mode. The values for the throughput and the fairness have recorded for two cases on this network. One uses the Proportional Fair and other Best CQI. Table 5.26 and Table 5.27, show the average user throughput, for proportional fair Sun and Best CQI respectively.

Table 5. 26 Average UE throughput of Femtocells overlaid with Macrocells deployment scenario by using Proportional Fair Sun

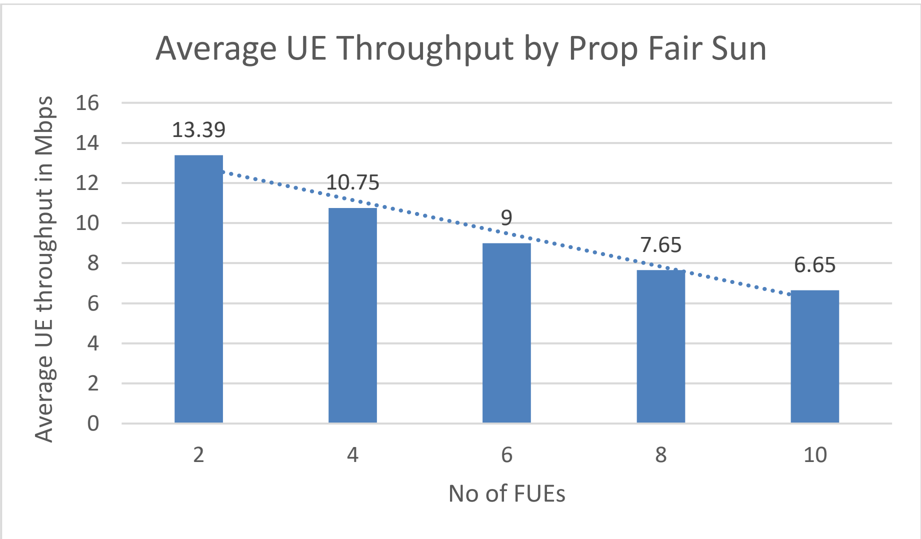

Table 5. 27 Average UE throughput of Femtocells overlaid with Macrocells deployment scenario by using Best CQI

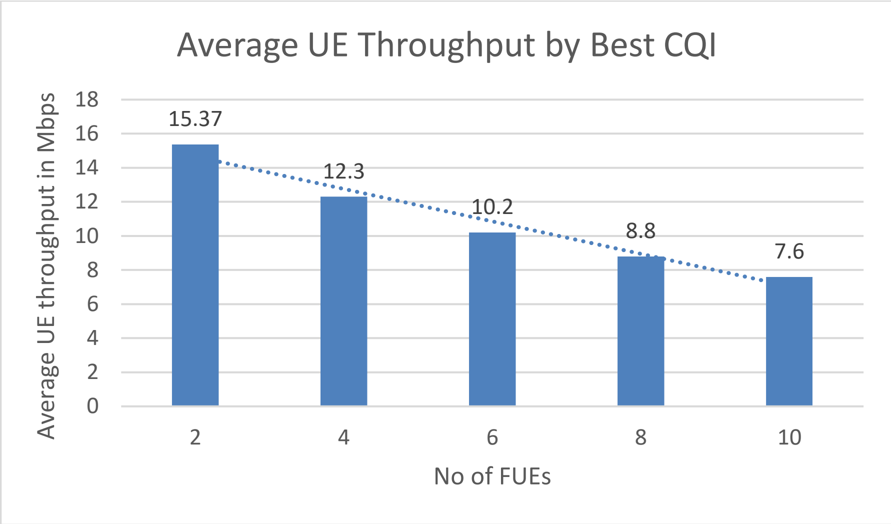

Table 5.26 and Table 5.27 show that, even though the Best CQI achieved higher average UE throughput, for certain users with addition of Femtocells, it is still having some certain users that were not served and hence having very low fairness. In contrast, even though the Proportional Fair Sun showed lower user throughput compared to Best CQI, but it had higher fairness. In addition, we note throughput that achieved by Best CQI decreased with increasing of FUE. Finally, Proportional Fair Sun also considered better than Best CQI. Table 5.30, shows the values of average UE throughput for Proportional fair Sun and Best CQI scheduling schemes.

Table 5. 28 Fairness Index of Femtocells overlaid with Macrocells deployment scenario by using Proportional Fair Sun

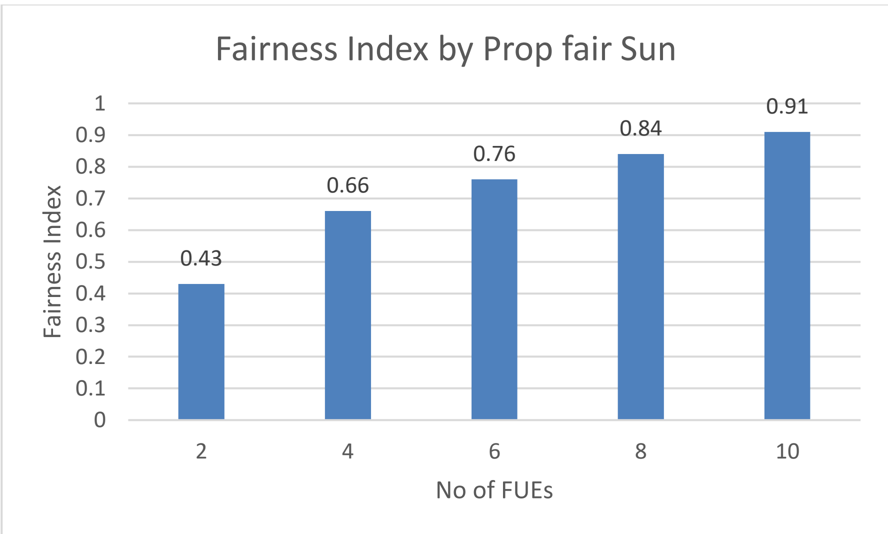

Table 5. 29 Fairness Index of Femtocells overlaid with Macrocells deployment scenario by using CQI

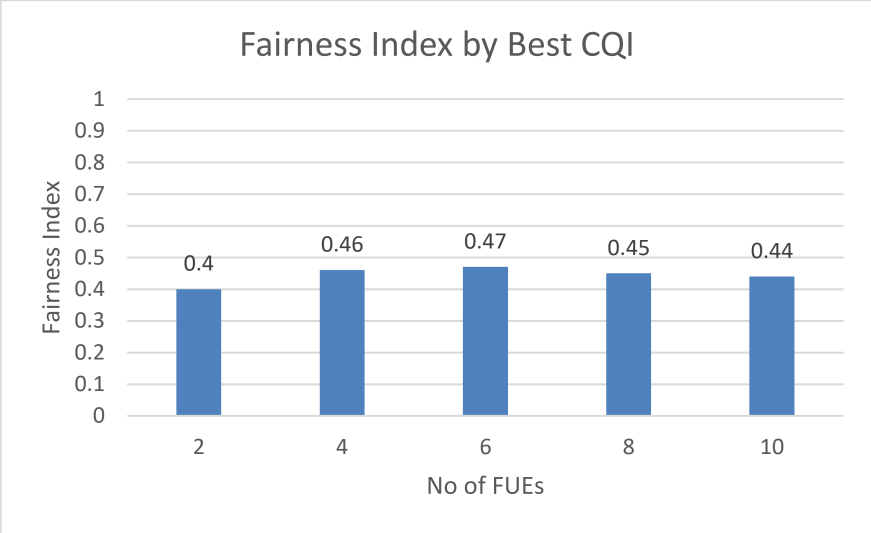

Table 5. 28 and Table 5. 29 show the fairness in the case of using Best CQI and Proportional Fair Sun respectively. As obvious, the Proportional Fair Sun achieved very high fairness for the users and the fairness have increased with increasing of number of FUEs. While Best CQI it is almost stay same value of fairness with increasing of FUEs and its produced very low fairness in comparing with proportional Fair Sun scheduling scheme. So, we can say the proportional Fair Sun scheduling scheme is the best one even in the case of deploying Femtocells. Table 5.31 shows the values of fairness index for Proportional fair Sun and Best CQI scheduling schemes.

Table 5. 30 Results of Average UE throughputs for Prop Fair Sun and Best CQI for Femtocells overlaid with Macrocells deployment scenario

No of UEs per Femtocell	Average UE throughput (Mbps) for Prop Fair Sun	Average UE throughput (Mbps) for Best CQI
2	13.39	15.37
4	10.75	12.3
6	9	10.2
8	7.65	8.8
10	6.65	7.6

Table 5. 31 Results of Fairness Index of Prop Fair Sun and Best CQI for Femtocells overlaid with Macrocells deployment scenario

No of UEs per Femtocell	Fairness index for Prop Fair Sun	Fairness index for Best CQI
2	0.43	0.4
4	0.66	0.46
6	0.76	0.47
8	0.84	0.45
10	0.91	0.44

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

Our thesis consists of two parts. In the first part, we have compared the performance of the network in the case of only Macrocells deployment and in the case of, using Femtocells overlaid with Macrocells deployment. In the this part, also we have compared the performance of the network system between two Femtocell access mode (OSG and CSG). So, we have proved the enhancements of Femtocells deployment on the network. Where the Femtocells addition have significantly increased the average UE throughput and cell throughput compared to only Macrocells deployment. Also, the Femtocells deployment have enhanced the edge UEs throughput and the signal quality. Finally, we conclude the Femtocells deployment have enhanced the coverage and capacity of the network. Also, we have compared the access modes of Femtocells and we have proved the OSG mode produce better average UE and cell throughput and also enhanced the edge user throughput and these edge throughputs increased ascendingly with increasing the users. OSG have improved the signal quality compared to CSG mode. The second part of our thesis is comparing three well known scheduling schemes Round Robin, Best CQI, and Proportional Fair Sun in the case of only Macrocells deployment and in the case of Femtocells overlaid with Macrocells deployment. So, we get the Proportional Fair Sun scheduling scheme is the best one in the both deployment due to this scheme have a very good throughput and fairness compared to the other schemes. The more important Proportional Fair Sun scheme ensure better fairness and throughput.

6.2 Future work

First of all, the same investigation can be can applied by using higher MIMO antenna system such as 8x4 and 8x8MIMO. Another suggestion can be done such as improve the implementing interference mitigation techniques and applied on this Vienna simulator. Also, studying the handover issues between neighboring Macrocells, between Macrocells and Femtocells and finally between neighboring Femtocells. Eventually Simulate the idea of new network that has many Femtocells within the Macrocells but the Femtocells are in idle/stand mode and are activated when the traffic increases over a previously determined threshold.

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APPENDIX-A

CALCULATION OF RESOURCE BLOCKS

Here, we will explain mathematically how resource blocks (RBs) can be calculated for Bandwidth (BW) of LTE-A as known (1.4, 3, 5, 10, 15, 20, 40, 60, 80, and 100MHz). So, we have calculated the number of RB for 20 MHz as a sample from the others bandwidths spectrum [1].

The known values:

BW = 20 MHz;
Subcarrier width = 15Khz;
Number of subcarriers in each Resource Block = 12.

Number of Resource block in each slot = BW / (subcarrier width * no of subcarriers in each RB) (A.1)

Substitute the known values in Equation A.1.

Number of RBs in each slot = 20 MHz / (15 KHz * 12) = 111.11

As, obvious the number of RBs, is not equal to (100 RB) per 20MHz, but we always approximated its value to 100RB, because of 10% of BW considered as guard band, which means, BW that should be taking into accounts, only 18 MHz, therefore we have approximated the RBs to 100.

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