FREQUENCY REUSE IN 3GPP-LTE DOWNLINK CELLUAR SYSTEM

By

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ABSTRACT

The purpose of the study was to implement a frequency reuse in 3GPP-LTE downlink cellular system which was to be used as the main measurement and as analysis tool for interference mitigation and to evaluate the performance for various conditions enabling the efficient deployment and optimization of femto cells on multi-tier networks. The Mat Lab Vienna LTE simulator was used to analyses the degrading impact of interference on channel capacity when Femto-cells are deployed over a Macro-cell network to buttress the need for interference mitigation techniques in modern wireless communication networks. It was seen that Femto-cells provide a better solution in terms of benefits experienced by both the CSPs and the subscribers such as ease of deployment and cost effectiveness. As a result of the Femto-cells operating on the same licensed band used by the Microcells, interference between the two tiers is inevitable if proper mitigation technique is not employed. The various categories of interference in multi-tier heterogeneous radio access networks are given with emphasis on Macro-cell overlaid with Femto-cells on indoor environment. To carry on the research, however there were various research and information gathering techniques such as desk research ,Mat Lab simulations and in addition the supervisors involvement in order to come up with the complete systems

DECLARATION

I, **Wisdom Chambwa** hereby declare that I am the sole author of this dissertation entitled "frequency reuse in 3GPP-LTE downlink cellular system". I authorize Midlands State University to this dissertation only for purposes of scholarly research.

Signature…………………………. Date ……………………………..

APPROVAL

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1 Supervisor………………………………… 2 Supervisor………………………………

Date……………………………………… Date………………………………………

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Firstly, I would like to thank the Almighty God so much for making this dissertation study a success. I express my profound gratitude and indebtedness to Dr A.Nechibvute and Mr F.Mazunga my supervisors for guiding me through this project and for their inspiring intellectual guidance, constructive criticism and valuable suggestions throughout the project.

My gratitude is extended to my friends like Denzel Samu, Arnold Chasara, Andrew Zibengwa, Shingai Simba and the rest of my classmates for making the degree program study a memorable one.

Finally, I would like to thank my family for love, motivation, moral and financial support which kept me in the race.

DEDICATION

To my mother Mrs. L.Pasipamire who motivates me and inspired me to write this and my Uncles Simbarashe ,Prosper and also my sister Sarudzai whole instilled me a fascination with computers. To my loving and supportive family, classmates and friends. Also to Mr & Mrs. Pasipamire moral support since the day I began this degree programme.

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List of Acronyms

3GPP	3rd Generation Partnership Project
ADC	Analog to Digital Converter
AMC	Adaptive Modulation and Coding
ASE	Area Spectral Efficiency
CA	Carrier Aggregation
CAPEX	Capital Expenditure
CCR	Cell Centre Region
CER	Cell Edge Region
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CRBM	Cognitive Resource Block Management
CSG	Closed Subscriber Group
CSI	Channel State Information
CSP	Communication Service Provider
DAS	Distributed Antenna System
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FFR	Fractional Frequency Reuse
FRF	Frequency Reuse Factor
HeNB	Home enhanced Node B
HUE	Home User Equipment
LTE-A	Long Term Evolution-Advanced
MAC	Media Access Control
MeNB	Macro enhanced Node B
MIMO	Multiple Input Multiple Output
MME	Mobile Management Entity
MUE	Macro User Equipment
OFDMA	Orthogonal Frequency Division Multiple Access
OSG	Open Subscriber Group
OSI	Open System Interconnection

OPEX	Operational Expenditure
PHY	Physical Layer
QoS	Quality of Service
RF	Radio Frequency
ROI	Region of Interest
SC-FDMA	Single Carrier-Frequency Division Multiple Access
SCTP	Stream Control Transport Protocol
S-GW	Serving Gateway
SON	Self Organizing Network
SINR	Signal to Interference plus Noise Ratio
TDMA	Time Division Multiple Access
TDD	Time Division Duplex
TTI	Transmission Time Interval
UE	User Equipment
UMTS	Universal Mobile Telecommunications System

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CHAPTER 1

INTRODUCTION

1.1 Motivation and Background

A communication gadgets calls for speedy, green and noiseless faultless connection being maintained all over cellular network systems. With the speedy boom of cellular customers, the demand of excellent faultless conversation machine is expanded on daily basis [1]. Clever antennas may be used establish a faster connection which can cover both huge cells and smaller cells. Servicing a totally huge wide variety of users with a limited bandwidth becomes a great extremely good venture [6]. Reusing frequencies in a vintage style isn't always the sufficient approach to provide quality of service these days. The mission of supplying great and excessive information prices to subscribers has raised eyebrows to the telecommunications network fields to be situation to steady but hastily sluggish development [10]. The increasing wide variety of subscribers and proliferation of gadgets consisting of smart telephones, tablets and laptops that continuously request massive bandwidth extensive offerings inclusive of on line gaming (OG), video on call for (VOD), and other online social networking sports, have kept on pressurising mobile conversation technology [11]. This has ensured their regular and gradual evolution in phrases of reliability to users and offering higher high-quality of provider (QoS) to subscribers. [1],[2].

Identical frequencies are reused time and again with the aid of massive number of users through the usage of the concept of frequency reuse and fractional frequency reuse, which reasons the sluggish increase of the opportunity of co-channel interferences in lots of areas of the network consequently poor quality of service [3]. For larger mobile the lower reuse thing or higher reuse element for smaller cellular have a high co-channel interference and complex hand-over. The bandwidth is restricted, the frequency allocation must be sensible. A wide range of reuse scheme is proposed in [7].

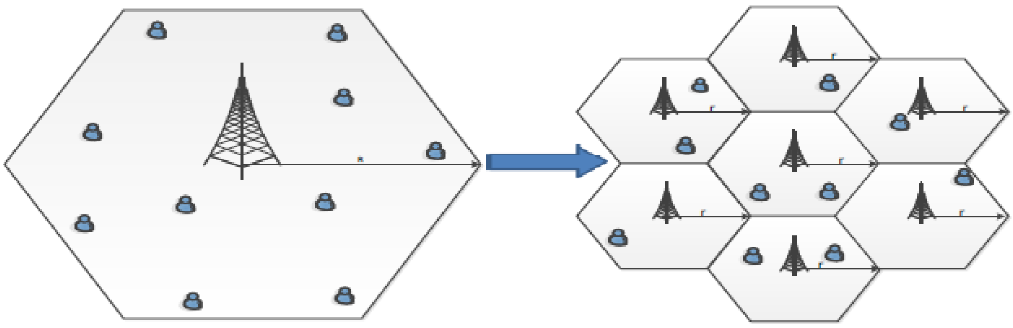

Figure 1.1: Cell shrinking mechanism [4].

This project studies will provide fractional frequency reuse in several approaches, such as the use of Dynamic Fractional Frequency Reuse factors (DFFR) or dynamic smart antennas, to offer forever improving and expanding Fractional Frequency Reuse (FFR) for Interference Mitigation 4G Wi-Fi Networks[9],[14].

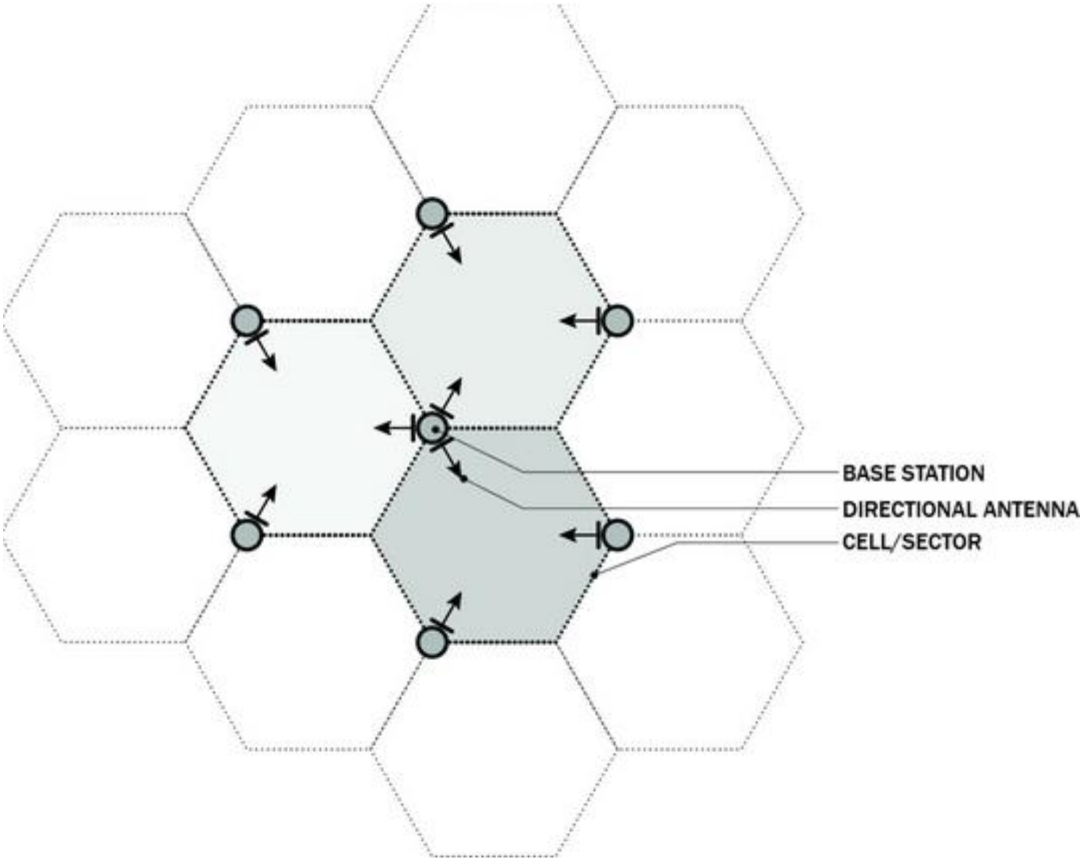

Figure 1.2 Heterogeneous cellular network systems [13]

Heterogeneous cellular community structures is along with carefully planned fraction frequency reuse (FFR) microcells and the random deployment of relays and femtocells.

Advanced interference mitigation method schemes are critical and its combination with other communique systems areas together with a couple of get entry to schemes modulation and coding has helped to growth the community performance in wireless community structures. The evident of theoretical attainable statistics fees of the generational evolution of the wireless communication technologies illustrated in figure 1.1 [3].

Table 1.1: Theoretical data-rates of mobile communication technology generations

Network Generation	**Approximate Date Rates**
First Generation	28-56Kbps
Second Generation	144Kbps
Third Generation	0.384-2Mbps
0.384-2Mbps	0.1-1Gbps

In first era generation (1G) frequency division a couple of get entry to (FDMA) became utilized by networks physical layer. FDMA it divides the whole frequency spectrum into quantity channels and makes use of the identical time interval. If all vital and right mitigation techniques are not carried out the consequent is adjacent channel interference. Consequently among consecutive channels guard bands are being included to save you the adjacent channel interference.

The advent of the protect bands on Wi-Fi networks even as adjacent channel interference is being effectively reduced has caused inefficient, spectral utilization in FDMA.

In 2nd generation era ('(2G) time department multiple get admission to (TDMA) become being used by systems wherein assets are allocated to users at specific time periods. The users can access the complete bandwidth most effective at extraordinary time periods, time element is being cut up into slots that can be without difficulty accessed by customers in a periodic' way. The frequency reuse strategies are getting used to mitigate interference control sports as to make sure the favoured signal content at the receiver.

In third technology generation (3G) networks code division more than one get admission to (CDMA) scheme become employed on the physical layer of the open device interconnection (OSI) version. The useful resource allocation isn't decided by using either time or frequency but pseudo codes or orthogonal codes which are getting used to spread the signal electricity over the whole frequency spectrum with a view to in cooperate more than one customers ,for this reason can be separated at the acquire quit. The 3G networks are not liable to interference because the gadget requires effective algorithms for energy manipulate there with the aid of preventing the customers from degrading the network channel conditions of every different and causing random discount in network capability.

Within the Fourth technology era (4G) networks orthogonal frequency division multiple get admission to (OFDMA) is being utilised at its physical layer. The slim band nature and multi-carrier of this 'network technique makes it possible for the implementation of many interference mitigation strategies with varying diploma of complexities' possible.

1.2 Heterogeneous and Multi-tier Networks

An average example of communique carrier issuer's (CSP) community that comprises of various cell conversation technology is defined diagrammatically in Fig. 1.2 [4]. Heterogeneous networks is an attractive way of enhancing the era mobile community potential. A Heterogeneous network generally it includes numerous 'radio access, architectures technologies, transmission answer with varying transmission energy [5], [8]

1.2.1 Heterogeneous and Multi-tier Networks

An average example of communique carrier issuer's (CSP) community that comprises of various cell conversation technology is defined diagrammatically in Fig. 1.2 [4]. Heterogeneous networks is an attractive way of enhancing the era mobile community potential. A Heterogeneous network generally it includes numerous 'radio access, architectures technologies, transmission answer with varying transmission energy [5], [8]

1.2.2 Compositional Structure of Heterogeneous Networks [4]

The Multi-tier Networks explained in Fig. 1.2 [4] can be valued as a subset of HetNet whereby for a single CSP, 'radio get entry to techniques varying in their transmission energy are deployed to provide insurance to subscribers with the intention to make certain that the pleasant of provider (QoS) necessities of the customers' packages are happy by the network'. they are deployed overlying every different in a geographical location and the concept of cellular shrinking explained earlier is exploited to improve wireless potential of the network[4], [6].

With 'Multi-tier networks, if all of the ranges are open, users can easily hook up with the tier that offers the quality signal to Interference plus Noise Ratio (SINR) and a maximised network performance can be experienced with the aid of the subscribers at' all instances.

1.2.3 The Indoor Coverage Challenge

With appreciate to distance sign attenuation, wall losses and multipath fading, radio waves used suffer big sign power degradation or amplitude as they propagate from the out of doors to the indoor surroundings, but the need for CSPs for provision 'excessive information charge verbal exchange in indoor areas cannot be overemphasized. From surveys, it has been verified that greater than 50% of voice calls and over 70% of statistics calls are being generated from indoor environments [7]. Again, the survey effects suggests that in Fig 1.five [8], offerings which can be especially utilized in indoor environment including online gaming, video streaming are on first rate upward push in terms of utilization and could retain and reach the climax for the next few years.

By using 2018, more than 79% of general global customer IP traffic can be video site visitors [8].A majority of these issues and factors whilst combined collectively they push for the provision nice indoor coverage a priority for community operators. moreover, the contemporary networking paradigm of net of things (IoT) and machine to Machine (M to M) communications, which will deliver a brilliant rapid upward thrust to packages to be able to lead heavy deployment in indoor environments inclusive of industrial applications (e.g. robotics manage in factories) 'and clever houses also are a few motives buttressing the frenzy for a better insurance in indoor' regions.

Femto-cells are small base stations with transmit power particularly low and small coverage radius, had been applied as a way to remedy the indoor insurance trouble in a cost-efficient manner. Femto-mobile networks implementation will face bottlenecks that present day requirements are but to address. By way of analysing the OSI protocol stack, critical overall performance problems are probable to conform at the delivery layer and physical. The physical layer demanding situations can even affect media get entry to control (MAC) layer and could contain issues regarding radio aid management and interference mitigation. For the shipping layer, troubles of problem to network fashion designer are site visitor's load balancing among the Macro-cellular and Femto-mobile ranges, mobility management, backhaul congestion management and optimization of control plane signalling. On this dissertation, the focal point could be at the interference mitigation on the bodily layer.

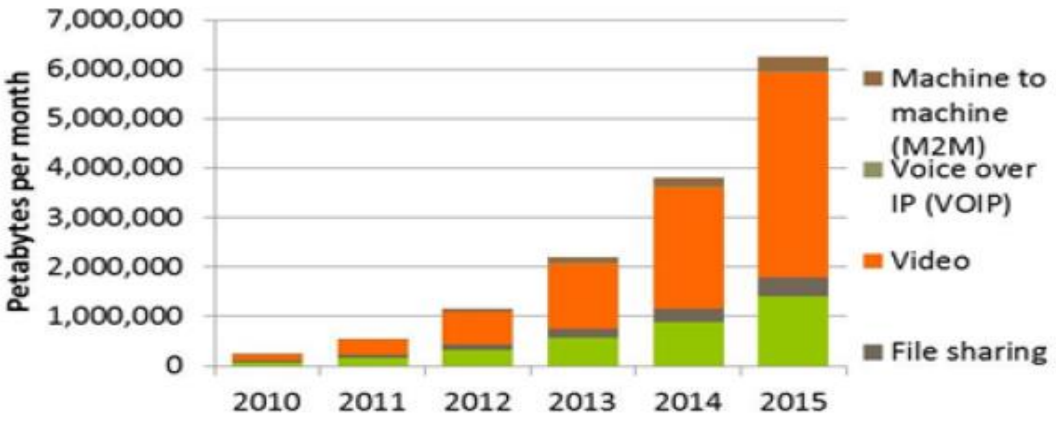

Figure 1.3: Global mobile traffic forecast (Cisco VNI) [8]

1.2.4 Interference Mitigation with Spectrum Reuse

When more 'Wi-Fi conversation times are initiated in a multi-tier network at the equal channel, interference occurs and it adversely influences the general network performance even main to total outage at the goal receiver if the total interfering sign energy supersedes that of the desired

Signal. A good way to solve the interference hassle, partitioned (constant) reuse and shared reuse had been taken into consideration for a multi-tier community which includes Macro-cells and Femtocells [6], [9], [10]. The partitioned reuse mode divides the spectrum into two separate portions, which might be then used by each network tier. Adopting partitioned reuse guarantees that interference among degrees 'of the community is extensively decreased. The demerit of this technique is that underutilization of the spectra assets in either tier' of the community can occur.

The 'second technique shares the frequency useful resource among the two ranges of the community i.e. full inter-tier frequency reuse. This presents higher ability however also increases the publicity of network nodes to inter-tier interference.

Since the Femto-cells have a good constraint on the to be had transmit electricity and they get right of entry to the spectrum using similar technique of underlay spectrum get right of entry to of the cognitive radio paradigm, they go through extra from tremendous interference contributed via' the Macro-cellular tier[11]

With the PHY layer technology of OFDMA for 4G networks, legacy interference mitigation techniques can in addition be optimised to offer higher interference mitigation schemes which might be very green and effects to lesser discount in trunking capacity according to cell. That is due to the fact Orthogonal Frequency division multiple get admission to' (OFDMA), via using narrowband subcarriers, provides a greater granular approach of allocating radio assets to customers within the community in both time and frequency [11], [13].

The mobile verbal exchange networks era put in force the idea of frequency reuse and fractional frequency reuse to growth the overall network overall performance capability. The strength this is radiated by electromagnetic indicators tend to minimize as the space of coverage increases [11].

For this reason, the equal frequency channels are being reused at geographical separated locations to keep away from both interference and attenuation. The 'disadvantage of frequency reuse is the loss in trunking or eight channel capability that a unmarried cell can provide to customers in its insurance place and frequently instances, exchange off needs to be made among the trunking capability that is preferred in step with cellular and the extent of interference publicity that network designers need for customers to' be uncovered. Fractional frequency reuse 'builds at the traditional frequency reuse schemes and it strives to improve the spectrum to be had consistent with cellular at the same time as preserving the interference ranges at bearable minimum. N.Saquib *et al*. in [12] and Lee et al. in [13] adopted FFR to multi-tier networks containing Macro-cells and Femto-cells. Their analyses showed the effectiveness of the adoption of FFR schemes to mitigate interference. FFR calls for minimum facts change between the levels that constitute the network making it flawlessly appropriate for Femto-cells as a way to be unable to percentage complicated circuitry due to its decreased price.

FFR is likewise suitable for interference mitigation on both uplink and downlink. The present FFR designs didn't provide a suitable mechanism to cater for consumer system connected to Femto-cells on the boundary area between the CCR and the CER and this turned into honestly talked about through the authors of [12]. Its miles consequently paramount to search for ways of mitigating this cross-boundary interference and create a greater optimized FFR scheme for multi-tier networks

2.2.6 OFDMA – Orthogonal Frequency Division Multiplexing Access

There are several and distinct get admission to technologies in Wi-Fi communique networks

Which might be being used for transmission and reception of information. because of an boom in need for green utilisation of bandwidth there exists a critical want for deciding on an remaining means of multiplexing approach which could resolve many demanding situations and nonetheless gain maximum efficiency. In long term Evolution (LTE), that is completed with the aid of Orthogonal Frequency division multiple get right of entry to (OFDMA), 'which enables the eNodeB to talk with numerous person gadget's on the equal time which results in benefit of minimum inter-symbol interference and fading as well as expanded spectral performance.

In LTE, downlink transmission uses the OFDMA method while uplink makes use of the SC-FDMA (unmarried carrier - Frequency division a couple of get admission to). The discern 1.6 suggests' concept of OFDMA in LTE

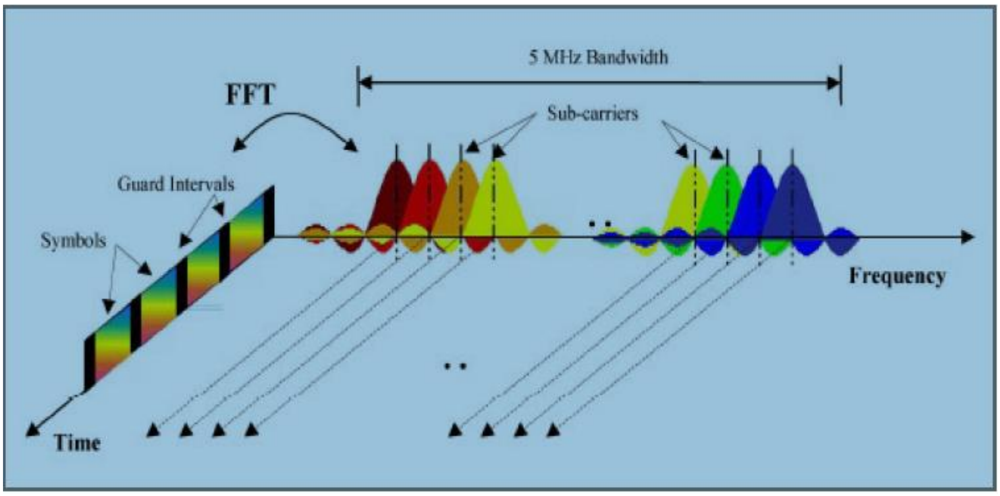

Figure 1.4: Orthogonal Frequency Division Multiplexing Access [4]

1.3 Research Aims

1) What stage of Time difference of Arrival (TDOA) positioning method in conjunction Positioning Reference sign (PRS) to calculate the location of a user system (UE) within a community of eNodeB the use of the LTE system simulator on mat lab command window?
2) To be able to deploy both the macro cell and femto cells on the LTE downlink cellular system.
3) Multiplied cellular-part bit-rate, for uniformity of service safety, reduced value per bit, implying improved spectral efficiency, and Simplified network structure, reduced delays, in phrases of each connection establishment & transmission latency and accelerated person information prices.
4) What degree of improvement can be achieved in phrases of in step with person ability and throughput if a buffer zone is incorporated into the present FFR scheme at the boundary place among the pre-existing mobile center and cell aspect vicinity?

5) To demodulate and decode a live eNodeB signal. Earlier than the consumer gadget (UE) can talk with the community it ought to carry out mobile search and choice techniques and acquire preliminary machine information.

1.3.1 Scope

This studies task entails demonstration of a powerful of frequency reuse on 4G long term Evolution (LTE) network technology on mat lab with Vienna simulator in order to examine numerous features of LTE in terms of performance of network providing a framework and answers to the troubles of community densification, efficient deployment and community congestion. This research involves the use of Mat lab Simulation, developed through the Institute of Math works and the Vienna simulator evolved by means of the Vienna institute of technology of Austria. MATLAB is an open source primarily based simulator. With the fast growth inside the variety of users in very geographical cells and geometrical increase in the use of excessive bandwidth killer packages, load and site visitors on the community has extended network congestion and densification. So as to conquer community congestion, a green aid allocation scheme is important.

On this assignment we examine and investigate results of different scheduling schemes and interference mitigation strategies at the wireless community. Network densification is any other trouble making customers revel in low signal high-quality in big buildings like department shops or massive businesses; we demonstrate how a lot of these customers may be served in reliable and green way with the aid of putting femtocells in densely populated or susceptible insurance areas of macro cells. Femtocells no longer only increase throughput but also enables in growing capability as well as insurance of the machine. The usage of this evaluation, we estimate growth of the network and analyse performance hence with the help of mat lab simulator. This facilitates the carrier carriers store revenue and ensure dependable communications to person

1.4 Organization of the Dissertation

This phase gives a quick creation to the following chapters that are on this dissertation.

Chapter Two - literature overview: in this bankruptcy the theoretical aspects to do with the studies are provided. An evaluation of literature is also provided with important consciousness on frequency re-use generation used for interference mitigation on in door environments.

Chapter Three - research strategies and techniques: the steps taken to complete this research are supplied on this chapter. More concentration is on the mat lab code layout, and to run the simulations

Chapter Four - outcomes and evaluation: The outcomes acquired from various checks on the mat lab are supplied in this section. The results presented on this chapter are analysed and findings are noted and the demanding situations come upon are discussed and solutions given.

Chapter Five - end: that is the last chapter of the dissertation and focuses on the research objectives, areas of similarly have a look at, boundaries, drawbacks and recommendations.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

With the growing technology, the world has witnessed tremendous evolution in every aspect of wireless technology for fitness to the way we communicate. Communication being an important aspect has seen evolution that revolutionized the world [1]. The Telecommunication networks evolution can be categorized into generations. The first generation (1G) networks supported analogy voice communications [3], [12].

The second generation (2G) had a major transformation of digitizing signal. It also increased efficiency and for the first time data services were introduced. 2.5G (GPRS) and 2.75G (EDGE) being the evolution of 2G provided increased speeds and for the first time had packet switched domain implemented in addition to circuit switched domain.

The next evolution was 3G (WCDMA), which has data rates of 200 kbps and led to assortment of "mobile broadband" experience. Many new features like video streaming, conferencing etc. were put forth [3], [12].

The most talked evolution of telecommunications is the fourth generation (4G) which revolutionized the industry by utilizing various features like high speed and efficiency. Currently it provides access to a wide range of applications such as IP Telephony, mobile web access, high definition video streaming, real time and interactive gaming and much more [8].Recently, Long Term Evolution technology is extensively deployed by all carriers and it can offer as much as 100 Mbps data rate satisfying requirement of major applications effectively. Even though LTE is able to mitigate most of the issues of existing networks there exists a constant demand for higher performance technology due to increasing high bandwidth applications and densification. In the next section we understand the major features and architecture of LTE [14], [23].

2.2 long term evolution

LTE is not unusual name given to conventional of subsequent era evolution of WCDMA. It evolved from earlier 3GPP system known as universal mobile Telecommunication system

(UMTS). This new era is an all IP based community which offers IP primarily based cell middle called the advanced Packet core (EPC). The important desires of LTE are growth peak records costs, provide low latency in RAN (Radio access community), and improve RAN bandwidth and spectral performance. The architecture of LTE consists of a new base station called the eNodeB and a single core referred to as the evolved Packet middle that gives get entry to each IP based totally voice and information offerings [6], [24].

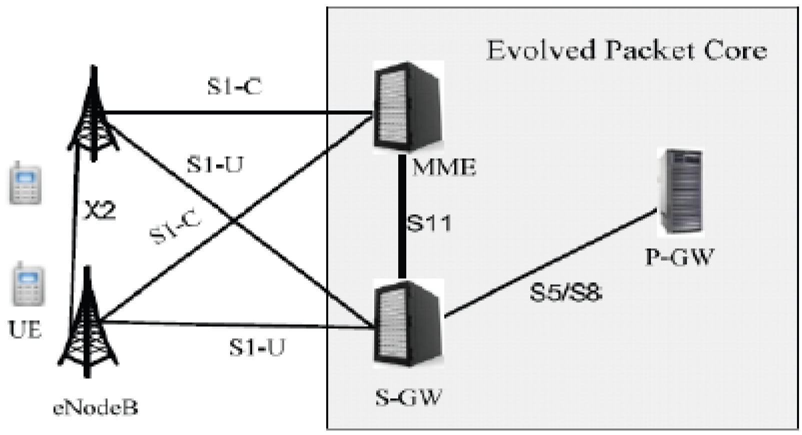

Figure 2.1: LTE Architecture [6]

The LTE structure consists of two key components specifically the eNodeB and the EPC. The eNodeB sends and receives information from consumer gadget (UE). The primary functions of eNodeB include mobile resource management with QOS consciousness, MME selection, routing the user information toward S-GW and help in intra LTE and inter LTE handover [5].

Every eNodeB in a geographical place are interconnected via an interface called X2 interface, which facilitates in handovers or mobile reselection tactics hence retaining UE in attached kingdom. The next key component is the EPC (evolved Packet middle), which includes all types of visitors. The EPC consists of Mobility control Entity (MME) - that is particularly associated with authentication and gateway choice, intra and inter LTE/RAT mobility, bearer management and integrity safety.

Serving Gateway (S-GW) - assists in packet routing and forwarding and intra LTE mobility anchor. Packet facts community Gateway (P-GW) - allocates the IP address to UE, it acts as a lawful intercept for policy enforcement and also assists in packet routing and forwarding. Coverage Charging and Rule feature (PCRF) - manages the QOS in connection by means of implementing diverse rules and also continues track of offerings accessed by using u.s.to resource in charging/accounting [4].

Lastly, domestic Subscriber system (HSS) - is the database that stores vital records of UEs. It assists in user identity and registration management. Each of those additives communicate thru particular interface and protocols. The eNodeB and the EPC are related to each different via the S1 interface. Having understood LTE structure, the subsequent component to be concept of is how the mobile communicates the usage of those additives. The solution is through a radio bearer that's a logical channel this is hooked up between UE and the eNodeB [6], [11]. It is also in fee of coping with QOS provision on the E-UTRAN interface.

LTE is designed to guide extensive variety of bendy bandwidth starting from 1.4 MHz to twenty MHz and radio get right of entry to approach is chosen to be exceptional relying at the route of records/name. Downlink transmission uses the OFDMA (Orthogonal Frequency division multiple get entry to) technique whereas uplink makes use of the SC-FDMA (single service - Frequency department multiple access) [22].

2.3 Multiple Access Method in LTE

OFDM is a multicarrier transport technology for high data rate communication system. The main concept in OFDM is spreading high speed data over the low rate carriers. These low rate carriers are called sub-carriers. Sub-carriers are generated using IFFT (Inverse Fast Fourier Transform) digital signal processing.

IFFT is an efficient scheme for generating orthogonal subcarriers. These orthogonal subcarriers are mutually orthogonal in frequency domain which avoids the inter-symbol interference (ISI) as shown in figure 2.2 below. Each sub-carrier has a bandwidth less than channel coherence bandwidth which is why these subcarriers experience flat fading. Firstly, Bit stream from the encoder are modulated using QPSK or QAM-16 or QAM-64 into symbols. These symbols are then fed to serial to parallel converter. The parallel data symbols from serial to parallel converter are then spread over N IFFT orthogonal subcarriers. The meaning of orthogonal subcarrier is that there is no interference between the subcarriers.

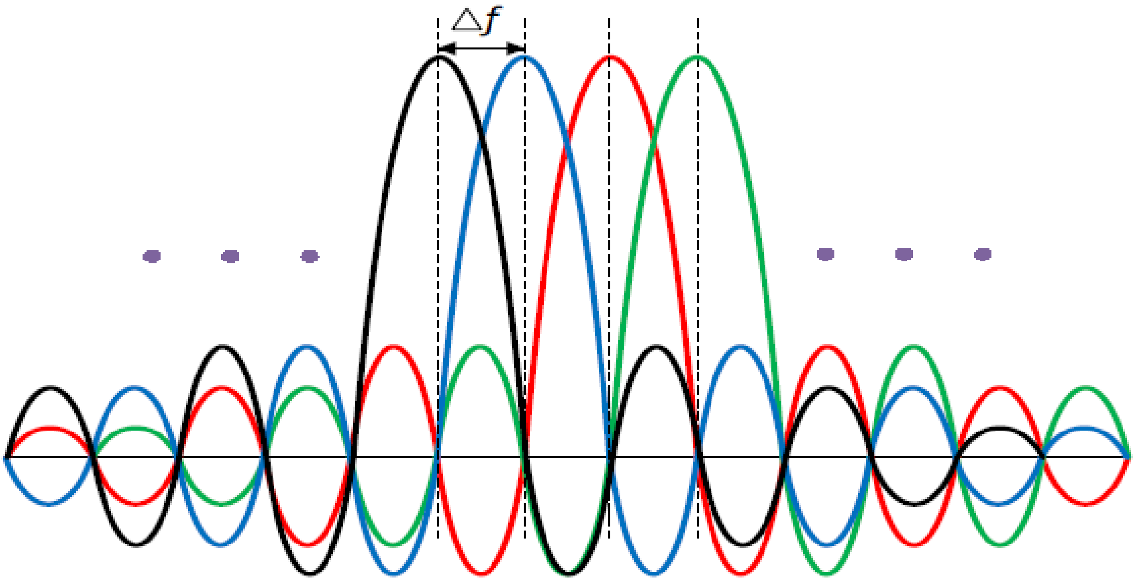

Figure 2.2: OFDM Orthogonal Sub-carriers [33]

Again the outputs from the IFFT which are modulated subcarriers are converted back to the serial form with the help of Parallel to serial converter. This again passed through the digital to analogy converter before transmitting to the air as shown in figure 2.3. In the receiver the reverse operation is done to the OFDM symbol to retrieve the data stream.

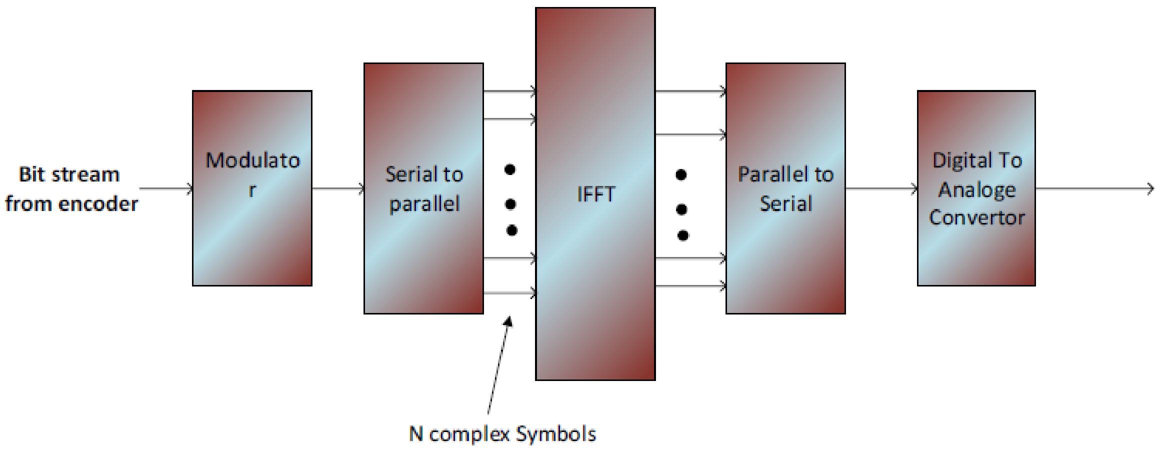

Figure 2.3: Simple OFDM System [33

2.4 Resource Allocation

With the knowledge of radio access spectrum used by LTE in downlink and uplink, the idea behind resource allocation is that whenever a user requests service, based on various network parameters like channel quality, RSRP (Reference Signal Received Power) and priority, resources are allocated to that particular user. Each system has different performance requirements and depending on this the resource allocation decisions are made. Few metrics that can be thought of are: Quality of Service requirement, size of the buffer, channel quality as reported by the user. If the per RB metric for a particular user is higher than any others requesting the service then that user enjoys the benefit of being allocated [23].

In order to understand resource allocation, it is very essential to understand how the available bandwidth is split into resource blocks. One of the important feature of LTE is that it can operate over wide range of flexible bandwidth ranging from 1.4MHz to 20MHz. In LTE, chosen bandwidth is divided into number of frames with each radio frame 10ms wide [8], [41].

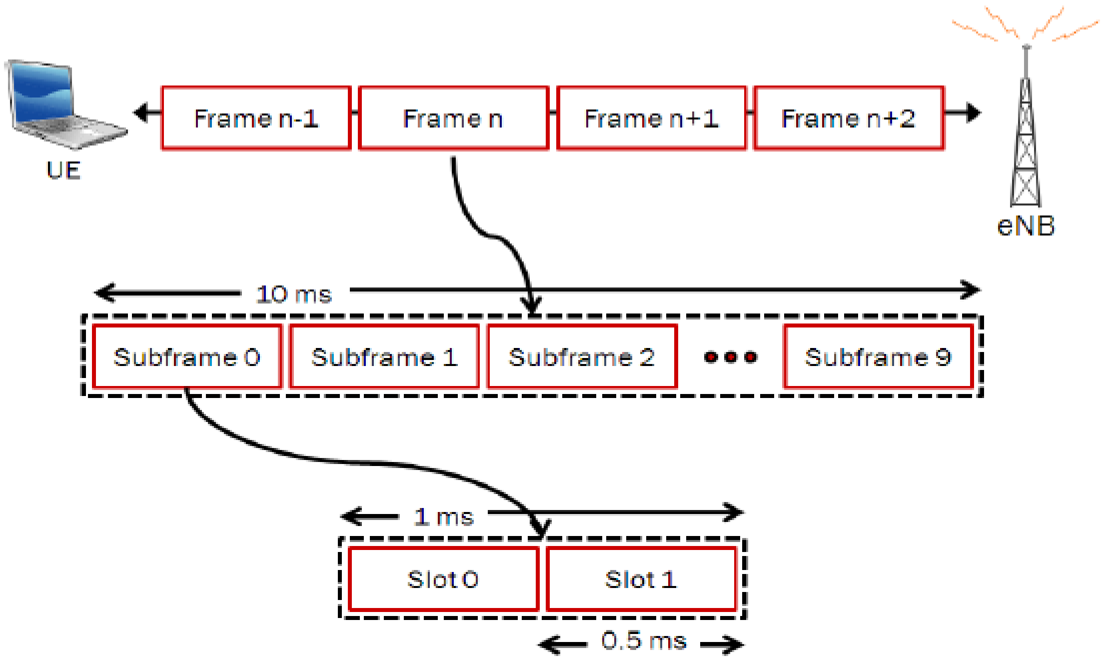

Figure 2.4: LTE Frame Structure [8]

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

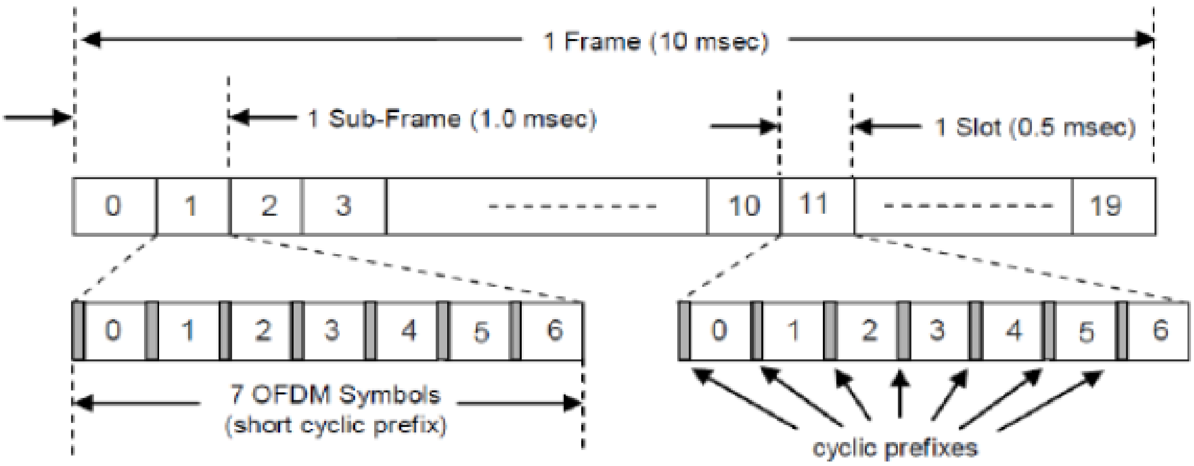

Figure 2.5: LTE sub frame [9]

The figure 2.6 shows a sub frame of 10ms wide. Further each sub frame is composed of two slots of 0.5ms wide. Each slot consists of 6 or 7 OFDM symbols depending on the type of cyclic prefix [Normal cyclic prefix – 7 OFDM Symbols, Extended cyclic prefix – 6 OFDM Symbols].

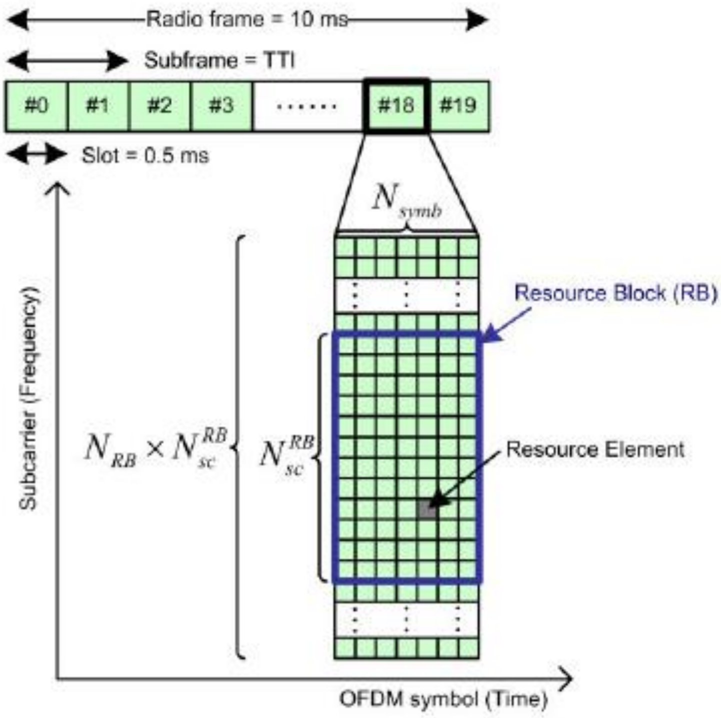

Figure 2.6: Resource Block [10]

2.5 Improving Indoor Communication

With the shortcomings of the regular Macro-cells to serve subscribers in indoor surroundings correctly becoming evident, CSPs decided to put in force solutions that can efficiently address this hassle and provide high great coverage to subscribers in indoor environments. The proposed solutions can be broadly labelled into outdoor approach and Indoor technique. Those are discussed in the succeeding sections [22].

2.6 Outdoor Approach

This technique seeks to improve indoor sign satisfactory with the aid of increasing the nice of the out of doors signals in an effort to lessen the attenuation suffered by means of electromagnetic waves as they move over from the outdoor to the indoor environment. Greater Macro-cells or outside micro-cells might be deployed in a given geographical area to boom the signal strength consistent with distance. The demerit of this technique is that, it is not very green and it is also luxurious as a whole lot of capital expenditure is incurred within the method of growing the Macro base-station density in a given vicinity [18], [27].

2.7 Indoor Approach

The want to optimize radio coverage without delay in indoor environment led to the development of the following systems for the improvement of indoor radio propagation.

2.7.1 Indoor Repeaters

These devices increase the insurance location of a mobile. They're useful in areas which might be carefully populated with limited network coverage. They also can be used to decorate the capacity of a community at mobile edges by means of improving the SINR. Those attributes make them suitable for utilization in indoor surroundings for overall performance improvement of current Macro-cells [14]. They choose up the outside signal that has been attenuated by the walls of the constructing, expand it and then retransmit the sign in the indoor vicinity. There are normally two types of relays, they are; lively and passive. Energetic relays are more advanced and that they carry out the interpreting, mistakes correction and reshaping of the attenuated acquired signal before re-transmission even as Passive relays on the other hand, simply pick out up the attenuated sign, amplify it and retransmit without performing any sign processing on the sign. Lively repeaters are generally greater luxurious whilst as compared with passive repeaters.

2.7.2 Distributed Antenna System (DAS)

The idea of a DAS was first proposed in the 1980s [14] and it entails locating antennas at different floors of a building to provide homogeneous coverage. Instead of a single antenna radiating at a very high power, Saleh et al in [15] proposed that multiple smaller antennas, each radiating at lower power levels can be used to cover the same area. In order to adequately improve network efficiency, the overlap between the coverage areas of each antenna must be reduced and the coverage areas of the antennas should fit the shape of the building as much as possible. Fig. 2.1 gives a visual illustration of the concept of DAS.

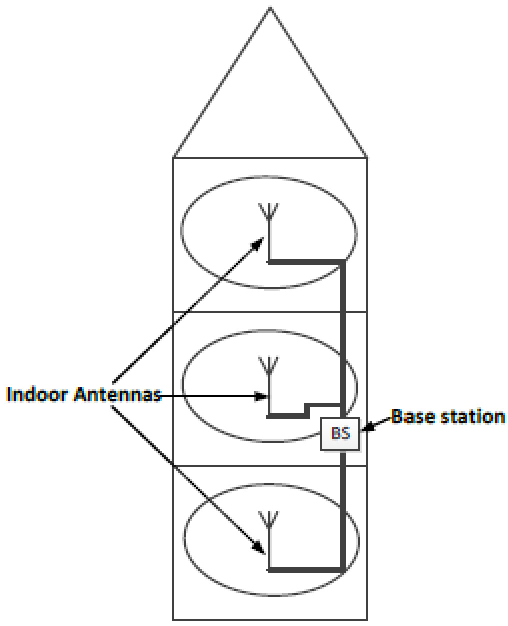

Figure2.7: Distributed Antenna System (DAS) [14].

2.7.3 Small Base-stations

These are the alternatives to the previously discussed techniques to improve indoor radio coverage. Instead of seeking the means to indirectly improve the indoor signal quality by first improving the radio coverage of the outdoor environment or extending the coverage of outdoor base stations into the interior of buildings with the use of DAS or Radiating cables, a much more interesting approach is to deploy small base stations directly inside the buildings. Two different types of Indoor base stations are in existence and they are discussed in the sub section below.

2.7.4 Pico-cells

These base stations could be deployed at outdoor locations such as street corners. They generally have transmission power ranging from hundreds of milliwatts to a few watts. They can provide a radius of coverage that is above one hundred metres. The reduction in coverage region that they provide when compared with Macro-cells and micro-cells allows for the provision of more capacity and higher data-rate to end users connected to them. Pico-cells are not a hundred per cent self-configurable; hence, the network operator is still responsible for deploying and maintaining them. The above demerit led to the introduction of the other type of small indoor base station called Femto-cells.

2.7.5 Femto-Cells

As the need to increase their presence in terms of the provisioning of quality signal coverage and high data rates in indoor environments becomes more important [7], CSPs decided to look for a lasting solution to this problem in a very cost-effective manner. This led to the development of Femto-cells. Currently, the smallest base station in existence, Femto-cells or Femto Access Points (FAPs) are described in [14] as "cellular network access points that connect standard mobile devices to a mobile operator's network using residential DSL, cable broadband connections, optical fibres or wireless last-mile technologies".

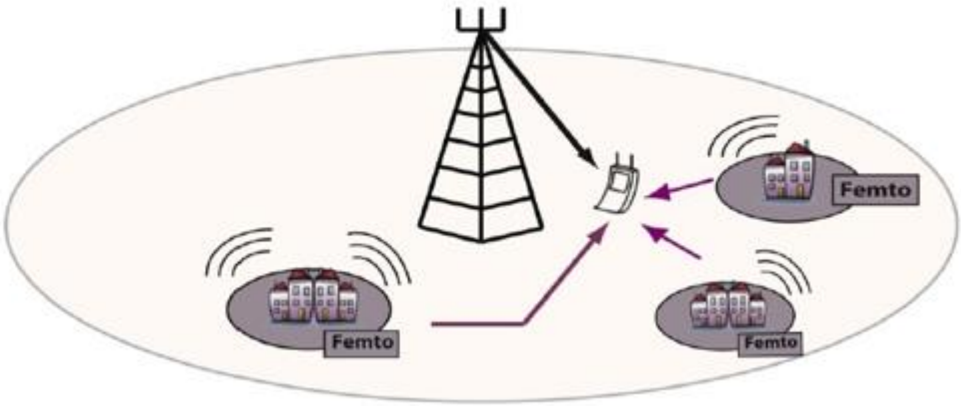

Figure2.8: Macro Network with Femto cells [11]

Figure 2.9: Practical Femto base station [44]

These are completely user deployable as they are a hundred per cent auto-configurable. In addition, the end users are solely responsible for the Capital expenditure (CAPEX) and Operational expenditure (OPEX) costs incurred for the installation and continuous maintenance of the FAP. This makes Femto-cells more cost-effective to CSPs when compared with Pico-cells that have to be deployed and maintained by a CSP.

2.7.6 Macro-Cells

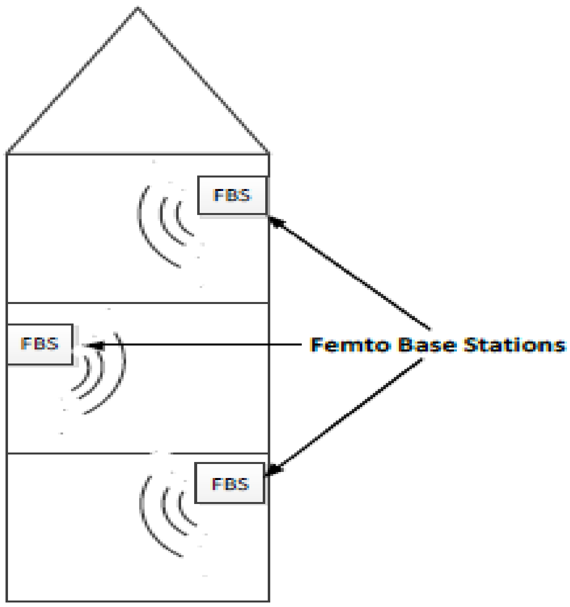

Figure2.10: Femto Base Stations [22]

If the same amount of bandwidth resource is made available to a big cell and a small cell (using the cell radius as the parameter to differentiate the sizes), more users are likely to be in the coverage area of the big cell while less number of users will be in the coverage area of the small cell. Therefore, if a round robin scheduler is considered, less frequency resource allocation will be available to each of the users attached to the big cell while the smaller cell users get more frequency resource allocated to them. Hence, the small cell users enjoy increased data rate and overall service QoS. Femto-cells make the realisation of the latter scenario possible thereby making its deployment of much interest to CSPs.

Table 2.1: Power and Average Comparison of Base Station Types

Macro	>km	20W-160W
Micro	250-1km	2W-20W
Pico	100-300m	250mW-2W
Femto	10-50m	10mW-200mW

2.8 Self-Configuration

Due to the plug and play nature of Femto-cells and the fact that they are user commissioned, it is very important that once switched on, the Femto-cells are able to communicate and integrate into the existing network. The Femto-cells set up their software and other parameters such as neighbours list, handover configuration, and pilot power and attached subscribers. All these must be done with minimal interruption to existing base stations.

Femtocells that are already switched on can also run their self-configuration phase algorithms if new base-stations or features are detected in the network [17].

2.9 Self-Optimization

Network measurements are carried out periodically by each Femto-cell and are processed. Femto-cells use these measurements to modify their algorithms and adjust parameters that are variable to suit changing conditions of their environment. Examples of metrics that can be optimized are the outage probability, channel capacity and the level of interference mitigation that can be provided [37], [41].

2.10 Self-Healing

This involves capabilities built into Femto-cells to enable them recover from situations of coverage loss, loss of connectivity to the core network and capacity failure. These could be due to radio board failure, channel processing implementation error, misconfiguration, power outage and back-haul connectivity failure [18]. Outage detection is a self-healing function that determines cells that are in outage conditions. After a downed Femto-cell has been correctly detected, the outage compensation procedure is initiated to reduce the effect of coverage loss and throughput reduction. Compensation procedure encompasses modification of parameters such as transmission power and channels allocated to nearby Femto-cells. Self-healing activities are aimed at reducing the impact of outages on the subscribers through rapid tuning of parameters of Macro and Femto base stations present in the network [21].

2.11 Femto-cells Operating Modes

Femto-cells will operate in the open subscribers group (OSG) access mode or the close subscribers group (CSG) access mode. With the OSG access mode, any user that belongs to the network is allowed to connect to a Femto-cell if they receive an SINR from the Femto-cell that is higher than that from the Macro-cell to which they were initially attached.

For the CSG access mode, only users belonging to a subscribers' list are allowed to be attached to a Femto-cell. CSG is the common mode of deployment since Femto-cells are user-deployed. OSG mode is useful when Femto-cells are deployed by a CSP itself for coverage in areas such as airports, stadia or street corners where Pico-cells can also be used.

CSG mode of deployment contributes more interference because User Equipment (UE) that is far away from their attached Macro-cells radiate at higher power levels, but if connected to a nearby Femto-cell, the power needed is reduced. A unit of Macro User Equipment (MUE) radiating at an increased power level causes severe interference to nearby Femto-cell base stations if they share the same set of resource blocks. The type of access mode proposed to mitigate this challenge is the Hybrid access mode.

The Hybrid access mode is similar to the CSG with the difference that some UE not belonging to the subscribers' list of a particular Femto-cell can still connect to it. They are given some level of service but they will not be able to get any preferential treatment and will be charged higher for any service they use as compared to UE belonging to the subscribers list.

This type of deployment is more likely to be found in relatively large office buildings and it is important for subscribers to know the different charging policies that apply [19]. The CSG access mode was assumed in the investigation that was conducted in this dissertation.

2.11.1 Advantages of Femto-cells

From the foregoing discussions, both the subscribers and the CSPs will benefit from the deployment of Femto-cells and some of these benefits include;

Good signal quality for indoor subscribers leading to improvement in call (voice, video or data) qualities i.e. the Femto-cell provides all-time 5-bar coverage.

Reduction in the power utilization of terminal gadget in indoor regions as lesser stage of radiation is needed due to proximity to the indoor cell; this complements the battery lifestyles of an UE.

Indoor traffics are off-loaded to Femto-cells and this ensures that fewer numbers of Macro-cells are desired in a geographical place. This reduces the capital expenditure (CAPEX) for the CSP and releases the resources which can then be used to serve the out of doors customers higher

Simplification of website online survey and making plans technique for community roll out or optimization activities.

Deploying Femto-cells reduces a CSP’s Churn rate. The Churn rate is described as the percentage of subscribers who stopped using an operator¡¦s service for one reason or the opposite at a given duration. It has been mounted via surveys that poor indoor coverage is the fundamental churn-inflicting aspect for CSPs.

Femto-cells create more demand for data-services for this reason increasing the sales for the CSP. It additionally enables the development of add-on offerings which includes Femto-quarter or domestic quarter wherein subscribers can get brought package deal applications for voice and facts at a lower value.

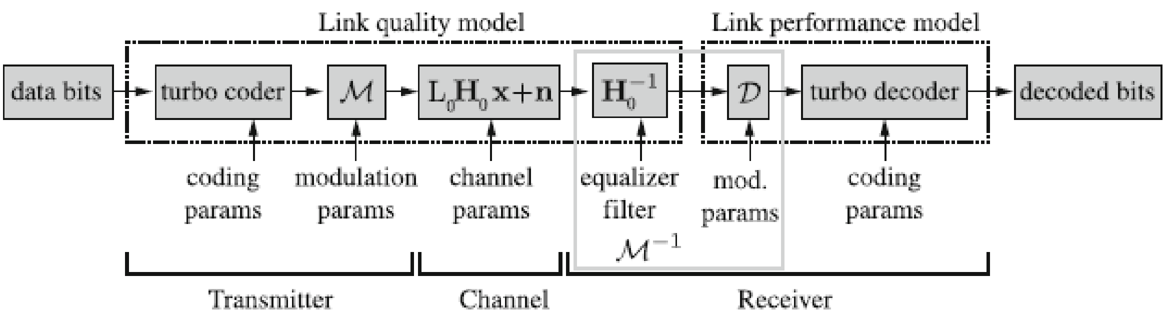

Figure2.11: LTE Physical Layer Modelling [50]

2.12 OFDM/OFDMA

Wireless channels are characterized by means of frequency selective fading impairments. This reasons extraordinary channels to experience exceptional levels Depending on the channel's frequency. Frequency selectivity outcomes from the phenomenon of multipath signal propagation that characterizes indoor and urban environments. Radio get admission to technologies using wideband alerts together with the 3G UMTS-CDMA systems can suffer tremendous distortion. This makes sign healing on the receiving stop difficult and leads to usual network performance degradation.

Narrowband signals as illustrated in Fig. 2.four offer better resistance against frequency Selectivity and this offers upward thrust to multicarrier modulation technology along with orthogonal frequency division multiplexing (OFDM). In OFDM, every subcarrier is orthogonal to each different; subsequently, the overlapping of subcarriers without inflicting inter-image interference (ISI) is made feasible.

This makes it more spectrally green when in comparison to FDMA as more symbols may be packed right into a given bandwidth. The analysis carried out on this thesis is focused on interference coordination and mitigation for Macro-mobile networks overlaid with Femto-cells in LTE-A networks which meets the requirements of the ITU-R's IMT-advanced specs for 4G networks. On the downlink, LTE-A builds at the framework of normal LTE and it sits on the Orthogonal Frequency department multiple get admission to (OFDMA) approach as its physical layer technology. The single service Frequency department multiple get admission to (SC-FDMA) is used on the uplink due to the fact it is value-green and conserves electricity. The following segment offers a quick element of OFDMA as it applies to LTE with emphasis on useful resource allocation.

2.13 LTE Femto-Cell Logical Architectures

The Third Generation Partnership Project 3GGP workgroup specified three architectural variants for the deployment of Femto-cells in a geographical environment [21] [22]. Since a CSP that wants to deploy Femto-cells already has an existing infrastructure in place, it is important to consider an architecture that is not intrusive and cumbersome to implement. The architecture also has to be scalable and easy to evolve in case of future adjustments. The differences in the variants lie in how the Home enhanced Node B (HeNB) is connected to the Evolved Packet Core of the LTE network on both the control and user plane.

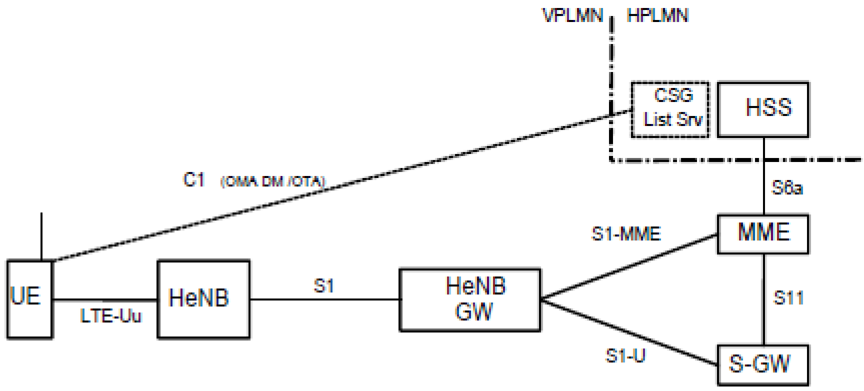

Figure 2.12: LTE Femto-cell Logical architecture (variant 1) [22].

The variant 1 is given in the Fig. 2.12. This architecture incorporates Home eNodeB Gateways (HeNB-GWs) which help to aggregate the traffic coming from the deployed HeNBs in the network on both the user plane (S1-U) and the control plane (S1-MME) before sending the traffic to the core of the network.

The advantage of this variant is that the increase in the number of deployed Femto-cells does not lead to a corresponding increase in the control plane signalling between the access and the core network. In the situation of massive HeNB failure that can occur due to power failure, the Mobile Management Entity (MME) in the core will not be overloaded when the HeNBs come back online. Furthermore, this approach provides better network security

As the IP addresses of the core network elements are not revealed to the UE. Useful information regarding interference coordination or mitigation can also be exchanged over the S1-MME interface between the HeNBs and the MeNB. The variant 2 depicted in Fig. 2.8 removes the HeNB-GW present in variant one and favors direct connectivity of the HeNBs to the core of the CSP. With this architecture, the MeNBs and the HeNBs are connected to the core with similar technique. Its benefit is that there are less failure points in the system and it does not include an additional single point of failure.

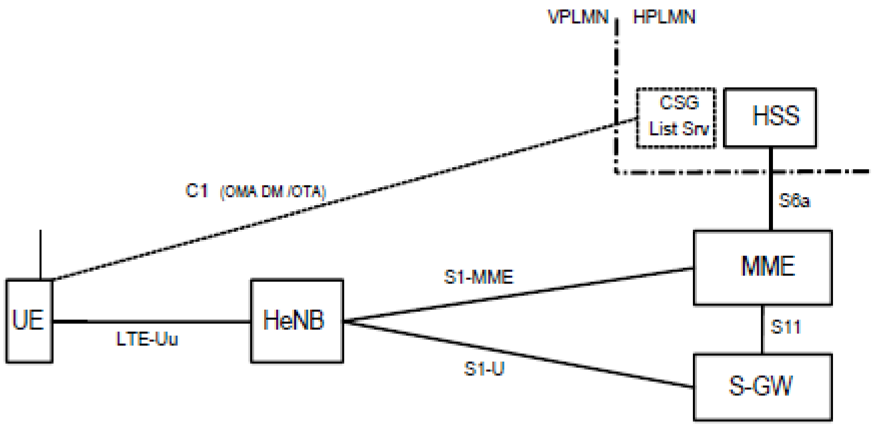

Figure 2.13: Femto-cell Logical architecture (variant 2) [22]

Furthermore, latency and system level processing are reduced since the HeNBs are directly connected to the core on both the control and data plane. The challenge of this variant is that increase in the number of deployed HeNBs will result in more frequent Stream Control Transport Protocol (SCTP) signalling which can lead to MME overload. Switching of HeNBs on and off by the user leads to similar problems.

Therefore, variant 2 can only effectively support a scenario where few numbers of HeNBs are scattered over the coverage area of a CSP. In order to solve the problem of possible control plane overload of the MME in variant 2, the HeNB-GW was re-introduced in variant 3 similar to variant 1 but it only terminates control plane signalling from the HeNBs. The user plane is directly connected to the S-GW at the core of the CSP. The variant 3 is depicted in Fig. 2.14, with this architecture; increasing number of HeNBs does not lead to SCTP overload towards the MME.

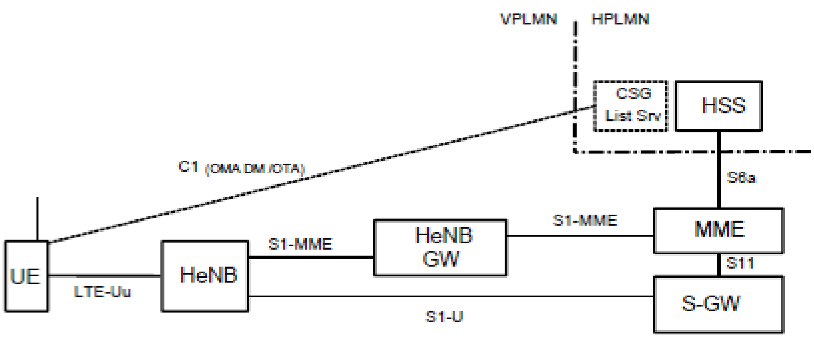

Figure 2.14: Femto-cell architecture (Variant 3) [22]

The demerits associated with the variant 3 include the possibility of an overload situation in the S-GW when the number of HeNBs deployed in the network increases. In addition, the presence of the HeNB-GW on the control plane reduces redundancy and load-balancing possibility as the HeNBs can only connect to one HeNB-GW at a time.

In order to deploy a convenient interference mitigation or coordination scheme, it is important to understand the type of Femto-cell logical architecture that will be employed in the network. This ensures that suitable design approach as to the exchange of control signals between the network entities is taken. Further extension in connectivity between HeNB and MeNB over the X2 interface has also been proposed by the related SDOs [23].

3.13.1 Effect of Femtocells on Network Capacity

With the constant increase in number of users in a network, the ability of the macro cell to handle all the data traffic efficiently decreases, making the throughput of the network drop and users experience bad quality of service[22],[25]. Recently, to overcome this problem effectively, a solution has been implemented which not only aids in increasing the capacity and coverage of the network but also helps in increasing the signal strength/connectivity of the cell edge users in the network providing efficient in-building solution to many large organizations. This solution is deployment of small cells (Pico cells and femtocells) in densely populated areas and at edge of coverage area of the macro network.

In our project, using the Vienna LTE simulator, we reveal how the deployment of a femtocell inside the macro network increases the throughput of the mobile side users and big number of users in an organization. We firstly don't forget a macro community with a random person distribution. The distribution is such that there are certain customers on the brink of the cellular and few are densely packed highlighting the state of affairs for massive buildings which includes department shops or an employer. For this network, we gain the community throughput, equity and common consumer throughput by means of using the Vienna LTE simulator [50], [51].

Now for this same community, we then location the femtocells to help the cellular facet customers and locations wherein we've got consumer densification like in department stores. We acquire the results that had been acquired for the macro network and examine the outcomes. After reading the effects, the significance of the femtocell inside the actual global community can be emphasized.

This look at enables us substantially due to the fact if a user complains about terrible fine of service, using Vienna we can take a look at the network performance of that region then suppose if by putting the small cells in that area could provide higher nice of service. This can appear earlier than real deployment of the small cells thus saving a variety of assets for the service company.

3.13.2 Demerits caused by Femto eNB's deployment

As it is mentioned above that Femto eNB's which are also called HeNBs can be operator deployed or user deployed. If it is operator deployed Macro user also have access to it which is called open access but if it is user deployed Macro user cannot get connected to it only limited number of users like family members of that particular home will have access to it which is called closed subscriber group (CSG).

In this situation when Macro UE (user equipment) is in edge of Femto cell there will be strong interference from Femto cell and may even not be able to access the Macro cell at all. In another situation strong Macro cell interferes the Femto UE.

This happens when sometime it is preferable to connect UE to the Femto cell even if the received power from the Femto cell is weaker than Macro cell. This is useful when strong cell has weak backhaul quality or when it is necessary to offload the traffic to Femto cell and to achieve true cell-splitting gains in the network [22]. Let's take an example when UE is in cell extension region and it is connected to Femto base station. But received power by the UE from the Macro is much higher than the power received from Femto. This Power difference cause severe interference to the Femto user by Macro base station. This scenario can be demonstrated by the figure 2.15.

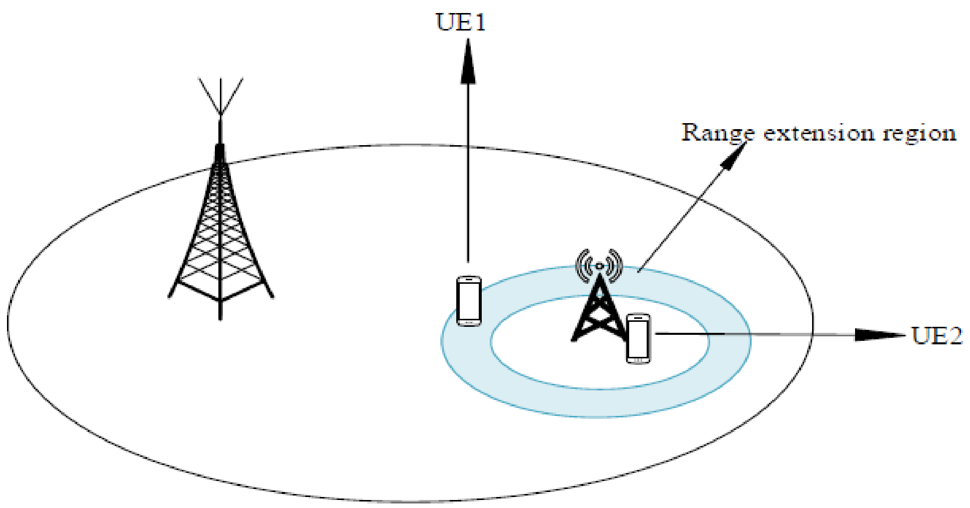

Figure 2.15: Illustration of CSG and range extension user [19].

As we can see UE2 is in well inside the Femto cell which is also called centre Femto user. Here, the received power of the Femto is stronger than the received power of Macro so there is no issue of interference. But if we see the UE2 it is in the cell extension region and it is connected to the Femto base station. Received Power by this user from the Macro is much higher than power received from Femto. So, UE2 undergoes severe interference imposes by Macro base station.

So this is one of the main disadvantages of heterogeneous network. Our thesis deals with the minimization of this interference. We have assumed the heterogeneous network of Macro and Femto base station. And there is an UE in the cell extension region which is interfered by the Macro base station.

2.14 Carrier aggregation in LTE

Carrier aggregation is used in Frequency domain multiplexing inter-cell interference Coordination scheme which is one of the most important features of LTE-A. This scheme allows LTE-A user to connect to several carriers at the same time. It also allows resource allocation across the carriers as well as fast switching between carriers without time consuming handovers, which means a node, can schedule its control and data information on separate carriers.

Main principle in a HetNet scenario is to partition the available spectrum into two separate component carriers and assign the primary component carriers (PCC) to different network layers as shown in figure 3.4 below.

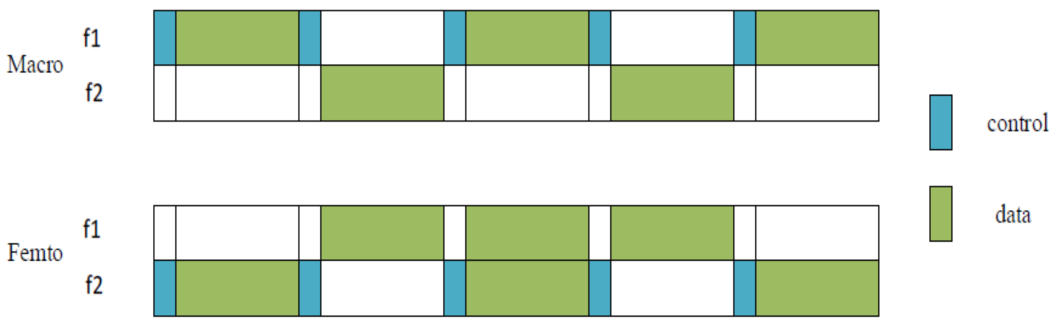

Figure 2.16: Illustration of Carrier aggregation in LTE [10]

2.15 Conclusion

In this chapter, the various techniques that have been proposed to provide high quality signal coverage in the indoor environment have been examined. The challenges of existing systems and the benefits of using Femto-cells have also been highlighted. The associated problem of Femto-cells interference has been discussed. In the next chapter, the extent of performance degradation, which can result when Femto-cells are deployed in the network without proper interference mitigation, will be presented using a standardized LTE simulator. Afterwards, a survey of interference mitigation schemes in literature will also be presented.

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CHAPTER 3

RESEARCH METHODS AND TECHNIQUES

3.1 Introduction

In this chapter, the Vienna LTE simulator was used to analyse the degrading impact of interference on channel capacity when Femto-cells are deployed over a Macro-cell network to buttress the need for interference mitigation techniques in modern wireless communication networks. The various categories of interference in multi-tier heterogeneous radio access networks are given with emphasis on Macro-cell overlaid with Femto-cells on indoor environment. Broad related works will then be discussed with more attention on the efforts in literature that were directed at interference coordination and avoidance techniques such as Fractional Frequency Reuse (FFR). The shortcomings discovered in existing works are noted and the proposed solution is clearly highlighted.

3.2 The Vienna LTE Simulator

The Vienna LTE simulator was developed by authors of [24], [25] as a platform that aids the alignment of research efforts directed at achieving the LTE specifications as given by the 3GPP workgroup. This serves as a common testing ground for implementing ideas and checking he results of analysis that can easily be reproduced and improved. This software package has link level and system level simulators as separate entities built on the MATLAB platform, and employs the Object Oriented Programming (OOP) development technique. The Vienna LTE simulator was used in this work instead of OPNET, OMNET or NS-3 because it was specifically designed for LTE and LTE-Advanced simulation purposes. Unlike the other simulators, which can be used for testing generic network communication protocols and different standards, the Vienna simulator is streamlined only for LTE related research purposes. Link level simulations are used to investigate the performance of channel estimation techniques, tracking and prediction algorithms, Multiple Input Multiple Output (MIMO) gains, adaptive modulation and coding (AMC) including its feedback [24]. Other features such as the receiver structure with reduced complexity, channel modelling, channel encoding and decoding are also implementable using the Vienna LTE link level simulator. System Level simulations on the other hand is useful for testing schemes that are network related such as resource allocation and scheduling, interference management, network planning and optimization, call admission control and multi-user handling [24]. Results of experiments from the Link level simulator such as the values of the received signal strength under different network link conditions, which are mapped to produce the channel quality indicator (CQI), are used as a benchmark for the system level simulator to ensure uniformity and reproducibility of results in both set of simulators.

In this section, the system level simulator was used to investigate the performance of a mobile network that initially consisted of only Macro-cells. Femto-cells were then overlaid on the Macro-cell and the channel capacity metric of the network was checked and compared with the result achieved when only the Macro-cells were deployed. Minimal interference mitigation was implemented and this was done to demonstrate and ascertain the impact of the deployment of Femto-cells on the Macro-cell network to improve the indoor environment.

3.2.1 LTE system level simulator

System level simulations focus more on network related issues for example resource allocation and scheduling, multi-user handling, mobility management, admission control, interference management and network planning optimization. Because of the vast amount of data processing that is needed for executing the radio links between all terminals and base station it is impossible to perform the physical layer simulations in this case describe before, so to perform system level simulation the physical layer should be abstracted by reduced models without losing the main characteristics and with high efficiency and low complication. [6]

3.2.2 Operating the Vienna LTE Simulator

The demonstration on how to use the Vienna Long Term Evolution (LTE) simulator is being shown on this section. Vienna LTE simulator its main advantage is that it’s an open source mat lab based simulator which is very important to researchers and equipment manufacturers for testing develop and implementation of their ideas before extending it into reality. This Long Term Evolution simulator is an open source mat lab-based simulation tool, it possess the mat lab software from 2008 up to date. It requires researchers to register with math works and accepting and agreeing with the license. Once you have been approved you will be able to use the simulation tool. Firstly the simulation launcher file in mat lab must be opened and configure network parameters according to the research goals and objectives. Step two is environment is being selected and additional configuration parameters in the simulation main file. The additional parameters of femtocell are to be added, various path loss, network plots display mode, coupling loss, and other parameters.

Simulator architectural elements include:

3.2.2.1 Module for User Input

Graphical user interface is being used by the researcher to communicate with the system. For accurate calculations, user input is required which include:

Femto BSs Location coordinates in a macro cell area

The femto and macro number of users and the femto Base Stations.

Since LTE-A has multiple configuration modes available the total base station .Bandwidth parameters and also the modulation scheme parameters are crucial. Based on the given information, User Equipment and respective antenna spots their distance can be easily calculated, resulting Estimation of the channel path loss. The femto cell topologies are assumed to be the case of an urban area only because the deployment of femto base station it requires high density of users, hence it is assumed to be deployed in city environment.

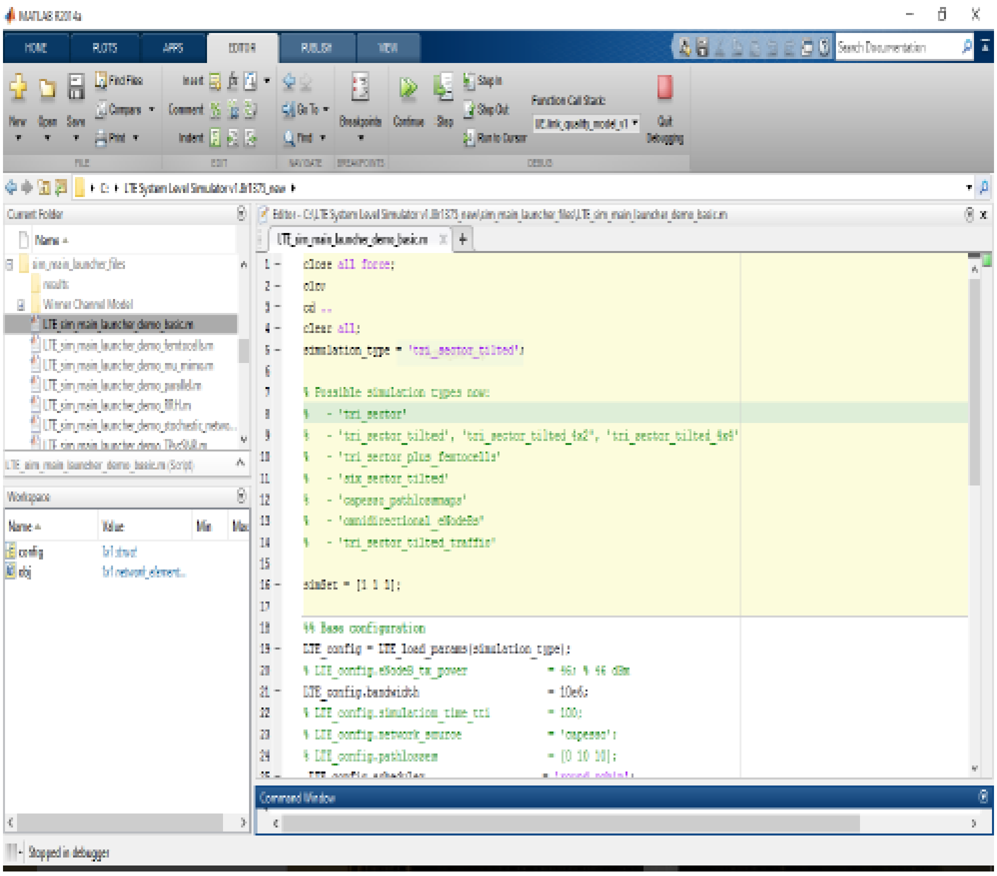

Figure 3:1 MATLAB Graphical User Interface

3.3 The Simulation Environment

The femtocell deployment process on the simulator is begun with the initial screen illustrated in the fig 1.2. The variety of macro customers, femto users and the wide variety of femtocells deployed has to be entered. Apart from those parameters, variety of constructing both lengthy x axis, y axis and the desired channel bandwidth according the current LTE-A standards (1.four, three, five, 10, 15 or 20 MHz) wishes to be furnished. Additionally, because of the carried out urban environment the person has to define the width of the map's streets, in meters. By means of clicking "making use of to Map", the buildings are installation as a consequence. A manual femtocell deployment and femto/macro person placement takes region through clicking onto particular factors in the microcell's area. The deployment is taken into consideration finished whilst the end-person has placed the closing macro person at the map. After this occasion, one can view the simulation data for each positioned unit, through hovering that with the mouse pointer.

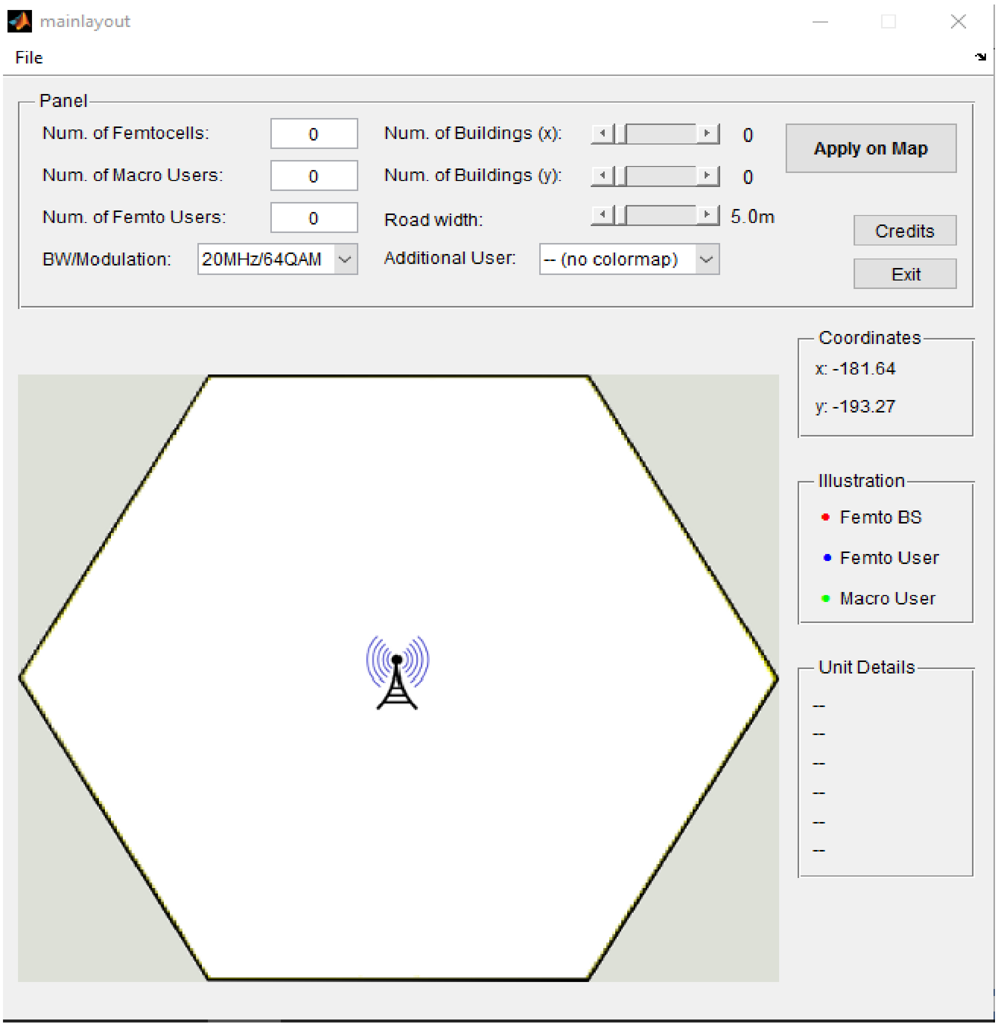

Figure3.2: Femto cells Network Deployment.

A sample scenario is supplied in fig1.3 in which i have taken into consideration 20 femtocells, 30 femtocell users and 10 macro cell customers. The Bandwidth is chosen as 20 MHz and the modulation as 64QAM. The numbers of buildings are 35, with four in x axis and four in y axis the road width is assumed to be default as 5.0m.

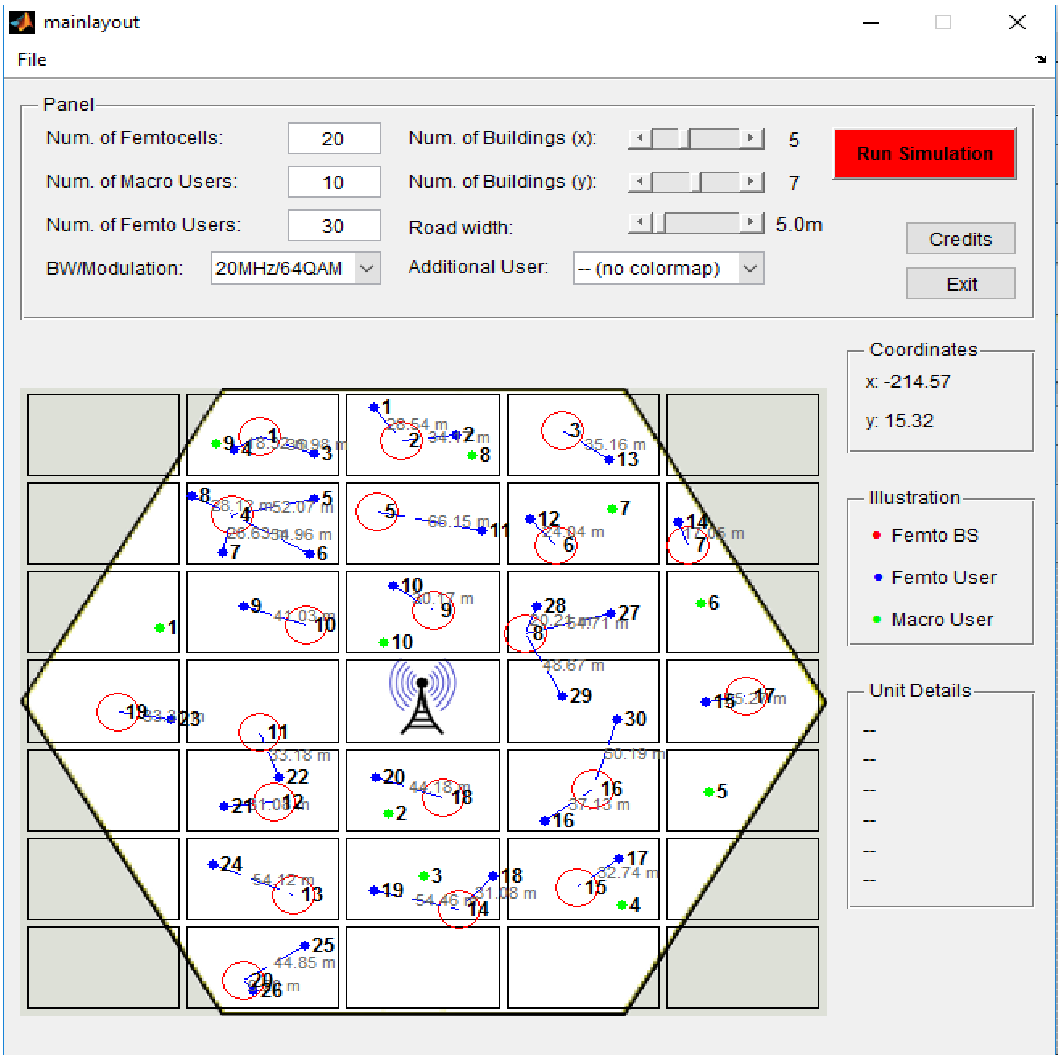

Figure 3:3 Sample illustration after femto cell deployment is completed.

3.4 Algorithm Design and Implemented

When an H-UE is turned ON, it starts measuring the received signal from all the neighboring H-eNB's. After this it determines those H-eNB's from which it is most likely to have interference. These values are sent back to the serving femto eNB and thus the femto eNB collects the information about all the allocated sub-bands and thus will allocated a sub-band which has not been used or the one on which it is experiencing the least interference.

If all the sub-bands are not used up by the neighboring eNB's, then the non-overlapping orthogonal sub-band is allocated to the H-UE by the serving femto base station. The Received Signal Strength Indicator (RSSI) is used by the H-UE to determine the signal strength from various femto base stations. RSRP is a combination of Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ).

Highest interference means that the signal strength obtained by the neighboring H-eNB is very strong, so instead of trying to mitigate it, using CoMP it can be converted to the user's benefit, thus jointly coordinating to provide high throughput to the H-UE. By using the above mentioned technique, the same sub-channel is allocated to the UE from which he is experiencing high interference; this mitigates the femto-femto interference to a large extent. As mentioned earlier, the user is allocated an unused sub-channel if available, the throughput of the user is maintained high in this case as he does not any interference from the neighboring H-eNB's. Though the H-UE is allocated a sub-channel, the H-UE continuously measures the RSSI from the neighboring femtocells at various time intervals and these values are simultaneously fed back to the serving H-eNB. This way the serving H-eNB allocates more than 1 sub-carrier to the user, if the sub-carrier is not used by the neighboring cells, thus bringing CA into place. CA is used only when more than 1 sub-carrier is available at the femto base station's disposal.

Table 3.1: Parameters for macro cell and femto cells deployment

Parameter	**value**
Microcell Radius	250m
Femtocell Radius	20m-50m
Macro BS Power	46dBm
Femto BS Power	20dBm
Indoor Walls Loss	5dB
Bandwidth	20/100Mhz
Modulation Scheme	64QAM

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CHAPTER 4

SIMULATION AND RESULTS

4.1 Introduction

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

4.2 Schemes Used

4.2.1 Conventional Scheme

SINR for each user j attached to cell i is calculated as:

$$SINR_{j,i} = \frac{P_i G_i PL_{j,i}}{\sum_{k=0(\neq i)}^{N} (P_k G_k PL_{j,k})} \qquad (4.1)$$

Where $PL_{j,k}$ is the path loss between user j and femtocell k.

Further, Capacity is calculated as:

$$C_{j,k} = BW.(1+\alpha.BER)SINR_{j,i} \qquad (4.2)$$

Where BW is the total bandwidth (20 MHz) divided by number of users at the femtocell.

4.2.2 Proposed Scheme

4.2.2.1 Carrier Aggregation

Step 1: Initialization:

Each femtocell is assigned 1 sub-band (out of 10), if all the sub-bands are already taken, then the one with least interference is selected, based on measurement of total capacity from the four(4) neighbouring cells.

Step 2:

After the initial sub-band is assigned to the user by the serving femtocell, a check is performed if 1 more sub-band can be allocated (repeat for all sub-bands) at the same time checking if the capacity is increased within the 3 neighbouring cells.

Step 3:

Repeat step 2 until there is no more change in the capacity across any femtocell Neighbourhood, or until the iteration limit is reached (Iteration limit 10 is used). So SINR for each user j attached to cell i is calculated as:

$$SINR_{j,i} = \frac{P_i G_i PL_{j,i}}{P_i (IM \times SB) \times SB_i^T} \qquad (4.3)$$

Where SB is the sub-band matrix having a value 1 where a particular sub-band is used

By particular femtocell and a value 0 when that femtocell is not using that band. The matrix is shown as:

$$SB = \begin{bmatrix} 1 & .... & 0 \\ : & & : \\ 0 & ... & 0 \end{bmatrix} \qquad (4.5)$$

The number of rows represents femtocell IDs (1…Number of femtocells) & the number of

Columns represent band IDs (1…Number of bands).

In (the first multiplication produces a vector of sums over all interfering femtocells at user j as:

]] (4.6)

Thus every element in the array produced by the first multiplication is a summation of interferences at a particular band. This is multiplied by a transposed band vector at the present femtocell i, producing sum of only those interferences which are using the same band as the present femtocell i.The capacity is thus calculated as:

Where (4.7)

4.2.2.2 CA along with Co-Ordinated Multipoint Tx/Rx

To model the CoMP, the most interfering components of the Interference Matrix (IM) are removed. One value is removed for each femtocell, so that each femtocell supports 1 CoMP user. In reality more CoMP users per femtocell can be supported, but for the simplicity case 1

CoMP user per femtocell is considered. For each femtocell, a maximum value of interference is found across all the users. This femtocell and the user form a CoMP pair, which adds to the throughput of that user, only at those points where the sub-bands coincide. SINR for each user *j* attached to cell *i* is calculated as:

(4.8)

Where, c index represent those femtocells that provide CoMP to the user j. Nc (j) represents the number of femtocells that can provide CoMP to user j. Nc (j) is found by counting elements of another matrix, called CoMP-matrix, which is same dimension as the Interference Matrix, but has a value of either 1 or 0, representing yes or no scenario for particular user-femtocell combination if they form CoMP pair.

The Interference Matrix, IM, is modified from the one used in CA by zeroing the elements which correspond to the CoMP user-femtocell pair. The zeroed elements are chosen based on maximum value of interference, as calculated along all the users per each femtocell i.e. one zero for each femto cell, at the place of worst interference. Capacity is later calculated in the same way as for Carrier Aggregation.

4.3 Topology Used and results

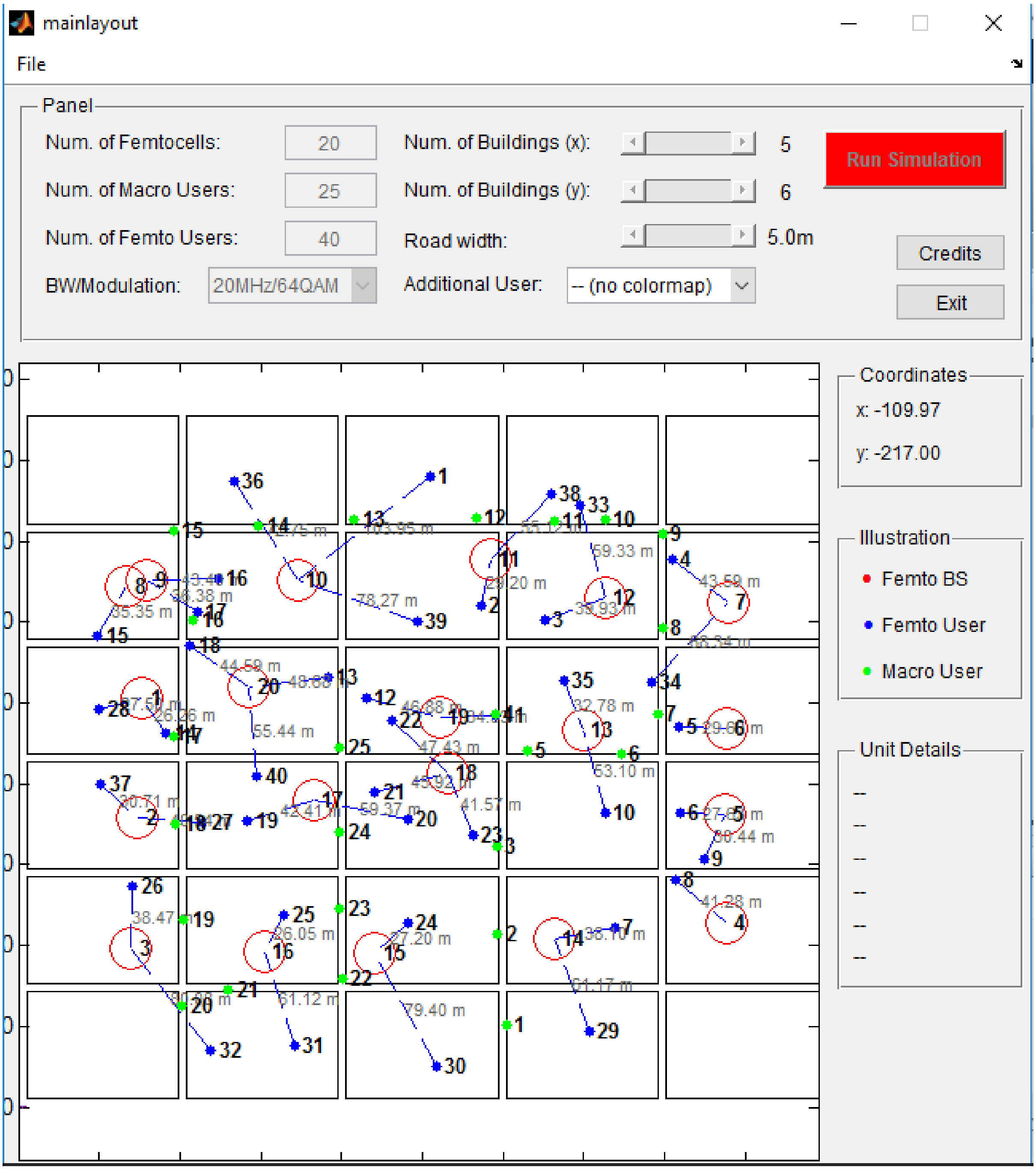

Fig 4.1: Topology with 20 Femtocells

The topologies used in the simulation are shown in fig4.1, fig4.2 and fig 4.3. The Fig 4.1 represents 20 femtocells, along with 40 femtocell users and 25 macrocell users. There are 30 buildings, with 5 along the x axis and 6 along the y axis. The road width is taken approximately as 5.0 m. The modulation scheme used is 64 Quadrature Amplitude Modulation (QAM) and the bandwidth is 20MHz. Fig 4.2 represents higher number of femtocell users, i.e. 50 femtocells, 70 femtocell users and 50 macro users. The numbers of buildings, road width, modulation scheme and the associated bandwidth parameters have been kept the same. Fig 4.3 represents higher number of femtocell users, i.e. 50 femtocells, 120 femtocell users and 50 macro users. The numbers of buildings, road width, modulation scheme and the associated bandwidth parameters have been kept the same

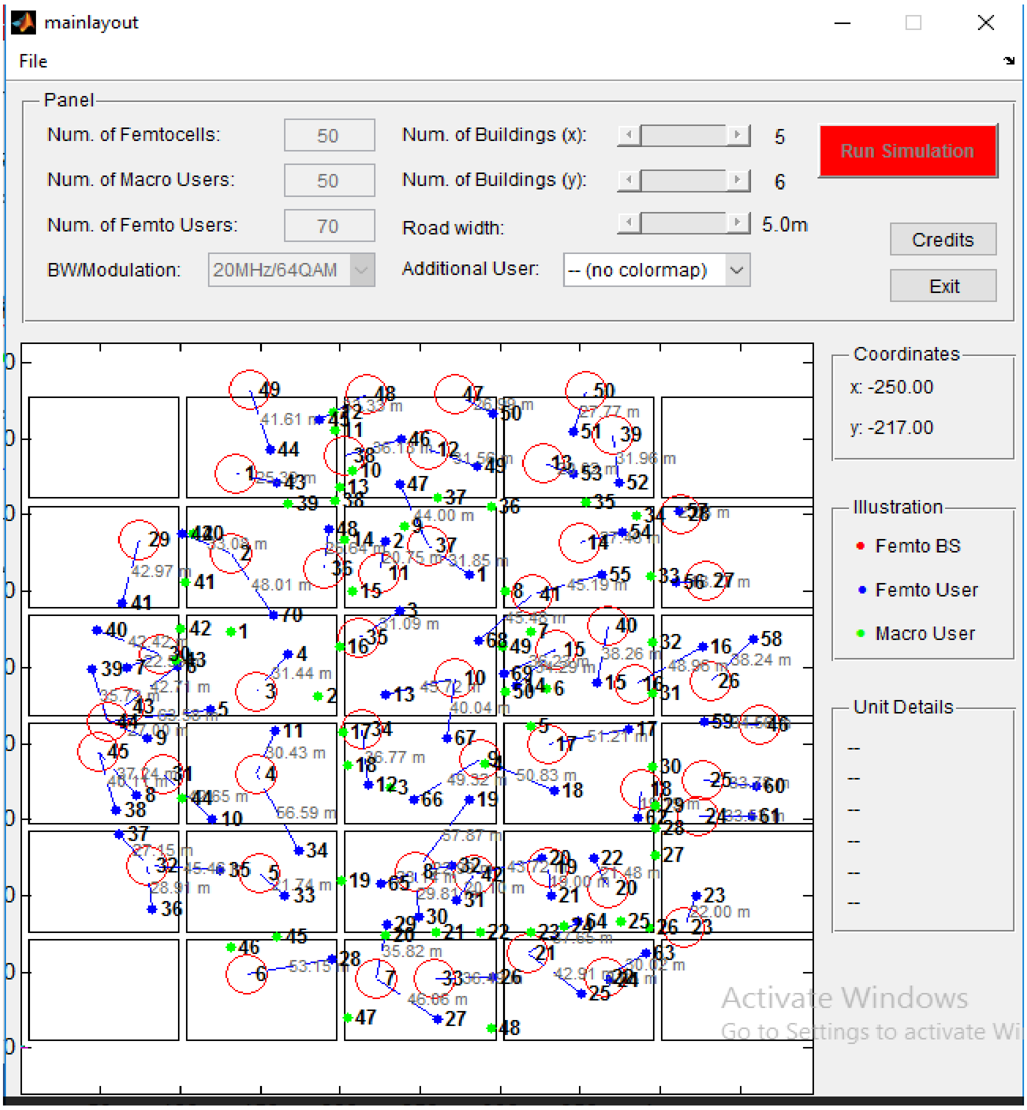

Fig 4.2: Topology with 50 Femtocells

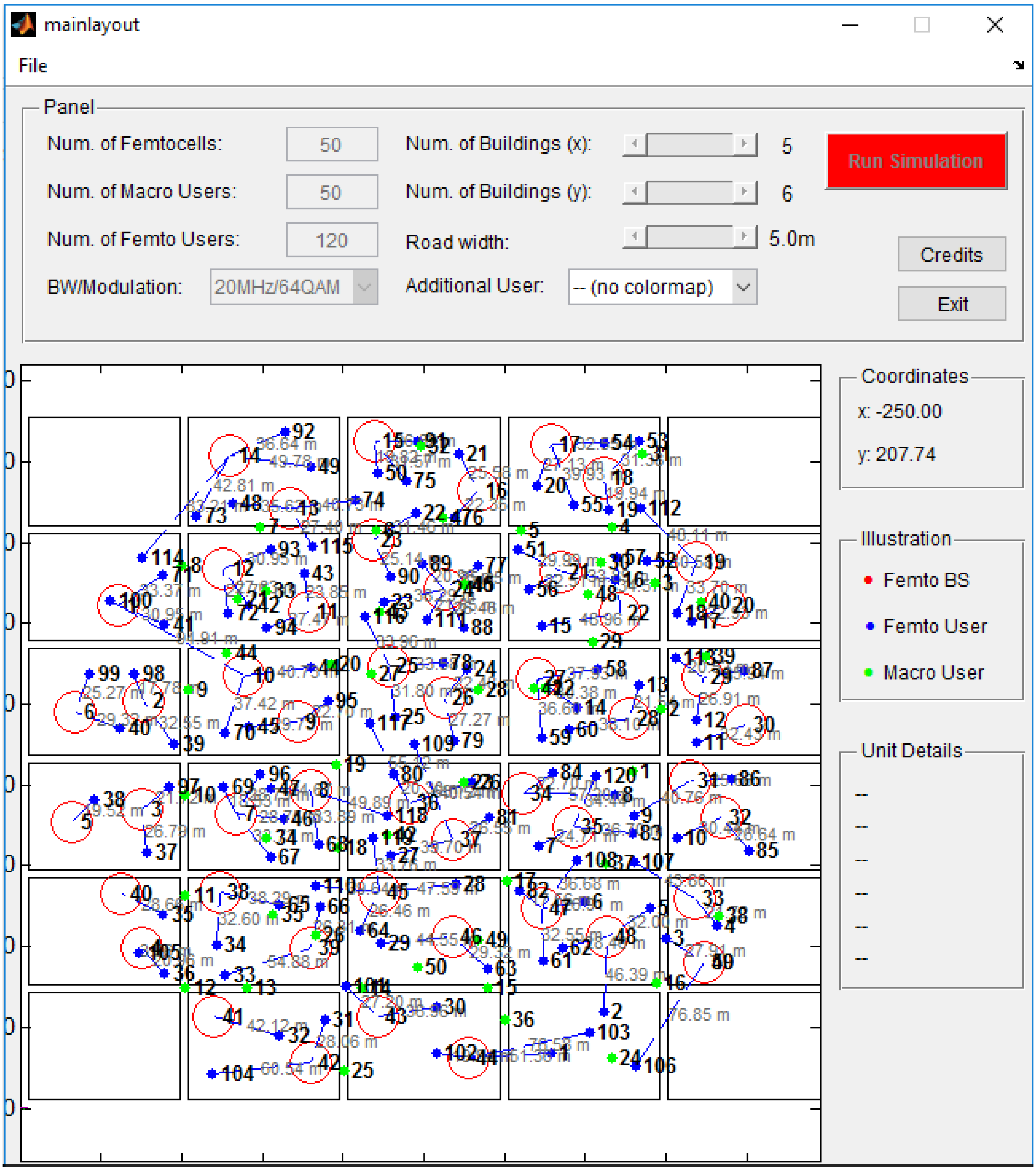

Fig 4.3: Topology with 70 Femtocells

All the plots are shown with respect to the implementation of Carrier Aggregation, Carrier Aggregation along with Co-Ordinated Multipoint transmission/reception. These techniques are implemented to show how these technologies would vary against the conventional scheme and its benefits in terms of capacity, SNR and bandwidth utilization are highlighted.

Fig 4.4: Femto cell performance of 70Mbps total throughput and 40 Femto cells.

Figure 4.4 presents the CDF of data rate when 15 femtocells have been scattered in the cell. Although as we saw power control behaves best regarding average throughput, it cannot provide protection to the worst-case users, as FR schemes do by allocating them exclusive bandwidth. The majority of worst-case users are located near the cell edge. In addition, due to weak signal received, it is the area where the use of femtocells is most needed, thus an increased femtocell density is expected in these areas. We consider a cell-edge user when he is located at distance greater than 120m from the macrocell antenna. The average throughput of cell-edge users for increasing femtocell density deployment is shown in Fig.4.5. The figure is similar with the total cell average throughput, but femtocell density is a more important parameter now, since inter-cell interference makes the area already substandard. Frequency partition methods (IFR, SFR) demonstrate better performance than simple co-channel for less than 15 Femtocells, while power control stops being the best solution for less than 25 femto BSs

Fig 4.5: Femto cell performance of 40Mbps total throughput and 40 Femto cells.

Fig4.5 presents a comparison of all methods, versus the number of femtocells. Simple power control behaves best in overall performance, since no bandwidth fragmentation takes place. However, as femtocells' number increases, its edge decreases, and finally diminishes for over 35 femtocells. Moreover, no provision (co-channel operation) becomes worse than FR methods when femtocells' number exceeds 22. This means that macrocell small spectrum utilization in ICIC is compensated in terms of overall performance, for large femtocell deployment, maintaining system's spectral efficiency. IFR compared to SFR presents slightly worse behavior, since SFR is characterized by greater spectral efficiency. One last observation on the figure is the catastrophic consequences of not adaptable femtocells

Fig.4.6 presents a comparison of all methods, versus the number of femtocells up to 40. Power control behaves best in overall performance although it is high when supporting up to 20 femto cells and decreasing gradually, Carrier Aggregation behaves best in overall performance again and decreasing gradually as the number of femto cells increases.

Fig 4.6: Femto cell performance of 60Mbps total throughput and 40 Femto cells.

Fig 4.7 shows a set (cell array) of eNodeB configurations is created, with the number of eNodeBs specified by NeNodeB. The configurations are derived from Reference Measurement Channel (RMC) R.5 using lteRMCDL. R.5 describes a 3 MHz bandwidth Downlink Shared Channel (PDSCH) transmission using 64-QAM modulation. For each eNodeB the configuration is updated to make the cell identity NCellID unique and the PRS parameters NPRSRB, IPRS and PRS Period are set. A random position given by an X and Y coordinate for each eNodeB is generated by h Positioning Position m. The positions of the eNodeBs and the UE are plotted for reference. The UE lies at (0, 0) and the eNodeBs are distributed around the UE.

Fig 4.7: Location of eNodeBs and UE

Fig 4.8: Plot Transmitted Waveforms

Fig 4.8 highlight that for each eNodeB, a transmission is made consisting of solely the PRS. An empty resource grid is created and a PRS is generated and mapped onto the grid using lte PRS and lte PRS Indices. The resultant grid is OFDM modulated to produce a transmit waveform. The colors are used to differentiate waveforms of different eNodeBs which time in seconds in relation to absolute values.

Fig 4.9: Delays from eNodeBs to UEs.

In fig 4.9 by using the known eNodeB positions, the time delay from each eNodeB to the UE is calculated using the distance between the UE and eNodeB, radius, and the speed of propagation (speed of light). Using knowledge of the sampling rate, information. Sampling Rate, the sample delay and stored in sample Delay. These variables will be used to model the environment between the eNodeBs and the UE but the information will NOT be provided to the UE. The received signal at the UE is modeled by delaying each eNodeB transmission according to the values in sample Delay, and attenuating the received signal from each eNodeB using the values in radius in conjunction with an implementation of the TR36.814 Urban Macro

Line Of Sight (LOS) path loss model. The received waveform from each eNodeB is padded with zeros to ensure all waveforms are the same length.

Fig 4.11: Estimate Arrival Times.

Fig 4.11 postulating that the arrival times of the signals from each eNodeB are established at the UE by correlating the incoming signal with a local PRS generated with the cell identity of each eNodeB. To be accurate the absolute arrival times cannot be used at the UE to calculate its position as it has no knowledge of how far away the eNodeBs are, only the difference in distances given by the difference in arrival times. Therefore the peak correlation for each eNodeB is used as a delay estimate to allow comparison.

Fig 4.12: UE throughput at 5/km,

Fig. 4.12, we examine femto UEs' performance when hybrid access mode is allowed, compared with CSG. For hybrid access mode, we evaluate two cases. In the first case, the femtocell sets a default number of subcarriers that MUE may have access. This number is predetermined and cannot change. The second case of hybrid access, follows the scheme described in the previous chapter. More subcarriers become available in order for the femtocell to compensate for the impact it caused. An upper limit of available subcarriers has been set, for the MUE not to drain all resources from the rightfully femtocell subscribers. At the same time, a minimum number of subcarriers is always reserved when a MUE is nearby and experiences low SINR, even if its inadequate performance is not due to femtocell. This way, femtocell deployment boosts the performance of MUEs across the network, when the latter are deployed in areas with attenuated macrocell signal. This includes cases of cell-edge users or users inside multi-floor or multi-apartment buildings. In the figure we also depict the capacity of MUEs before the deployment of femtocell for comparison.

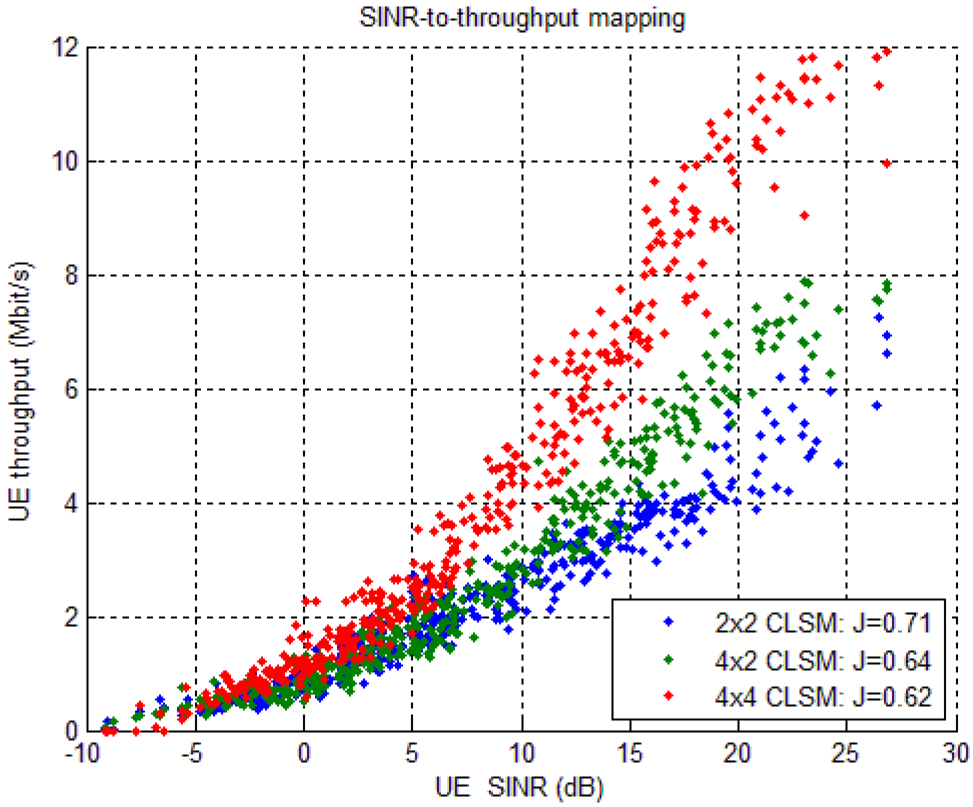

Fig 4.13: UE SINR throughput mapping

Fig. 4.13 demonstrates the simulation results for an indoor and an outdoor femto user respectively. The examination of both figures reveals that the throughput of the femto user decreases as the user moves towards the femtocell edge. However, contrary to the macro user case, the decrease is smoother and even at the femtocell edge the throughput is high enough to serve the user. More specifically, for the case where the distance between the indoor user and the macro BS is 250 m, the achieved throughput decreases by 97.83% (from 1.9 Mbps to 41.3 Kbps). For an outdoor user the decrement reaches 96.2% (from 1.10 Mbps to 41.75 Kbps). The achieved throughput at the femtocell edge is low; however, the corresponding throughputs for a macro user are even lower (1.1 Kbps for an indoor and 10.2 Kbps for an outdoor macro user at the macrocell edge). This fact indicates that the cross-tier interference has bigger impact on macrocell transmissions.

4.4 Chapter Summary

This chapter has demonstrated the evaluations which was carried out with the proposed scheme using both MATLAB simulation and analytical approaches. Evaluations was based on multi-cell network deployments femto cells. It was discovered that signal strength, interference at cross boundary between the CER and CCR could be significant in terms of the degradation it causes on the performance of the link capacity achievable by the units of HUE located at this border region. Moreover, the multiple-users evaluations were done using both Vienna Simulator schematics and MATLAB command window, agrees with the initial analytical evaluation in terms of the throughput recorded for the HUE units. In the next chapter, conclusion and addresses that has been discussed in the whole research and also recommendations are highlighted.

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CHAPTER 5

CONCLUSION

5.1 Introduction

The main goal for the research was to study and review the Femto cells network as a solution and future of wireless communications. A review of already implemented systems was done as well as an analysis of the already implemented systems. This chapter reveals the conclusion, limitations of Femto cells implementation and recommendations for future improvements.

5.2 Findings and Recommendations

Femtocells are an integral part of the LTE-A heterogeneous networks as documented according to LTE-A standards. They promise superior increase in the throughput and reduced latencies to the customers. These however come at a risk of high interference due to which indoor users observe lot of outage. In such a scenario, the whole purpose of providing indoor base stations is defeated. Femto-cells provide a solution to the challenge of provisioning high-speed communication capabilities in indoor environment. This is crucial because surveys have established that wireless communication services are requested more from indoor areas and the traditional Macro-cell infrastructure is unable to perform well in indoor areas because of signal attenuation when crossing form outdoor areas to indoor areas. The disadvantage associated with the deployment of Femto-cells is mainly the increased possibility of interference between the Femto-cell and the Macro-cell tiers of the network.

In this dissertation, the various techniques for provisioning quality indoor signal coverage have been explicitly discussed, highlighting the strengths and weaknesses of each approach. It was seen that Femto-cells provide a better solution in terms of benefits experienced by both the CSPs and the subscribers such as ease of deployment and cost effectiveness. As a result of the Femto-cells operating on the same licensed band used by the Microcells, interference between the two tiers is inevitable if proper mitigation technique is not employed. A survey of the various techniques available in the literature reveals the suitability of the FFR-3 technique for interference mitigation in Multi-tier networks that consists of MeNBs and HeNBs in terms of its effectiveness and low complexity, which is important for the relatively inexpensive circuitry that will be used in the Femto-cells. The main purpose of this thesis was to design a scheme where this interference is mitigated, providing the user favorable signal to noise ratio values thus giving the user high throughput, which in turn increases the overall capacity. To achieve the required, Carrier Aggregation (CA long with Co-Ordinated Multipoint transmission/reception (CoMP) technologies as described in the LTE-Advanced features specified by IMT-A are used.

An open source system level simulator was used. The simulator's framework consists of a macrocell with multiple femtocells embedded in it. The user has the freedom to place these femtocells, macro users, femto users at any point in the topology. Various other factors such as the modulation scheme, the road width, number of buildings in the x and y axis are also to be entered by the user in the provided graphical user interface. Metrics such as SNR, throughput, distance from the femtocell, CDF are considered to highlight the difference in the performance between the conventional scheme and the scheme proposed in this thesis. The plots shows a significant performance increase when compared with the conventional scheme. The conventional scheme provides higher throughput to those users who are not affected by any interference and very low throughput and outage for many users who are affected by interference. The proposed scheme reduces these outages by are fully allocating the sub-channels to all the users, thus providing a guaranteed throughput irrespective of their distances from femtocell.

Future works can include investigating the effect of non-uniform distribution of the users in the different regions of the cell on resource allocation. With reference to the future work, more macro cells along with higher number of macrocell users should be considered and schemes need to be designed to reduce these cross-layer interferences. MIMO increases the throughput considerably, by exploring the advantages of the space time coding schemes. These multiple antennas have to be incorporated into these femtocell networks, to see how the performance increases. The downside to this technology is the increase in overall complexity due to CA and CoMP Due to dynamic allocation of subcarriers, the complexity involved will be on the higher side. Future studies can also be focused on lowering this complexity, reducing the overhead and making the process even simpler thus exerting less pressure/lower strain on overall resources. With the rapid increase in the usage of smartphones and due to need for higher data rates, even more enhanced techniques would be needed to reach higher speeds and reduce latency.

5.3Areas of Application

The commercial use of cellular networks has evolved considerably over the last few years. According to statistics more than 85 percent of adults have cell phones, which drives operators to invest more in technologies such as femtocell. Femtocell is not limited to indoor use only, and can be a great option for subway stations, tunnels, and other public areas underground.

Callers usually lose signal from cell towers while driving through tunnels, under bridges, or traveling in subways. These situations can easily be solved by initiating a handover between conventional cellular networks to femtocell access points installed at multiple spots in urban areas. This deployment will also enable travellers to seamlessly surf the internet or make clear quality phone calls while traveling in the subway or through places that used to be without coverage. According to ABI research, the number of worldwide users will jump to 102 million for 32 million access points. In terms of deployments in the near future, AT & T is planning on offering its femtocell products in April 2010. The device should be able to carry voice and 3G data.

5.4 Limitations of femto cell deployment

1 Femto cell interference issues: One key issue associated with femtocells is that of interference. There is only limited spectrum on which the cellular systems can run. Some 3G operators for example may only have one channel in some places. Therefore it is necessary that femtocells are able to operate within the normal spectrum shared with many other cellular base stations. There are a number of ways in which this can be achieved: the use of cognitive radio technology; the use of systems that are tolerant to interference (3G and 4G are able to tolerate interference and single channel working); spectrum planning where possible.

2 Femtocell spectrum issues: radio spectrum is a particularly scare resource, especially when large amounts of data are required. Planning the available spectrum so that it can be used with the possible huge numbers of femtocells can require careful attention, although in some instances single channel operation with main base stations may be required.

3 Femtocell regulatory issues: Femtocells operate in licensed or regulated spectrum. Unlike Wi-Fi which operates in unlicensed spectrum, femtocells need regulatory approval. The spectrum and radio regulations vary from one country to the next and therefore regulations may need to be changed in each country. International agreement may also be required, because private individuals may take femtocells from one country to the next.

4 Femtocells and health issues: With a large public awareness of the possible dangers of RF radiation, one key issue has been that of health and safety. As a femtocell is a cellular base station, there could be public concern regarding the levels of RF radiation received. However the power levels emitted by femtocells are small - no greater than most Wi-Fi access points which are common in very many homes. As a result it is not believed by the industry in general that there are any health issues that should cause any concern.

5.5 CONCLUSION

The research in this paper focused in the mitigation of the interference in LTE networks that integrate femtocell overlay. Our technique is based on the idea of frequency reuse in order to reduce SINR and achieve higher values of throughput. The proposed mechanism selects the optimum values for the application of the FFR based on the maximization of user satisfaction. Our mechanism seems to be far more effective when it comes to fairness even though it seems to be worse concerning total cell throughput. For further evaluation we present the comparison when maximization of total cell throughput is used as a metric and scenarios where different frequency reuse schemes are applied.

REFERENCES

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Appendix A

This appendix gives a brief overview of the OSI reference model as related to Femto-cells in 4G networks. The aim of this appendix is to briefly establish the relationship between inter layer services and protocols in LTE multi-tier networks. The relationship between the layers in the context of interference mitigation in Macro-cell and Femto-cell will be emphasized.

A.1 The Access Stratum of the OSI reference Model and Protocols in LTE.

Out of the seven layers of the popular OSI model, the physical layer and the data link layer

(PDCP, MAC and RLC) are more directly involved in interference mitigation and control. They are associated with the radio access portion of the network, hence they constitute the Access stratum (AS) while the upper layers, which perform more core network (CN) related signaling and data transfer constitute the Non Access Stratum (NAS). The logical representation of the LTE protocol stack is given in Fig. A.1.

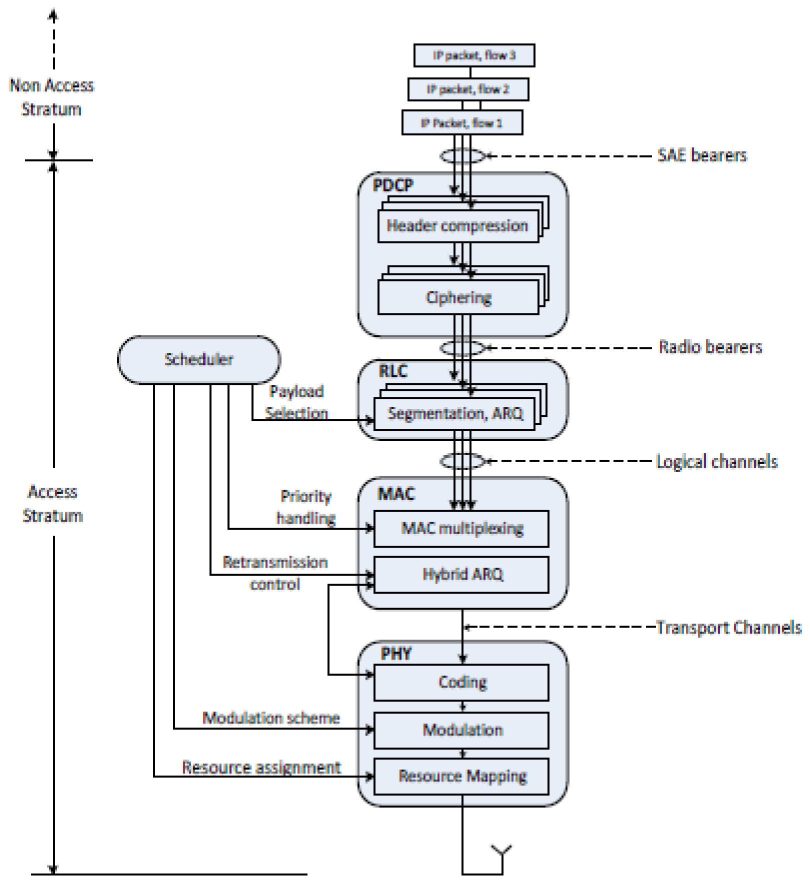

Figure A.1: The LTE Protocol Stack [1]

LTE is an all-IP based system and data packets travel through the layers and sub-layers as illustrated in the Fig. A.1 before they are transmitted over the air interface. Generally, an upper layer encapsulates data into protocol data units (PDUs) and sends the PDUs to the adjacent lower layer. The lower layer receives the PDU from the upper layer as a Service data Unit (SDU), provides a service and then outputs another PDU to the next lower layer or sub-layer in the protocol stack. The general flow of transmission processes and functionalities present each layer/sublayer and offered to the adjacent layers/sub-layers from the Data link layer to the Physical layer of LTE is depicted in Fig. A.2.

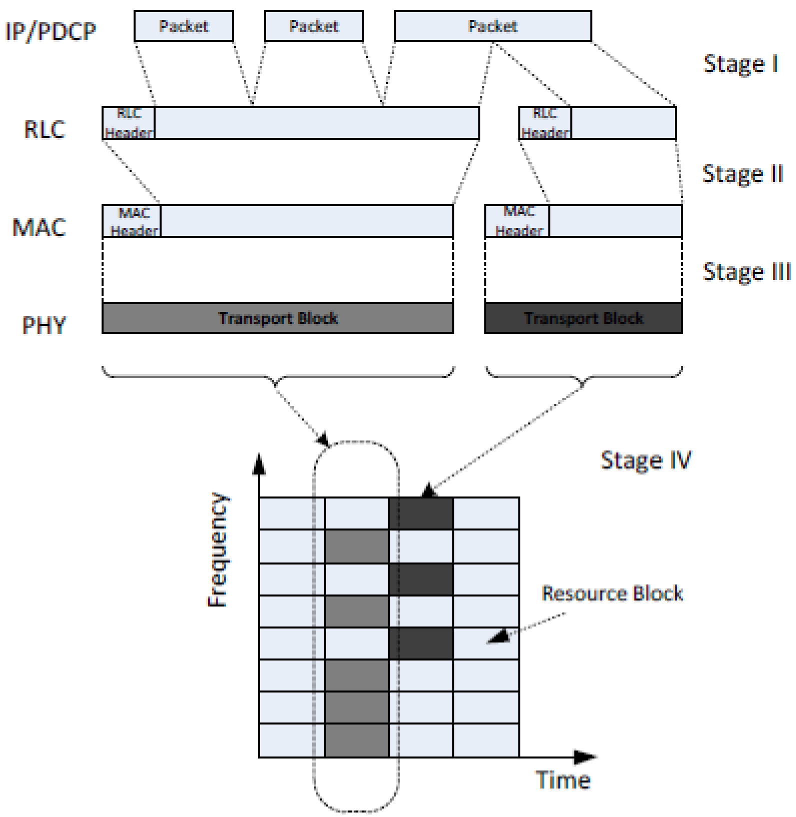

Figure A.2: Data flow and resource mapping in LTE [2]

A.1.1 The Data-Link Layer

The Packet Data Convergence protocol (PDCP) is the topmost sub-layer of the data-link layer (layer 2) and is responsible for the compression and ciphering of IP headers received from the Network layer (Layer 3). These compressed packets are forwarded to the Radio Link Control (RLC) protocol.

The RLC layer performs segmentation and concatenation of packets received from the PDCP into RLC Protocol Data Units (PDUs). It also enhances the radio bearer with Automatic Retransmission on Request (ARQ). The retransmission is triggered with the use of sequence numbered data frames and status reports. The size of the RLC PDUs depends on the resource allocation offered by the MAC layer (illustrated in stage II of Fig. A.2).

The MAC sub-layer on the other hand performs resource allocation and scheduling. The MAC sub-layer is the lowest sub-layer in layer 2 of the LTE radio protocol stack and it plays a crucial role of coordinating how the upper layers access the wireless physical medium. It connects to the physical layer below it through the transport channels and to the RLC above it through logical channels. It therefore performs multiplexing and de-multiplexing between the logical channels and transport channels.

The Logical channels used by the MAC sub-layer in providing data transfer services for the RLC sub-layer can further be divided into Control logical channels (used for signaling transfer purposes on the control plane) and Traffic logical channels (used for actual user data transfer on the data plane). The logical channels used on the control plane includes the following; Broadcast Control Channel (BCCH), Paging Control Channel (PCCH), Common Control Channel (CCCH), Multicast Control Channel (MCCH) and Dedicated Control Channel (DCCH). The traffic logical channels include the Dedicated Traffic Channel (DTCH) and the Multicast Traffic Channel (MTCH) [47].

For the MAC sub-layer and Physical layer interaction, the transport channels are used for data exchange. Data is multiplexed onto the transport channels depending on how it is transmitted over the air interface (see Fig. A.1 and A.2 (stages III and IV)). The transport channels are further categorized as Broadcast channel (BCH), Downlink Shared Channel (DL-SCH), Paging Channel (PCH), Multicast channel (MCH), Uplink Shared Channel (UL-SCH) and Random Access Channel (RACH). Additional information about the functionalities associated with each of these channels can be found in [2].

The MAC layer performs the scheduling of users onto the physical transport channels offered to it by the Physical layer. It consists of a HARQ entity, a multiplexing/de-multiplexing entity, a logical channel prioritization entity, a controller which performs various control functions and a random access control entity. A logical architecture of a LTE MAC sub-layer is given in Fig. A.3.

The HARQ entity performs transmit and receive HARQ (combination of forward error control (FEC) technique and traditional ARQ) operations for error mitigation purposes. In an adaptive HARQ scheme, variations in the channel condition together with transmission resource allocation in the frequency domain are taken into consideration and used for the selection of modulation and coding scheme at each retransmission.

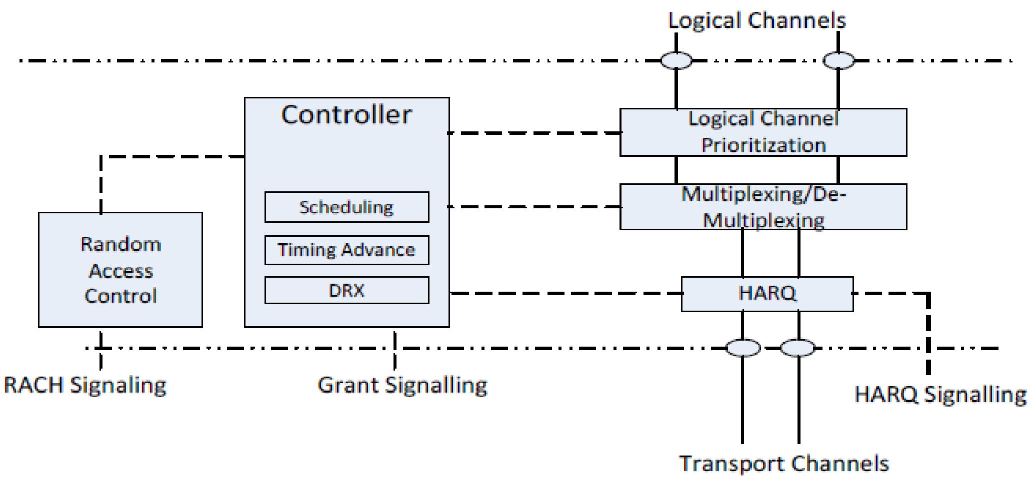

Figure A.3: Logical layout of the MAC layer [2]

The Femto-cells are structurally similar to the Macro-cells, hence they share the same layers and protocols of the OSI model. Interference (either cross-tier or co-tier) must be avoided on the transport channels as they cause poor decodability of both control and data plane signals at the receiver.

A.1.2 The Physical (PHY) layer

The modulation, coding and actual resource mapping take place at the physical layer. Orthogonal Frequency Division Multiplexing (OFDM), a multicarrier technology is employed at the LTE physical layer. The system model of OFDM transmitter and receiver is depicted in Fig. A.4. Orthogonal Frequency Division Multiple Access (OFDMA) which is based on OFDM is the multiple user access scheme for LTE. The granularity with which physical channel resources can be allocated to users makes OFDMA an attractive scheme for interference avoidance schemes. In Fig. A.4, the inverse Fast Fourier Transforms (IFFT) at the transmitter can be said to construct the OFDM signal in the frequency domain . The *N*-sample output from the IFFT block is an OFDM symbol and it consists of the sequence given as

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X[k] e^{\frac{2\pi jnk}{N}} , n = 0,\dots, N-1 \dots\dots\dots\dots\dots\dots\dots\dots \text{A1.0}$$

Each complex symbol $X[k]$ is an OFDM subcarrier and they are arranged in an orthogonal manner relative to each other. Multicarrier schemes are suitable for combatting channel frequency selectivity as each subcarrier can be said to experience an almost flat frequency response. As a result of this, multi user diversity (MUD) can be achieved whereby users (either attached to the Macro-cell or Femto-cell) are assigned subcarriers on which they have the best channel gain. Aggregation of the subcarrier in both time and frequency domains as explained in section 2.9.2 and Fig. 2.5 leads to the creation of resource blocks (RBs), which are then presented as the physical channels that the transport channels are mapped onto for the transmission of MAC PDUs illustrated in Fig. A.2 over the air interface.

In multi-tier networks, orthogonalisation of RBs and intelligent scheduling at the MAC layer are crucial to minimizing cross-tier and co-channel interference. Therefore, efficient coordination between the MAC sub-layer and the PHY layer is very important.

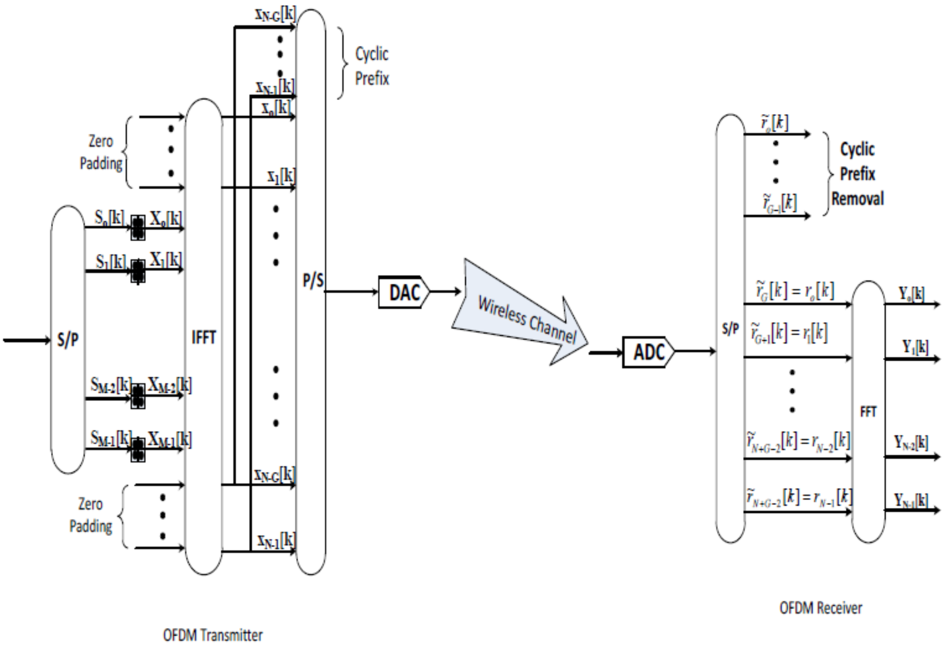

Figure A.4: OFDM System Model [2]

Appendix B

This appendix presents the MATLAB codes used in evaluating the performance of the network prior to the deployment of Femto-cells and after Femto-cells have been overlaid on the macro cells in the network as explained in chapter three. The code was implemented in the Vienna LTE system level downlink Simulator which some parts of the demo codes can be downloaded from [3]

```
function varargout = mainlayout(varargin)
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @mainlayout_OpeningFcn, ...
                   'gui_OutputFcn',  @mainlayout_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end
 if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% --- Executes just before mainlayout is made visible.
function mainlayout_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;
% Update handles structure
guidata(hObject, handles);
 % --- Outputs from this function are returned to the command line.
function varargout = mainlayout_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;
 % --------------------------------------------------------------------
function FileMenu_Callback(hObject, eventdata, handles)
% --------------------------------------------------------------------
function OpenMenuItem_Callback(hObject, eventdata, handles)
file = uigetfile('*.fig');
```

```
if ~isequal(file, 0)
    open(file);
end
 % --------------------------------------------------------------------
function PrintMenuItem_Callback(hObject, eventdata, handles)
printdlg(handles.figure1)
% --------------------------------------------------------------------
function CloseMenuItem_Callback(hObject, eventdata, handles)
selection = questdlg(['Close ' get(handles.figure1,'Name') '?'],...
                     ['Close ' get(handles.figure1,'Name') '...'],...
                     'Yes','No','Yes');
if strcmp(selection,'No')
    return;
end
 delete(handles.figure1)
  % --- Executes on selection change in popupmenu1.
function popupmenu1_Callback(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function popupmenu1_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
     set(hObject,'BackgroundColor','white');
end
 set(hObject, 'String', {'plot(rand(5))', 'plot(sin(1:0.01:25))', 'bar(1:.5:10)', 'plot(membrane)', 'surf(peaks)'});
 % --- Executes during object creation, after setting all properties.
function axes1_CreateFcn(hObject, eventdata, handles)
axis([0 250*2 0 216*2]);
imshow('images/macrocell.png');
handles.axes1 = hObject;
function edit1_Callback(hObject, eventdata, handles)
normalizeInput(hObject);
setAttachMenu(handles);
% --- Executes during object creation, after setting all properties.
function edit1_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
```

```
    set(hObject,'BackgroundColor','white');
end
femtoObject = hObject;
% --- Executes on button press in pushbutton4.
function pushbutton4_Callback(hObject, eventdata, handles)
)
drawMap(handles);
%deployFemtocells();
% --- Executes on button press in pushbutton8.
function pushbutton8_Callback(hObject, eventdata, handles)
if ~(strcmp(get(hObject, 'String'), 'Run Simulation'))
   drawMap(handles);
else
   drawColormap(handles);
end
function edit2_Callback(hObject, eventdata, handles)
normalizeInput(hObject);
% --- Executes during object creation, after setting all properties.
function edit2_CreateFcn(hObject, eventdata, handles)
if          ispc          &&          isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function edit3_Callback(hObject, eventdata, handles)
normalizeInput(hObject);
 % --- Executes during object creation, after setting all properties.
function edit3_CreateFcn(hObject, eventdata, handles)
if          ispc          &&          isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
% --- Executes on selection change in popupmenu4.
function popupmenu4_Callback(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function popupmenu4_CreateFcn(hObject, eventdata, handles)
```

```
.ifispc&&isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))

    set(hObject,'BackgroundColor','white');

end

% --- Executes on selection change in popupmenu6.

function popupmenu6_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.

function popupmenu6_CreateFcn(hObject, eventdata, handles)

if          ispc          &&          isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))

    set(hObject,'BackgroundColor','white');

end

function pushbutton4_CreateFcn(hObject, eventdata, handles)

function axes1_ButtonDownFcn(hObject, eventdata, handles)

function slider1_CreateFcn(hObject, eventdata, handles)

if                                    isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))

    set(hObject,'BackgroundColor',[.9 .9 .9]);

end

% --- Executes during object creation, after setting all properties.

function slider2_CreateFcn(hObject, eventdata, handles)

if                                    isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))

    set(hObject,'BackgroundColor',[.9 .9 .9]);

end

  % --- Executes on slider movement.

function slider1_Callback(hObject, eventdata, handles)

set(handles.text10,'String',int2str(uint16(get(hObject,'Value'))));

set(handles.text10,'Value',get(hObject,'Value'));

% --- Executes on slider movement.

function slider2_Callback(hObject, eventdata, handles)

set(handles.text11,'String',int2str(uint16(get(hObject,'Value'))));

set(handles.text11,'Value',get(hObject,'Value'));

 % --- Executes on slider movement.

function slider3_Callback(hObject, eventdata, handles)

set(handles.text14,'String',strcat(num2str(get(hObject,'Value'),    '%.1f'),
'm'));

set(handles.text14,'Value',get(hObject,'Value'));
```

```
% --- Executes during object creation, after setting all properties.
function slider3_CreateFcn(hObject, eventdata, handles)
if                                  isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor',[.9 .9 .9]);
end
  % --- Executes during object creation, after setting all properties.
function text10_CreateFcn(hObject, eventdata, handles)
function figure1_WindowButtonMotionFcn(hObject, eventdata, handles)
axis equal;
setCurrentCoordinates(handles);
function figure1_WindowButtonUpFcn(hObject, eventdata, handles)
axis equal;
setCurrentCoordinates(handles);
 % --- Executes on button press in radiobutton1.
function radiobutton1_Callback(hObject, eventdata, handles)
% --- Executes on button press in radiobutton2.
function radiobutton2_Callback(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function popupmenu7_CreateFcn(hObject, eventdata, handles)
if        ispc        &&        isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
 % --- Executes on selection change in popupmenu7.
function popupmenu7_Callback(hObject, eventdata, handles)
if strcmp(get(handles.pushbutton8, 'String'), 'Run Simulation')
   if (get(hObject, 'Value') == 1)
      set(handles.pushbutton8, 'Enable', 'off');
   else
      set(handles.pushbutton8, 'Enable', 'on');
   end
end
% --- Executes on button press in togglebutton4.
function togglebutton4_Callback(hObject, eventdata, handles)
% hObject    handle to togglebutton4 (see GCBO)
```

```
function pushbutton10_Callback(hObject, eventdata, handles)
credits_display();
 % --- Executes on button press in pushbutton11.
function pushbutton11_Callback(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function text21_CreateFcn(hObject, eventdata, handles)
defaultBackground = get(0,'defaultUicontrolBackgroundColor');
set(hObject,'BackgroundColor', defaultBackground);
 % --- Executes during object creation, after setting all properties.
function text20_CreateFcn(hObject, eventdata, handles)
defaultBackground = get(0,'defaultUicontrolBackgroundColor');
set(hObject,'BackgroundColor', defaultBackground);
  % --- Executes during object creation, after setting all properties.
function text25_CreateFcn(hObject, eventdata, handles)
defaultBackground = get(0,'defaultUicontrolBackgroundColor');
set(hObject,'BackgroundColor', defaultBackground);
```

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