KADIR HAS UNIVERSITY
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OPTIMAL RATE AND POWER ALLOCATION ALGORITHM IN TDD-OFDM BASED TWO-TIER FEMTOCELL NETWORKS

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“I, MHD TAHSSIN ALTABBAA, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

OPTIMAL RATE AND POWER ALLOCATION ALGORITHM IN TDD-OFDM BASED TWO-TIER FEMTOCELL NETWORKS

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Master of Science in Electronics Engineering

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People nowadays are witnessing the acceleration of development of electronics. The new technologies of electronic devices has made mobile phones smarter and more technologically advanced, where they support software platforms and applications that increased the demands on high data rates and gives the users the ability to play online games, video chat, upload-download data, and watch videos on social networks and other video-streaming websites. According to statistics of researches and telecommunication companies, the average usage area of a mobile data transfer users are generated from indoor places e.g. houses.

Mobile operators seeks out for providing high data rates to increase their capacity to suit the demands of indoor users for those who experience weak signal power; However, the current studies suggests a distance decreasing between the Mobile Station (MS) and Base Station (BS) for a lower distance of wireless communication. Femtocell technology, also called Home Base Station (HBS), provides a high data transfer rates and better coverage area for limited number of indoor users, where the conventional base station used by the telecommunication company that has a wide coverage correspondingly named Macro Base Station (MBS). In home base station technology, the femtocell users uses the same spectrum for uplink and downlink frequencies that the other mobile stations are using for communication with the MBS.

However, for such a communication system, it brings out a new area for research regarding interference management.

In this thesis, an adaptive power control algorithm based on the network's present parameters with two constraints performed at the femtocell users' uplink channels for interference mitigation in a Time Division Duplex-Orthogonal Frequency Division Multiplexing (TDD-OFDM) wireless communication fashion. The constraints aims to ensure the quality of service of communication of MBS's user and to preserve the data rate of femtocell users from collapsing. The first constraint is regarding the mitigation of the interference coming from the femtocell user to the macro mobile station; this constraint depends on the availability of the time slot that both femtocell and macrocell users are sharing subject to a certain frequency. The second constraint is regarding the limitation of the femtocell user's transmitting power based on the maximization of the weighted rate sum of the femtocell users subject to the power summation of each femtocell user on each subchannel.

Accordingly, we study the scenarios that considers both the cross-tier and co-tier interferences to mimic the realistic femtocell environment.

Keywords: Wireless Networks, Power Control, Femtocell, TDD-OFDM.

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List of Abbreviations and Symbols

1G	1st Generation
2G	2nd Generation
3G	3rd Generation
3GPP	3rd Generation Partnership Project
3GPP2	3rd Generation Partnership Project 2
4G	4th Generation
AAA	Authorization, Authentication and Accounting
AMPS	Advanced Mobile Phone System
AuC	Authentication Centre
AWGN	Additive White Gaussian Noise
BS	Base Station
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver Station
CA	Carrier Aggregation
CC	Carrier Components
CDMA	Code Division Multiple Access
CIBER	Cellular Intercarrier Billing Exchange Record
CN	Core Network
CoMP	Co-ordinated Multipoint Transmission
CS-MGW	Circuit Switched Media Gateway
DS	Doppler Shift
DSL	Digital Subscriber Line
EC	Echo Canceller
EDGE	Enhanced Data rates for GSM Evolution
EIR	Equipment Identity Register
eNodeB/eNB	E-UTRAN Node B
EP	Element Procedure
EPC	Evolved Packet Core
EPDCCH	Enhanced Physical Downlink Channel

EPS	Evolved Packet System
E-TACS	European-Total Access communication System
ETSI	European Telecommunications Standards Institute
E-UTRAN	Evolved UTRAN
FAP	Femtocell Access Point
FBS	Femtocell Base Station
FC	Femtocell
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FFL	Femto Forum Limited
FFT	Fast Fourier Transform
FFR	Fractional Frequency Reuse
FGW	Femtocell Gate Way
FMS	Femtocell Mobile Station
GGSN	Gateway GPRS Support Node
GMSC	Gateway MSC
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HeNB	Home evolved Node B
HeNBMS	HeNB Management System
HeNB-GW	HeNB Gateway
HBS	Home Base Station
HeNB PF	HeNB Policy Function
HeNB-GW	HeNB-Gateway
HLR	Home Location Register
HNB	Home Node B
HNBAP	HNB Application Part
HNS	HNB Subsystem
HNB-GW	HNB Gateway
HSCSD	High Speed Circuit Switched Data
HSDPA	High Rate Downlink Packet Access
HSUPA	High Rate Uplink Packet Access
HSPA	High Speed Packet Access

HSS	Home Subscriber Server
HSUPA	High Rate Uplink Packet Access
IEEE	Institute of Electrical and Electronics Engineers
IMEI	International Mobile Equipment Identity
IMSI	International Mobile Subscriber Identity
IMT	International Mobile Telecommunications
IP	Internet Protocol
ITU	International Telecommunication Union
IWF	Internetworking Function
LA	Location Area
LTDDF	Listening-Time Division Duplex Frame
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MBS	Macrocell Base Station
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
MMS	Macrocell Mobile Station
MS	Mobile Station
MSC	Mobile Switching Centre
MSISDN	Mobile Subscriber Integrated Services Digital Network Number
MSRN	Mobile Subscriber Roaming Number
NMT	Nordic Mobile Telephone
NSS	Network Switching Subsystem
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OMC	Operation and Management Centre
PDN-GW	Packet Data Network Gateway
PAPR	Peak to Average Power Ratio
PDP	Packet Data Protocol
PLMN	Public Land Mobile Network
PSK	Phase Shift Keying
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service

QPSK	Quadrature PSK
RF	Radio Frequency
RAB	Radio Access Bearer
RAN	Radio Access Network
RANA	Radio Access Network Relocation
RANAP	RAN Application Part
RNC	Radio Network Controller
RNS	Radio Network Subsystem
RRC	Radio Resource Control
RUA	RANAP User Adaptation
S1-AP	S1-Access Part
SCTP	Stream Control Transmission Protocol
SC-FDMA	Single Carrier Frequency Division Multiple Access
SGSN	Serving GPRS Support Node
SGW	Serving Gateway
SIM	Subscriber Identity Module
SINR	Signal to Interference plus Noise Ratio
SIR	Signal to Interference Ratio
SMS	Short Messaging Service
SNR	Signal to Noise Ratio
SS	Spread Spectrum
TAP	Transferred Account procedure
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TH-CDMA	Time Hopped CDMA
TDD-OFDM	Time Division Duplex-Orthogonal Frequency Division Multiplexing
TNL SCTP	Transfer Network Layer Stream Control Transmission Protocol
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
VoIP	Voice over IP
WCDM	Wideband Code Division Multiplexing

WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
R_c	MBS Coverage Area Radius
E	Channel Gain
P_k^m	Transmitting Power of FMS *k* on *m*
P_i^m	Power of Femtocell User i on *m*
P_k^{MAX}	Maximum Transmitting Power allowed
P_k^{*m}	Equilibrium Power Equation of FMS *k*
N_k^m	Noise Power of FMS *k* on *m*
Q_k^m	Interference at the Receiver of FMS *k* caused by MMS on *m*
M	Number of Subchannels
m	Subchannel
I_m	Interference Tolerance
f_m	Subchannel *m* Availability
h_{kk}^m	Channel Response between FMS *k* and its FBS on subchannel *m*
h_{ki}^m	Channel Response of FMS i at FMS *k* on subchannel *m*
h_k^m	Channel Response between FMS *k* and MMS on subchannel *m*
w_k, w_i	Weight
R_k	Rate of FMS *k*
λ_k	Shadow Price of FMS *k*'s Power
μ_m	Shadow Price of Subchannel *m*
α_1	Outdoor Path Loss Exponent
α_2	Indoor Path Loss Exponent

1. INTRODUCTION

In 1946, when Bell labs invented the very first mobile phone, the idea behind it was to serve the truck derivers' fleets where they drive across the country (USA), and in need for a mobile communication to call their base station in case of accidents. At that time, the primitive network could not handle a large volume of calls; a single transmitter on a central tower with a handful of channels was enough to provide a wireless communication for an entire metropolitan area, where at most three truck drivers could make calls at a certain time in a certain city.

Along the years, communication methods has been increasingly developed with respect to technology changing and needs; for example, smart phones became smaller and cheaper, and as a result of this evolution, the number of subscribers incredibly increased, and the existent systems couldn't handle the huge amount of subscribers.

However, mobile telecommunication companies and researchers had to find a newer generation based on a newer communication technique to enlarge the capacity of the system; otherwise, the system's quality of service will fall. The conventional cellular concept was introduced by AT&T Bell Laboratories, where they invented the known GSM (Global System for Mobile Communications) using the famous technology of Frequency Reuse (FR), and achieved the mobility issues regarding users' movement from a cell to another in case of an ongoing call (handover). Mobile operators designs their network to suit both coverage and capacity. Coverage enlargement not just offers a less location update mechanism and paging, but also a fewer capacity, which the latter leads to a low quality of service. On the other hand, if the operator uses Microcells and Picocells, this will reduce the coverage area, and gives a better capacity; but unfortunately, this solution has a high cost. For this reason, mobile operators' researchers and scientists are working on a short-ranged low powered cellular structure to expand the coverage, capacity, and data rate for a better quality of service; this category of cellular structure were given the name (five bar coverage) [8], but the name *femtocell*, which is also known as *home base stations* [3] is more common. The researchers are working on a numerous of mechanisms to advance the home base station structure and meets the development of Long Term Evolution (LTE) and Long Term Evolution-Advanced (LTE-A) technologies with respect to the famous communication techniques e.g. CDMA and OFDMA systems. Different aspects regarding the technical challenges for femtocell design are discussed through research papers, master and doctoral theses such as spectrum allocation, timing and synchronization, adaptation of femtocells on an existent network, quality of service requirements, interference managements, access methods, handoff and emergency services. In addition, recognized foundations like Femto Forum Limited (FFL), European Telecommunications Standards Institute (ETSI) and Third Generation Partnership Project (3GPP) are working on standardization of femtocells. Femto Base Station (FBS) design includes many ways for outer-communication; the latter can be connected to a backhaul with broadband connection such as; cable modem, Digital Subscriber Line (DSL) or with Radio Frequency channels [11]. As the demand on developing femtocell technology, there exists more than one communication topology for such a system. Researchers have been developing FBSs that suites the 3rd and the 4th generations of mobile communications; for instance, '3G Femtocells' which is also called Home Node Base-Station (HNB) that uses Wideband Code Division Multiple Access (W-CDMA) for uplink, downlink communication. '4G Femtocells' uses Orthogonal Frequency Division Multiple Access (OFDMA) and Single Carrier Frequency Division Multiple Access (SC-FDMA) technology for downlink and uplink communication, respectively; 4G Femtocells is also called Home evolved Node Base-Station (HeNB)

Due to the lack of spectrum, Femtocells and Macrocells have to share the same frequency band (spectrum) which puts this system in a serious case of study to suit and meet the mobile telephony network's environmental circumstances to the closest form of a free-interference network. The solution lies behind controlling the power of the femtocell mobile stations such that, each mobile station has to update its uplink power to meet the current wireless environment. Open loop and closed loop power control algorithms are a famous power control approaches that used by the topology of macrocell. In open-loop algorithm, the mobile station regulates its transmitting power inversely proportional to the received power, while in the closed-loop algorithm, the Base Station (BS) iteratively transmits the commands to the mobile user over the downlink channel indicating whether to increase or decrease the uplink power. Unfortunately, the femtocell technology does not fit with the standards of conventional network's methodology, which let researchers to look forward for alternative solutions for a newer interference mitigation technique. Writers of [3] worked on the methodologies of a mobile station access to a femtocell base station. These methodologies are briefly as follows: closed access, open access, and hybrid access. In closed access method, only authenticated subscribers are allowed to connect to the femtocell base station. Contrary to this, in open access model, all subscribers can use the femtocell base station, while the hybrid method is comprised of the previous two options with a higher priority given to the authenticated users. Authors of [1,2,6] proposed solutions for the *cross-tier interference*, and *co-tier interference*, for both uplink and downlink communications for Femtocells and Macrocells, where they presented the interference experienced from femtocell users to macrocell base station and macrocell users, and the interference among femtocells themselves. Authors of [1] proposed an interference management plan, which states that each Macrocell finds the interference price for a set of frequency spectrums that being used by its mobile stations and the femtocells in its neighborhood, which the femtocell users are harming these spectrums, and assigns a different frequency spectrums to its mobile stations. Assuming a Time Hopped CDMA (TH-CDMA) communication model, authors V. Chandrasekhar and J. G. Andrews in [2] proposed an uplink capacity analysis and interference avoidance strategy by assuming a sectorized antenna reception at both Macrocell, and Femtocell base stations, which diminishes the cross-tier interference and the density of femtocells becomes 7-times greater. H. Lee, D. Oh, Y. Lee in [6] proposed a Fractional Frequency Reuse (FFR) communication model to mitigate the co-tier interference where they used femtocell location information to alleviate the co-tier interference at the cell edge.

R. Juang, P. Ting, H. Lin, and D. Lin in [7] G. Ning, Q. Yang, K. Kwak, and L. Hanzo in [15] considered (FFR) in their femtocell interference case study for the cross-tier downlink interference mitigation for the cross-tier interference coming from femtocells to macrocell. The solution considers forming the femtocells in a cluster shaped group, and each cluster acts as a virtual cell with distributed antennas, resulting in alteration of the obstructive interference into a constructive signals.

Writers of [4] proposed an algorithm that ensures a Macro Mobile Station (MMS) could obtain its SINR target even with the presence of 100 femtocells in the area, by considering a utility function. The proposed utility function has a cost and profit functions to control the transmit power with a centralized and decentralized pricing schemes for Femtocell Mobile Stations (FMSs) in a CDMA system; that is to say all FMSs within a coverage area of a macrocell gets the same price calculated for each Mobile Station. In [26], the writers proposed an algorithm for LTE systems that solve the interference regarding Femto Base Station's downlink power based on the MMS's uplink power. The algorithm notices the nearby MMS, and adjust its downlink power to alleviate interference with MMS. Writers of [31] proposed a network layer-based solution, where a Listening-Time Division Duplex Frame (LTDDF) communication model proposed. The femtocells' uplink-downlink periods were altered to suit into MBS's downlink time only, and during the Macro station's uplink time, the FBS listens to the uplink signals of MMS(s), and adaptively adjusts its downlink powers, and reports its FMS(s) to do so. Authors of [5] used Stackelberg strategic game in an OFDMA-based Femtocell structure to study the joint utility function subject to the maximum tolerable interference power constraint at the MBS using a centralized pricing structure. The MBS (leader) determines the interference price to enable serving in adequate conditions, and then FMS(s) (followers) updates their powers with respect to this interference price. The study of [9] is a generalized work of [4] and [5] together; it investigates the effects of the number of active users and distance between MBS to FBSs square grid for randomly activated FBSs in a known region with adaptation of game theoretic power algorithm with respect to a given SINR thresholds for a single antenna systems.

In this thesis, we generalize the study in [10] and [20] for a better interference mitigating of femtocell networks. We reshape and enhance the formulas by including the terms that reflects the co-tier interference coming from other femtocell mobile stations for a better interference alleviation in an adaptive model that iteratively uses the current state of the network in a Time Division Duplex-Orthogonal Frequency Division Multiplexing (TDD-OFDM) network using Lagrange multiplier vectors.

The rest of the thesis is organized as follows; Chapter 2 includes an introduction to mobile communications and their evolution, network architectures and communication techniques. Chapter 3 includes an introduction to femtocell technology and its system models. Chapter 4 discuss the performance of the proposed algorithm for interference mitigation with simulations. Chapter 5 concludes the work and discuss the future work.

2. MOBILE COMMUNICATIONS

2.1. Introduction

Advanced wireless communication systems solved several difficulties over the past decades by providing a variety of communication utilities. However, mobile communications started as a primitive system (compared to the present systems) and enhanced by researchers up to the born of the existing technologies to satisfy the needs of users at a numerous application areas. Due to this variation, these technologies classified under many specifications, such as communication technique, service type, data rate, throughput, performance, and reliability. Nevertheless, since the cellular system is the most widespread wireless communication system among humanity, this category became the most intensively used among wireless communication systems, which led to a rises of subscribers' quantity, which in turn led to a higher bandwidth demands that takes a serious problematic research area. Due to the diversity of applications that technology tends to offer such as internet, that smart phones' platforms started to provide, such as e-mail, location services, social media applications, and real-time video conference, the needs for having a cellular-based internet access raised, and a variety of developed generations introduced for a proper internet service that enhances data rate. On the other hand, different aspects of advancements at many levels added to wireless communications, where the reason behind these advancements is to serve different purposes related to mobile communication systems, together with advanced communication technologies. The first mobile communication standard that been launched for commercial purposes was the 1st Generation (1G) standard, which was invented in the 1980's, where this generation used analog technology for communication. At that time, the mobile device was large, and the power components such as power amplifier, synthesizer, and antenna equipment were enormous. Advanced Mobile Phone System (AMPS), European-Total Access communication System (E-TACS), and Nordic Mobile Telephone (NMT) developed 1G. Unfortunately, these systems was not compatible with each other; in other words, if a user who uses an AMPS systems travelled to a country that uses E-TACS or NMT system, the mobile phone won't be able to access the visited network.

2.1.1. Location Management

Location management consists of location update and paging, where location update is the name of the procedure that mobile phone does when moves to another cell in an idle (no ongoing call) mode, and let the Mobile Switching Centre (MSC) knows about the movement to another cell. Paging is the name of the procedure that MSC makes when it has a delivery to a mobile station. There is a tradeoff between location update and paging; where both of them related to each other and a correlating mechanism has to link them for an ultimate employment. If the system use no paging mechanism, this means that mobile stations has to update their locations very roughly, and there will be an unwanted location updates on the system, where mobile stations will consume an unneeded power to achieve that, and floods the system with unneeded traffic, this category called *Never Update*. In addition, if mobile stations never updates its location, this means that the system has to flood its network with unneeded traffic to find the intended mobile station, this category called *Simultaneous Paging*.

There are several methods regarding updating the location of each mobile station, where these algorithms are based on many aspects such as time-based algorithm, where the mobile station updates its location at a specific time whether it is moving or not, where this category is called *static location update* . The disadvantage of static location update method is that when a mobile station moves repeatedly between the boundaries of two or more location areas, including a high location update rate with a low physical mobility, this called *Ping-Pong effect*. Other methods are more adaptive and less power consuming, such as *movement-based* method, where the mobile station reports the location update after a specific number of cell crossings.

Another location update method that is based on distance, where mobile station updates its location at a specific distance away from the last location update. Also, a fewer amount of location updates and paging can be done if the cell became larger; in this case, the users may move while staying attached to the same base station, but unfortunately this solution affects the system's capacity.[14][37]

2.1.2. Roaming

Since the methodology of mobile telephones is based on giving the subscribers the ability to use a portable telephone service, roaming strategies and roaming agreements had its way and made it easier for them to use their phone number outside their areas and their subscription country. There are several types of roaming; the most popular roaming is the international roaming; where this type is considered when mobile user travels outside the country, which means travelling to an area where the subscriber's International Mobile Subscriber Identity (IMSI) does not exist in the visited mobile operator's database.

National roaming is used when the user can uses another operator's network in the same subscription country, where the subscriber pays no more expenses. This kind of roaming is usually useful for the new operators who has a not-fully-built network, and makes a roaming agreement with another existing operator that has a better coverage area, where subscribers roams to the other network when needed. Mobile operators at large countries e.g. USA, Russia has a regional roaming agreements, where the country is divided into regions, and each operator has a coverage area for a specific region(s). Inter-MSC roaming occurs whenever the MS travels to an area that being served with another MSC, and roams to another MSC while being in the same country. The Inter-Standard roaming is the type when the user travels outside its subscription country but uses another mobile generation's network, that means another technology is used, e.g. CDMA, GSM. In this case, the two operators uses a data converter from Transferred Account procedure (TAP) to Cellular Intercarrier Billing Exchange Record (CIBER), and vice versa, that gives the operators the ability to interchange data regarding MS's location, and call logs for billing and security issues on a compatible environment.

2.1.3. Handover

A handover is a procedure that occurs when a mobile station with an ongoing call moves to another cell. Due to the limited number of frequencies in each cell, there are several strategies regarding the channel assigned to the mobile station at the entered cell, where these strategies works to provide a free channel, and prevents an ongoing call from being blocked. Channel assignment schemes can be classified into *fixed*, *dynamic*, and *flexible*, where the MSC administrates the frequency assigning-releasing at the both entered and left cells [29]. In fixed channel assignment strategy, a group of frequencies is kept for serving arriving mobile stations, where these frequencies are reused by another cell at a minimal distance called *cochannel reuse distance*, which equals to three cell units, in the seven-cell cluster model. In basic fixed assignment strategy, the entered cell provides the incoming mobile station with a new channel, if available; otherwise, the call will be blocked, while in *simple borrowing fixed assignment* strategy, if the entered cell has no available frequency, it borrows a channel from a neighboring cell, where MSC administrates the borrowing-locking procedures. Dynamic channel assignment strategy is where cells has no channels kept for themselves, where they requests a channel from the MSC, which the latter has a cost function regarding each channel, which shows the future blocking probability and reuse distance of the channel. Based on the information of channel occupancy distribution under the current traffic conditions and other network criteria such as radio channel measurements of mobile stations; MSC gives the decision regarding channels on a call-by-call basis, where this decision includes which channel to assign to which call attempt, by looking for the available channel that has the minimal cost. Flexible channel assignment strategies are a combination of fixed and dynamic techniques, where each cell has a set of permanent channels, and the MSC hold emergency channels and assigns them to the cells that its permanent channels are occupied and suffers from an inadequate traffic loads. [12]

2.2. GSM System

Developed electronics had found its way into mobile communication productions for both user equipment, and base station. GSM was invented to solve the issues of first generation's system such as, speech quality, system capacity, security (eavesdropping), and coverage, where this generation was supported by digital technology using circuit switching technology. Second-generation cellular networks utilizes the use of both Time Division Multiple Access (TDMA), and Frequency Division Multiple Access (FDMA) for communication that allows larger transmission rates, which makes the capacity three times greater compared to the first generation analog systems. Both uplink and downlink bandwidths are 25 MHZ, with the interval of 890-915 MHZ for the uplink, while the downlink frequency range is

935-960 MHZ, with a channel capacity of 200KHZ, and a 20 MHZ space to separate the uplink-downlink frequency bands, where the system provides 124 channel per frequency band. The time unit in GSM called *burst period* and equals to 15/26 ms, and one TDMA frame consists of eight burst periods which is the unit that forms the logical channels. Second generation system became very popular for its features such as international roaming, Short Messaging Service (SMS), and its excellent speech quality. The data rate of the 2^{nd} generation was not enough; the data rate at its peak reaches 64 Kbps that let the researchers to think of enhancements to be added to the existing system.

In addition to circuit switching, packet switching introduced in 2.5G systems that General Packet Radio Service (GPRS) offers a data rate of 140 Kbps that offers Gaussian Minimum Shift Keying (GMSK) for both links. Unfortunately, these enhancements were not enough, the thing that let a newer type of second generation to be born. In 2003, 2.75G or Enhanced Data rates for GSM Evolution (EDGE) is considered to be the final type of second generation systems, where only a compatible transceiver should be installed at the base station side, with no other hardware or software changes needed to be made at the core network of GSM. With GMSK, and a higher order of 8PSK, the EDGE can produce a better data rate than 2.5G that reaches 384 Kbps. [28] Unfortunately, the capacity provided by the previous types of GSM was not enough for nowadays' demands, and a newer generations had to be born.

2.2.1. GSM Network Architecture

GSM network architecture includes three main sub-systems, Base Station Subsystem (BSS), Network Switching Subsystem (NSS), and Operation and Management Centre (OMC). In BSS sub-system, each BSS consists of several Base Station Controllers (BSCs), that the latter controls the channel allocation at the Base Transceiver Stations (BTSs), manages the handovers within BSS area, and informs the Visitor Location Register (VLR) to update the subscriber's information. BTS is also called Base Station (BS), where each BS covers a geographical area through a certain amount of frequencies, where the power used for transmission determines the area of coverage. Each BTS consists of one or more radio transmitter and receiver, radio transmission equipment, antennas, and amplifiers, where BS is responsible for decision making regarding handovers, and radio power levels. NSS contains mobile switching center MSC and Gateway-MSC (GMSC), where they links the mobile stations with each other within the network, and links the network with other networks and Public Switched Telephone Network (PSTN), respectively. MSC unit switches the processes requested by the subscriber through BSCs such as incoming and outgoing calls to subscribers, originates inter-MSC handovers, call setup, call termination, and call forwarding, where each MSC is responsible for a several BSCs.

Home Location Register (HLR) and Virtual Location Register (VLR) are also an essential parts of NSS, where HLR is a central database that contains data regarding each subscriber that is a registered member with the mobile operator network. HLR assists the operator's operations to ensure a better performance of the network. It stores the essential information regarding subscribers such as, Location Area (LA), roaming references, and IMSI number, which the latter is the primary key to each subscriber's record in HLR, where IMSI is the number of the subscriber at the mobile telephony company that is different from the number that the subscribers use. VLR is also a database that contains data regarding each subscriber that is a registered member at the mobile operator's core network or not. In the case of international roaming, when a MS roams, the VLR at the visited operator will obtain a copied version of MS's HLR record from the home operator's database. A virtual version of Mobile Subscriber Integrated Services Digital Network Number (MSISDN) used to make this MS as a virtual member at the visited operator's database called Mobile Subscriber Roaming Number (MSRN), which the latter is hidden from the subscriber's side and used by the visited operator only. The logic behind two data registers is that the MS cannot be a member at more than one VLR, so the latter contributes in the paging process by finding the MS needed and assists MSC in connecting the parties together by having MS's updated location. Moreover, Equipment Identity Registry (EIR), and Authentication Center (AuC) are also a databases, where the AuC is located at HLR which holds a copy of the secret key stored in each subscriber's Subscriber Identity Module (SIM) card, that is responsible for authentication and encryption over radio channels. The EIR is a database that consists of a three main databases that in general holds a list of all valid mobile stations within the network; the first list contains the white lists that all list members are known, black and grey lists contains stolen and uncertain mobile stations, respectively. EIR can identify each mobile station through its International Mobile

Equipment Identity (IMEI). EC is the Echo Canceller that reduces the annoying effect caused by mobile network when it is connected to PSTN, where XC corresponds to the transcoder.

As the network consists of a numerous number of parts connected to each other, a connecting mechanism had to be found so the parts can communicate properly with each other and exchange the data that the result shows the ultimate use of the system. This is done by using interfaces such as Internetworking Function (IWF), where IWF is the interface between the MSC and other networks such as ISDN and PSTN. Operation and management centre is responsible for controlling and maintaining MSCs, BSCs, and BTSs, it is also in charge of an entire Public Land Mobile Network (PLMN) or some parts of it. In addition, OMC is the management system that assists the network operator in maintaining the GSM network, where hardware redundancy and intelligent error detection techniques helps prevent network downtime. [30]

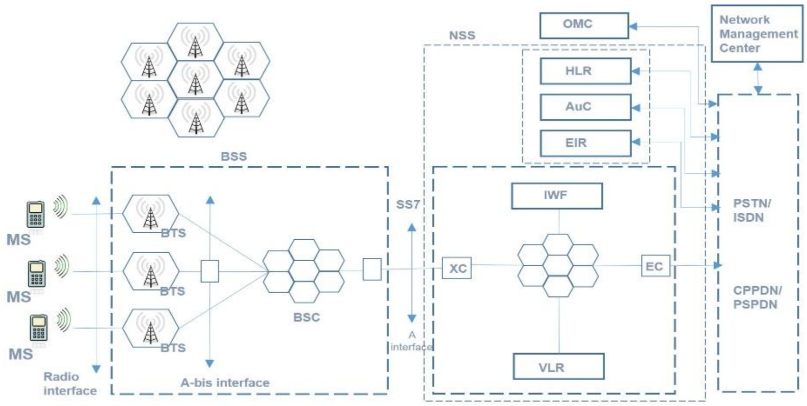

Figure 2.1 GSM Network Architecture [41, Fig2.1 (a)]

2.3. UMTS System

The increased demands on a better technology that can be able to serve a larger amount of subscribers with a better voice quality and a faster internet access; a newer technology born to satisfy these needs. UMTS systems that based on CDMA technology can offer six to eight times the capacity of analogy technologies (AMPS), and up to four times the capacity of digitalized technologies that uses TDMA. The speech quality offered by CDMA is superior compared with any other digital cellular system, particularly in difficult radio frequency environments such as mountainous regions.

UMTS is the 3rd generation system of mobile broadband system, where two different working teams 3GPP and 3GPP2 performed studies related to developing a Universal Mobile Telecommunication System (UMTS). However, due to a conflict between the groups, two different standards was produced; the Wideband-CDMA (W-CDMA) invented by 3GPP, and CDMA2000 developed by 3GPP2, where both standards supports multimedia services, conventional and turbo channel coding, and a power control on both links. Third generation of mobile broadband communication got many different adaptations at different countries, where Japan and Europe uses W-CDMA type, while in Korea and North America, CDMA2000 system is adapted.

2.3.1. WCDMA

Since the two standards of third generation of mobile communication uses CDMA, that the latter uses Spread Spectrum (SS) technology. Spread spectrum is a signal structured communication technique that each signal is modulated with a chipping code sequence that each code of this set is orthogonal to other codes, and the generated waveforms are transmitted on a bandwidth that is wider than the minimum bandwidth required where several mobile stations shares the same time and frequency. Due to the nature of spread spectrum, it offers secure communication, increases the resistance to natural interference, noise, jamming, and prevent detection.

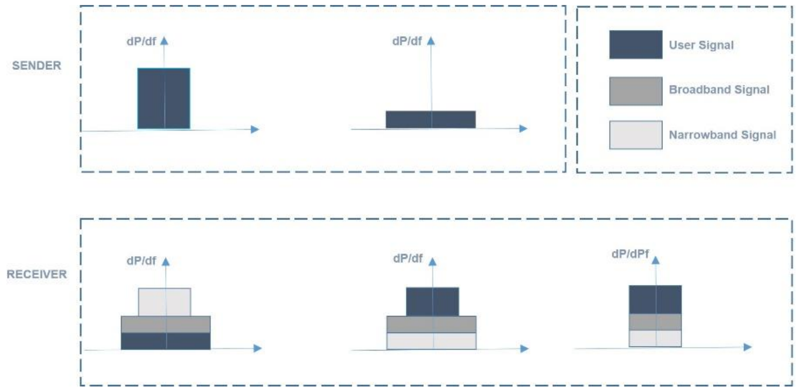

Fig.2.2 Spread Spectrum, Spreading and Despreading [30, Figure 2.32]

The initial technical sheet of W-CDMA shows that it has a 5 MHz bandwidth, with 4-256 channelization codes, and a chip rate of 3.84 Mcps, with a frame length of 10 ms for physical layer, and 20, 40, 80 ms for transport layer. In addition, W-CDMA uses QPSK modulation for both links, with FDD and TDD modes of operation with a unique scrambling codes assigned by sector for mobile source identification code, and a peak data rate of 2 Mbps, where 3GPP keeps adding many improvements in different releases at various layers.[28]

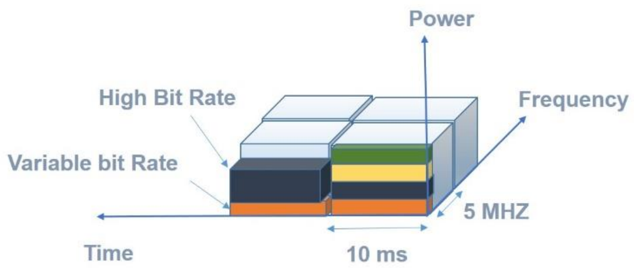

Fig.2.3 Bandwidth Allocation of WCDMA

In 3GPP release 5 and 6, High Speed Packet Access (HSPA) was introduced for both links, where release 7 has doubled the capacity of release 6 with the emphasis on the capacity of VOIP service. In release 6, High Rate Downlink Packet Access (HSDPA) was introduced for downlink communication, where it provides a peak bit rate of 14.4 Mbps, with a spectral efficiency of 0.75 b/s/Hz, and a throughput for edge cell user of 0.006 b/s/Hz. The same release also introduces the High Rate Uplink Packet Access (HSUPA), where the peak bit rate is 5.7 Mbps, and the spectral efficiency is 0.26 b/s/Hz, and the throughput for edge cell user still 0.006 b/s/Hz. With the added advancements on releases; release 7 uses High Speed Packet Access Plus (HSPA+) that its peak rate can reach 28.8 Mbps for downlink using MIMO antenna solution, and 11.5 Mbps for uplink with higher order modulation.

2.3.2. UMTS Network Architecture

Due to the variation of technologies and modulation techniques used at different generations of mobile communication, the network architecture of UMTS composed of several entities that some are in common with those used in second-generation while others are different. UMTS network consists of two main objects, the Core Network (CN), and the UMTS Radio Network Subsystem (RNS). RNS consists of a multiple Radio Network Controllers (RNCs) that the latter controls several NodeBs, which serves the users with an air interfaces access method using WCDMA technology. Where the term NodeB in UMTS refers to the BTS in GSM, where it acts as a transceiver, and it is responsible for modulation and demodulation, physical channel coding, and power control for interference mitigation. RNC is responsible for the radio resource control, admission control, channel allocation, power control settings, handover control, ciphering, and open loop power control, which is similar to BSC in GSM.

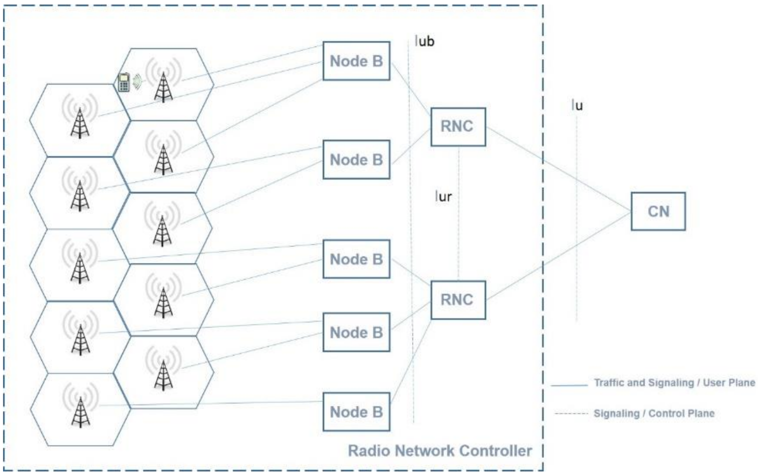

Figure 2.4 UMTS Network Architecture

The core network part provides switching, routing for users' traffic; it also contains the needed databases and network management components to achieve the process of data storage and traffic control using a new parts and separation method for a better outcome. Core Network includes MSC, GMSC, HLR, VLR, AuC, and EIR, where they have the same functionality that GSM has. In addition, UMTS core network includes GRPS Register (GR), Serving GPRS Support Node (SGSN), and Gateway-GPRS Support Node (GGSN). [30]

GGSN establishes a mobility management context that contains the mobility information, where SGSN establishes a Packet Data Protocol (PDP) context for routing purposes inside the GPRS public land mobile network. SGSN and GGSN are connected via Gn interface and they have an IP routing functionality; when SGSN and GGSN are in different PLMNs, they are connected via Gp interface, where this interface provides the Gn functionality interface, and a security functionality for an inter-PLMN communication. [40] GR is a part of HLR, and its functionality is storing all GPRS-relevant data.

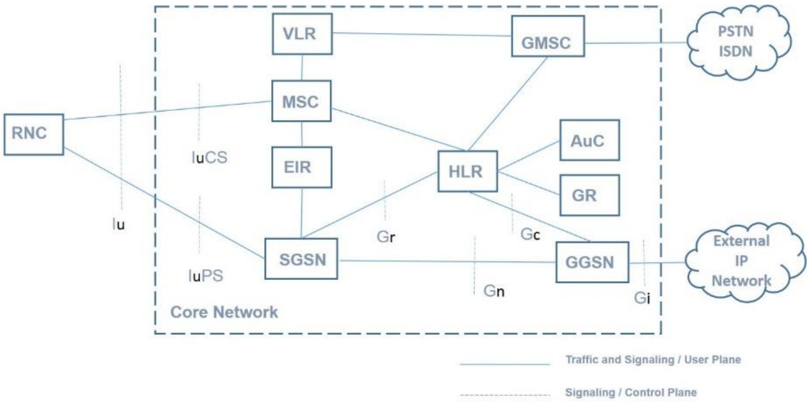

Figure 2.5 Components of UMTS Network

Figure 2.4 shows UTRAN's main interfaces that are in charge of supporting the system with the needed protocols. The first interface is Uu that relies between the mobile station and the NodeB for both uplink-downlink communication. The Iub interface carriers users' data, and control information; this interface relies between the NodeB part and the RNC part, where Iur interface is the interface among the RNC's that handles the inter-MSC handover, and Iu is the interface between the RNC, and the core network.

2.4. LTE and LTE-A Systems

The growing demands on high data rates and quality of service for mobile broadband services has been forcing researchers to find newer solutions that the latest electronics technology is able to provide. Long Term Evolution (LTE) system is considered as the 4th generation of mobile broadband communication, with a different technology aspects and features that uses a different network architecture with different radio interfaces along with the core network that offers the subscribers to have a higher potential data rate for several data applications with a better Quality of Service (QoS).

LTE was approved in 2008, within 3GPP release 8; that the latter shows a 20 MHZ bandwidth with a peak data rate of 300 Mbps and 75 Mbps for the downlink and uplink, respectively. In 2009, the European commission announced the total amount that will be invested into researching the deployment of LTE and LTE-Advanced (LTE-A) is 18 million euros. 3Gpp has released a newer release called release 9, that has a different aspects of enhancements to be added to LTE system such as multimedia broadcast services and location-based services. However, release 9 meets the requirements engaged by IMT (International Mobile Telecommunication) that states this advanced version of mobile communication as the fourth mobile communication generation. In this release, the peak data rate is 1 Gbps with an operating bandwidth of 100 MHZ for the downlink. The overall capacity, network management, quality of service management are the attributes that makes LTE-A gives its best performance compared to LTE systems. More enhanced features that provides a better data rates for a best user experience are Multiple Input Multiple Output (MIMO), Carrier Aggregation (CA), Co-ordinated Multipoint Transmission (CoMP), Enhanced Physical Downlink Channel (EPDCCH) that operates on a new carrier type, where it improves the spatial reuse of channel resources, were added to 3GPP releases 11 and 12.

2.4.1. Coordinated Multipoint

3GPP has completed a study on coordinated multipoint transmission and reception techniques to facilitate cooperative communications across multiple transmission and reception points that enables User Equipment (UEs) to have a better throughput for the LTE-A system. [32]

Coordinated multipoint transmission and reception technique is deployed at the macrocell side, where base stations jointly serve one or more user equipment that utilizes the use of multiple transmitting and receiving antennas for more efficient management of co-channel interference that increases received signal quality, data rate and decrease the received spatial interference. That cell-edge users suffers from severe interference, where CoMP technique mitigates the co-channel interference and increases the cell-edge user throughput, where the mobile station is connected to a single base station at a given time, with the luxury of having a multi-downlink from the adjacent base station(s), and thus increasing its data rate. In CoMP, base station measures the uplink signal of a user equipment and use it as a reference to estimate the downlink channel condition for a multiple antennas communication. However, each user equipment is passively involved within the antenna selection, where those selected antennas appears transparent to the user equipment. Then the user equipment measures and returns the downlink channels status from all visible antennas. Based on user equipment's uplink information and antennas downlink information, a central baseband-processing unit chooses, coordinates, and configures multiple antennas with suitable transmission parameters.

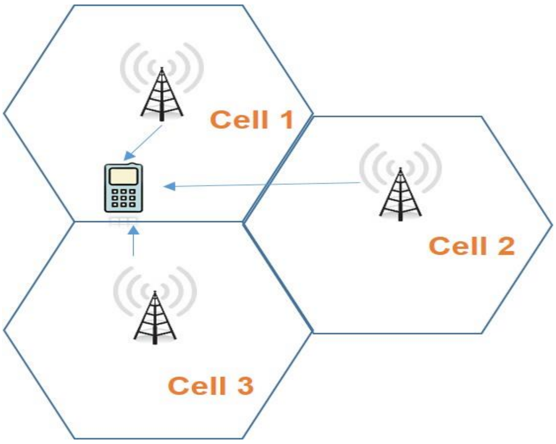

Figure 2.6 Downlink CoMP Transmission

2.4.2. Carrier Aggregation

Carrier aggregation is one of LTE-A main features that gives this system the ability to reach 1 Gbps and 500 Mbps data rate for both downlink and uplink, respectively. 3GPP release 10 includes the deployment scenarios of carrier aggregation that the latter enables the mobile broadband operators to utilize their available spectrum resources to increase the data rates in LTE-A systems. Carrier aggregation supports very-high-data-rate transmissions and achieve up to 1 Gbps peak rate at downlink transmission for static and pedestrian mobile users, and 100 Mbps peak rate for mobile environment over wide frequency bands. Carrier aggregation method to increase data rate is by aggregating LTE components that called Carrier Components (CC) into continuous and non-continuous carrier(s). The component carrier can be consisted of 1.4, 3, 5, 10, or 15 or 20 MHz and five component carriers is the maximum number of aggregated carriers. Continuous and non-continuous carrier aggregation techniques are used when multiple available component carriers are adjacent to each other with a band that is greater than 20 MHz, and when multiple available component carriers are separated along the frequency band (different frequency band), respectively. Non-continuous carrier aggregation helps in achieving higher throughput and it improves carriers' stability that has a different propagation environments. [42]

However, both carrier aggregation techniques supports LTE-A with many features such as spectrum efficiency, deployment flexibility, and backward compatibility that helps mobile broadband operators to upgrade their systems with a smooth system migration and maximal reuse of LTE releases in 8 and 9. [38, 39]

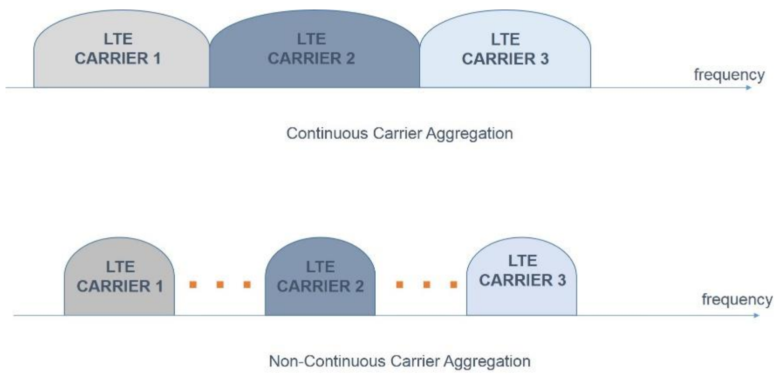

Figure 2.7 Carrier Aggregation Scenarios

2.4.3. Frequency Division Multiplexing

Frequency Division Multiplexing (FDM) is a communication method, where the available bandwidth is divided into a series of sub-bands, each of is called a carrier that carries voice or data signals. Frequency division method family has many members that are used for different communication techniques. Frequency Division Multiple Access (FDMA) is used in GSM, where it coordinates the accessing method among multiple users. Orthogonal Frequency Division Multiplexing (OFDM) is a digital multicarrier modulation method that is used in wireless communication systems. OFDM utilize the use of a large number of closely spaced orthogonal subcarriers that are transmitted in parallel, where each subcarrier is modulated with a conventional modulation scheme such as Quadrature Amplitude Modulation (QAM), and then the combination of subcarriers enables the data rates to be similar to the conventional single carrier modulation. OFDM has been used for a long time, but not for mobile communication; this due to the nature of OFDM that requires a high power processing to perform many Fast Fourier Transform (FFT) operations. Orthogonal Frequency Division Multiple Access (OFDMA) method offers a multiple access for users by dividing the available spectrum into a several channels, where the mentioned FDMA's carriers are not orthogonal to each other. Coded OFDM (COFDM) is one of the members of OFDM family that refers to forward error correction at the phase of transmission. Since the nature of OFDM is featured with its spectral efficiency and robustness to multipath fading, and its ability to provide a high data rate, the technology was recommended to be used for LTE systems in downlink communication.

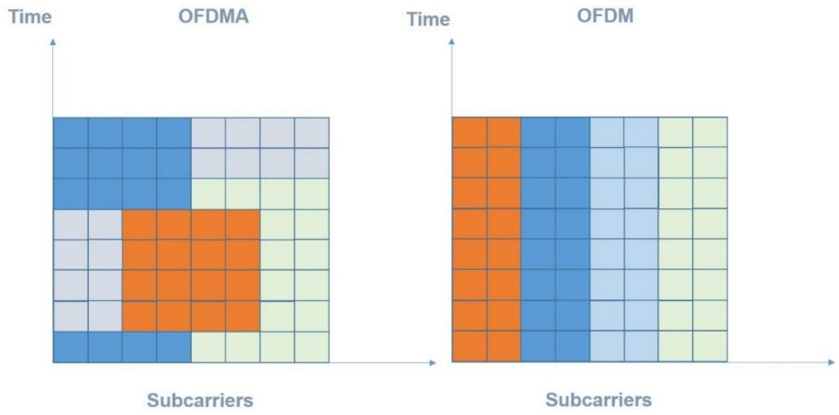

Figure 2.8 OFDM vs OFDMA Subcarrier Allocation

In figure 2.7, shows the users' allocation on channels, where this technique separates the channels assigned among the users using TDMA. OFDMA transmits information on M orthogonal subcarriers, each operating bit rate of 1/M fold bit rate of the original signal, where this rate decrease helps the alleviation of multipath effect of the channel and reduces the equalizer complexity at the receiver side. In addition, OFDMA suffers from Doppler Shift (DF) that creates interference between carriers; moreover, the nature of OFDM requires a high Peak to Average Power Ratio (PAPR), that requires high transmission powers, and by that, it wastes mobile stations' powers. A newer technology invented to protect this loss, where Single Carrier-FDMA (SC-FDMA) technology proposed to be used at the uplink part in LTE, where SC-FDMA spreads the energy of one subcarrier over a range of all subcarriers. [27]

2.4.4. LTE Network Architecture

In new proposed mobile broadband systems, the network architecture contains new features that are different from the previous systems' architecture. In LTE's network architecture, the name eNodeB corresponds to the base station that is connected directly to mobile stations, and controls the radio related functionalities such as modulation/demodulation, channel coding/decoding, mobility management, ciphering/deciphering, data delivering, radio signal level measurements control, and resource control that consists of allocation and modification. eNodeB is connected to the Evolved Packet Control (EPC) via S1 interfaces that connects eNodeBs properly with the Serving Gateway (SGW) at the core network. X2 is the interface that connects the eNodeBs together that works in a meshed way. The reason behind having X2 interface is to minimize packet loss due to a user mobility among cells; as the UE crosses through a cell, an unacknowledged packets which are stored at the left-eNodeB queues can be forwarded to the entering-eNodeB through X2.

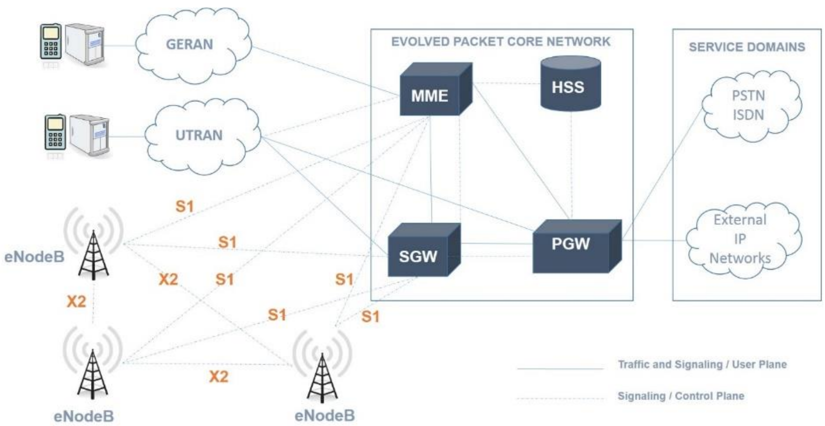

Figure 2.9 LTE Network Architecture

EPC is composed of several functional entities, for controlling communication along the network, the entities are Serving Gateway (SGW), Mobility Management Entity (MME), Packet Data Network Gateway (PDN-GW), and Home Subscriber Server (HSS). SGW is used at the EPC part, where it acts as the first interface at the EPS, receives and passes the UEs’ ingoing and outgoing traffic through the network. In addition, it is in charge of UEs mobility when a mobile station is handing over to another eNodeB. MME is the key control node for LTE access network, it is responsible for choosing UE’s SGW at both initial attach and at handoff process. Moreover, location management including location update and paging, activation/deactivation, authentication, security, roaming are the tasks of MME.

Similarly to SGW, Packet Data Network Gateway acts as the end point of the EPC towards packet data network such as internet; it provides users with IP addresses, policy enforcement for resource allocation and usage and packet filtering. In addition, PDN-GW plays an important role in system compatibility; it acts as an anchor for mobility between 3GPP and 3GPP2 technologies.

Home Subscriber Server is the HLR, and AuC of the 2G, 3G networks. HSS keeps information regarding user subscription, determines user ID, user privileges, and tracks users' activities such as visited networks, Authorization, Authentication, and Accounting (AAA). MME and HSS are connected via interface called S6a that HSS enables the information provided by the HSS helps the management system finding the intended user in paging process. [17]

3. Home Base Stations: Femtocells/ Five Bar Coverage

This chapter addresses femtocell technology, evolution, and its network architecture in both UMTS and LTE technologies. The second part discuss a system model for interference mitigation method based on an adaptive power control algorithm designed for femtocell network that concerns about femtocell base stations' data rate, and macrocell mobile station's communication.

3.1. Femtocell Technology

Through the past years, the different demands has forced researchers to find a better communication methods; e.g. 3G was developed to provide high data rates, but due to the variant applications that increased the demands on a higher data rates, made 3G not sufficient for users; the reason that made research centers for having 4G. Moreover, indoor users suffers from having a low signal strength; the problem could be solved by mobile broadband operators by deploying more base stations to decrease the distance between the users and their attached base stations to guarantee a better data rate, capacity, and a battery power-saving for indoor users without the need of modification of uses' handset devices. Unfortunately, this approach is infeasible and too expensive, the reason that made the researchers to think of a newer method to solve indoor users' issue.

Home Base Stations or *Femtocells*, are a short ranged and low powered base stations, that uses a mature mobile technology, and operates in a licensed spectrum. Femtocells offers its users coverage and capacity and communication with the core network over an internet backhaul, with a low price. A full management by the mobile broadband operator that users can self-organize and manage is supported by femtocell. Femtocell base station offers indoor users an enough coverage to use in their indoor environment with a reasonable price, where they communicate with the network operator over DSL connection, Radio Frequency (RF) backhaul or cable modem [5].

Operators seek for a better coverage and capacity, when an area is suffering from a leak of resources, generally, the operators installs a base station to that area, and re-plan the network; in the case of using femtocell technology, the operators has no more to do that.

Deploying a femtocell guarantees indoor users to have a better data rate with a cheap price; also it reduces the burden of using the resources of other mobile users that are connected to the operator’s base stations (that in the deployment of femtocell are called Macrocell), which gives the macrocell users a better quality of service. Home base stations has the plug-and-play property, which means that they do not need any configuration at the installation part. UMTS femtocells are called *Home Node B* (HNB) that was published by 3GPP at release 8 where it use WCDMA technology for communication, while the LTE femtocells that was published in 3GPP release 9 are called *Home evolved NodeB* (HeNB) which uses OFDMA and SC-FDMA techniques for communication as for downlink and uplink, respectively.

3.2. HNB and HeNB Network Architecture

Since the technology of femtocell is developed to be used by customers randomly, and the number of activated HNBs is numerous, a scalable network architecture has to be found to serve them properly. Home Node Base-station (HNB) is the name of femtocell that is used in UMTS, where Home evolved Node Base-station (HeNB) is the unit used in LTE systems. The femtocell has changed the network architecture of both UMTS and LTE systems; conventional systems cannot operate HNB or HeNB, the thing that let the network architecture and integration of both mentioned technologies has to be modified.

The Evolved Packet Core (EPC) part includes many Mobility Management Entities (MMEs), Packet Data Network Gateway (PDN-GW), and a Home Subscriber Server (HSS). MME is the core of the EPC; where it is connected to both enodeBs and HeNB-GWs, and it is responsible for signaling of UE, managing the UE’s connection, authentication, and security. With the help of Serving Gateway (S-GW) sub-entity that included at the MME part, S-GW provides UEs with roaming, paging, and handover services. HSS is a database that has records for each subscriber; the concept behind HSS is not new; it is used within the name home location registry, that HSS is defined as a database where subscribers’ profiles are stored and updated. In addition, HSS acts as an authentication center that facilitates the generation of security information from user's identity keys.

Evolved-UMTS Terrestrial Radio Access Network (E-UTRAN) of LTE system consists of eNodeB (eNB) that corresponds to the conventional base station, and femtocells. Femtocells involves UE, HeNB, and HeNB-GW. HeNBs supports its users with the same privileges that enodeBs does, where the procedure taken by MME at the EPC part with the enodeB is the same as for the HeNB. However, the new entity that now involved at the femtocell part called HeNB-Gateway (HeNB-GW) that acts as a concentrator. The role of HeNB-GW is to make the HeNB appearance as an eNB to the MME side that exists at the EPC part, where it also provides the appearance of MME to the HeNB. HeNB Policy Function (HeNB PF) is an embedded entity that concerns about user type, access mode of HeNB's current load, distribution of signaling and data, supports the registration of HeNB and UE, makes decisions according to HeNB's state regarding whether the admission quest could be accepted or not. [43, 46]

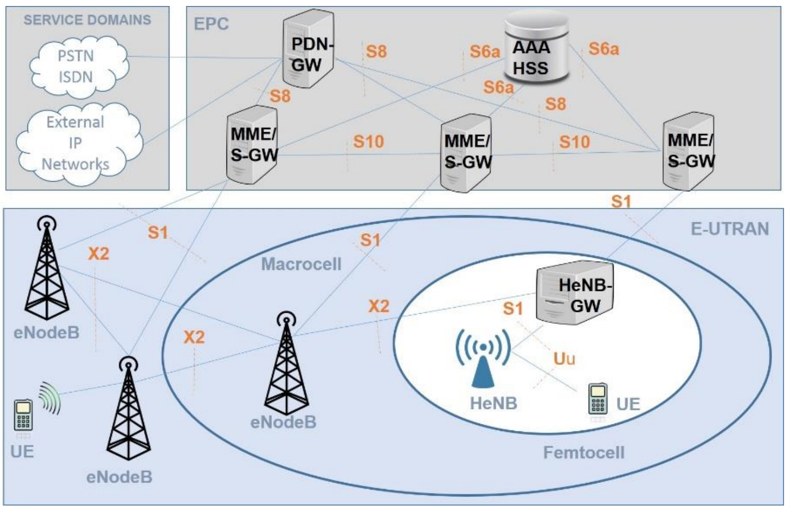

Figure 3.1 HeNB Network Architecture

UE communicates within the connected HeNB by radio frequency through Uu interface that uses SC-FDMA and OFDMA for uplink and downlink, respectively. HeNB communicates with HeNB-GW through S1 interface, and HeNB-GW uses the same interface to communicate with the MME/S-GW at the EPC part. In LTE systems, the S1-Access Part (S1-AP) interface is designed to control message exchange procedure between eNB and MME, where it consists of a set of elements such as S1 setup, Paging, Error indication, Trace. However, for HeNB, the interface chosen for HeNBs uses S1 interface and S1-AP protocol, which are the same used at the eNB part, but this element has modifications on one of its sub elements that differs from the ones used at the eNB; this element is Element Procedure (EP).

EP represents the interaction function between eNB/HeNB and MME for initiating the communication messages and reply messages, where two types of EP (type1) and (type 2) exists; these types represents a reply message with a response of success of failure, and no response message, respectively. When the HeNB is turned on, the HeNB configure itself using HeNB Management System (HeNBMS) using TR-069 protocol. A setup procedure is also done at the point that uses Transfer Network Layer Stream Control Transmission Protocol (TNL SCTP) association within the HeNB-GW or with the MME, whether the HeNB-GW topology is not used, then the HeNB is considered as registered at the MME that resides in the EPC part. The purpose of this registration is important; it informs the availability of the HeNB and enables MME to support the node with a connection within the core network [38]. UMTS femtocell base station is called HNB; where 3GPP has defined a special Iuh interface and an application protocol Home Node Base-station Application Part (HNBAP) that the latter consists of a set of procedures such as HNB registration/ deregistration procedure. 3GPP has defined a special Iuh protocol for HNBs, where the main protocols are RANAP, SCTP, HNBAP, and RUA. RANAP protocol provides signaling services between HNB and the core network that fulfills the Radio Access Network Relocation (RANA) and Radio Access Bearer (RAB), management, paging, and transport between mobile station and the core network. HNBAP conducts HNB-GW discovery, HNB and UE registration, where SCTP represents the transport protocol operating on top of a connectionless packet network. RANAP User Adaptation (RUA) transfer RANAP messages between HNB and HNB-GW through five procedures. The first procedure is called *connect*, where this procedure is responsible for carrying the RANAP user equipment message from HNB to HNB-GW. The second procedure is called *direct transfer* that lets the RANAP flows of messages between nodes. The third procedure is called *disconnect*, where this procedure terminates the connection between nodes. The fourth procedure is called *connectionless*, where this procedure is responsible for transporting a connectionless RANAP messages between nodes. The final procedure is called *error indication*, where it reports detected errors in an incoming messages. Second, third, fourth, and fifth procedures are all initiated by the HNB or HNB-GW.

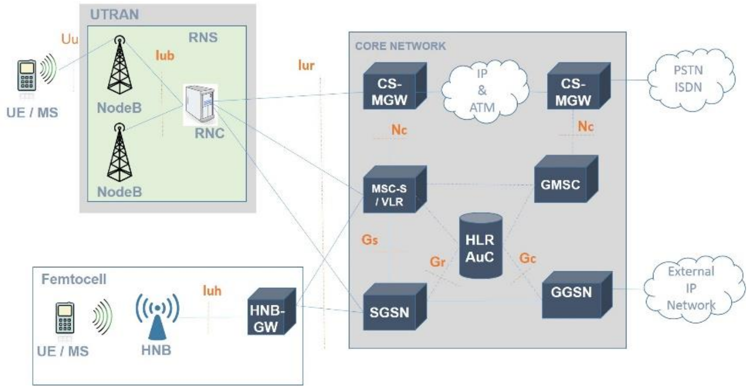

Figure 3.2 HNB Network Architecture [9, Figure 3.1]

In UMTS femtocell network architecture, the term Femtocell Access Point (FAP) refers to HNB that also provides a gateway within the name FGW that refers to HNB-GW that provides the communication for the femtocell to the Radio Network Controller (RNC). However, Home NodeB Subsystem (HNS) is the entity that includes the HNB, and HNB-GW that integrates the functionality of NodeB and RNC by connecting the UTRAN network with the backhaul network. Handover procedure is important to be studied for femtocell; in femtocell handover, the handover goes through two phases to make it feasible for the UE and the core network. The first phase is called the handover phase that consists of information gathering, and handover decision, while the handover execution phase is the second phase. During the information gathering phase, the HNB collects the needed information regarding the handover candidates and authentications are also required for security related purposes, where handover decision phase gives the handover candidate decision determination. However, when a mobile station that uses a HNB decides to handover to macro station (NodeB), the difference relies in Radio Resource Control (RRC), that represents the difference in the base station that used to serve the mobile station, with the other base station that is limited with its radio resources, due to its availability to further amount of users.

3.3. Power Control in Femtocell Networks

Power control is the name of an approach used in wireless communications that lets stations adjusts their transmitting powers according to the network current state that power control techniques alleviates the interference among mobile stations that harms other mobile stations, where these approaches insures a better wireless communication environment. In addition to interference alleviation, power control assist the network from having dead-zones, where the mobile station user is located at the cell edge of the macro base station that has to transmit its uplink signal with a higher power level that leads to an interference with the mobile users at the adjacent cells. In femtocell power control, the interference experienced by the network is divided into two main tiers that depends on the type of the network that its signal is interfering with the other network. The interference experienced at the Macro Cell (MC) side coming from Femto Cell (FC) side, and vice versa, is called cross tier interference, while the interference experienced at the FC side coming from another FC is called co-tier interference.

In adaptive power control algorithms, many types of limitations can be deployed to alleviate interference; however, macro stations adjust the uplink transmitted signal powers of their users with respect to SINR parameters by sending them the updated threshold to decrease-or-increase their transmitting power. In femtocell networks, the macro base station calculates the SINR and inform the femtocells to obey the new parameters for an interference-free environment with the attention of keeping femto mobile users within an acceptable data rate.

3.3.1. System Model

The system model is illustrated in figure (3.3). The MBS provides a wireless communication within a coverage radius R_c. where K represents the number of FCs available in that area, where each femtocell has one active user. Using the projection of Time Division Duplexing (TDD) technique on OFDM technology, the designed model divides the whole frequency band into M different sub-channels for uplink transmission whose bandwidths are equal. Both users of femtocell and macrocell can share the M subchannels, except that whenever the interference received at the macro mobile user side coming from femtocell users exceeds a certain threshold, where the adaptive power control algorithm *allows* or *prohibits* femto mobile stations from using a specific subchannel(s).

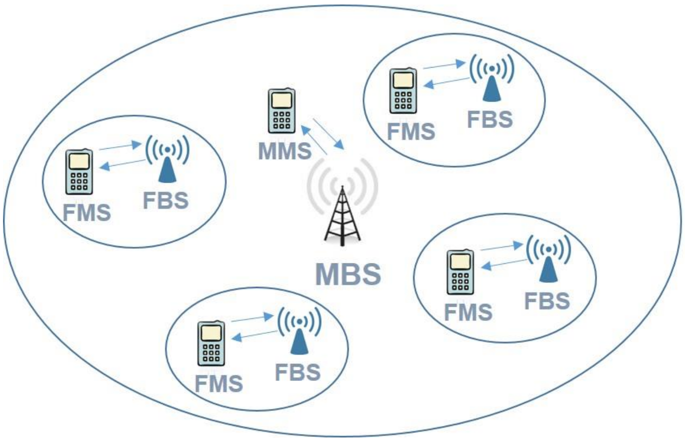

Figure.3.3 *System Model*

3.3.2. Problem Formulation

Let f_m denotes whether the subchannel *m* is allowed to be shared with the FMSs, that is when f_m = 1, or not f_m = 0. I_m denotes the interference tolerance of MMS on subchannel m. AS shown in figure (3.4), the subchannels M = 1, 3, M-3, M are not allowed to be occupied by the femtocell users. On the other hand, in order to protect the communication of MMS, all FMSs' transmit powers must satisfy the following constraint

$$f_m \sum_{k=1}^{K} P_k^m \; h_k^m \leqslant f_m \; I_m \tag{3.1}$$

Where P_k^m represents the power of femtocell user k on subchannel m, h_k^m represents the channel response from the transmitter of the femtocell user k to the receiver of the MMS on sub-channel *m.* Equation (3.1) guarantees that whenever the summation of the transmitting powers of the FMSs is higher than it should be, the value of the term f_m at the left side of the inequality will be altered to the value zero to protect MMS's communication. In addition, the above constraint permits femtocell users to use the subchannel *m* with no constraints, as long as the macrocell user does not occupy this channel.

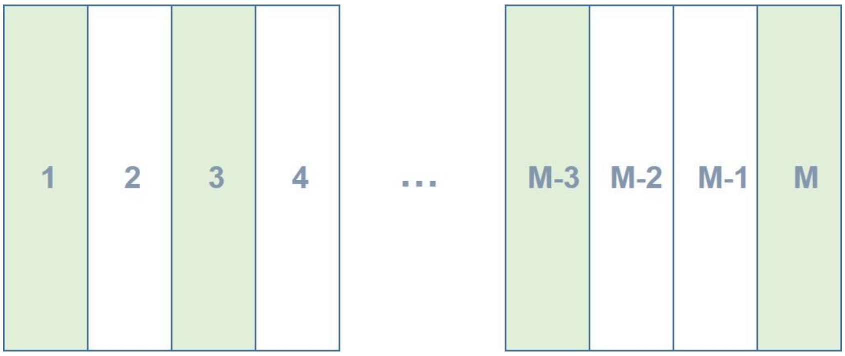

Figure 3.4 System's Occupied (White) and Unoccupied (Grey) Subchannels

Define $\eta^2 = N_k^m + Q_k^m$ that represents the summation of the Additive White Gaussian Noise (AWGN) and the interference coming from the MMS at the receiver of FMS k, respectively. Then the transmit rate of a femtocell user k on an available subchannel can be formulated as

$$R_k = \sum_{m=1}^{M} \log_2 \left(1 + \frac{E\ h_{kk}^m P_k^m}{\eta^2\ + \sum_{i \neq\ k}^{K} h_{ki}^m\ P_i^m}\right), \tag{3.2}$$

Where E represents the gain, h_{kk}^m indicates the channel response between femtocell user k and its femto base station on subchannel m, h_{ki}^m indicates the channel response between femtocell user $i \in K$ on subchannel m received at femtocell user k, P_i^m denotes the power of FMS i on subchannel m, where the summation of multiplications ($h_{ki}^m P_i^m$) is used to for the co-tier interference alleviation. Another constraint is proposed to maintain and maximize the weighted rate sum of the multiple femtocell users. The optimization problem can then be formulated as

$$U = \max \sum_{k=1}^{K}\ w_k\ R_k \tag{3.3}$$

Subject to

$$\sum_{m=1}^{M}\ P_k^m\ \leqslant\ P_k^{MAX}, \tag{3.4}$$

where w_k is the rate weight of femtocell user k that is larger than zero, and P_k^{MAX} denotes the maximum transmitting power that the FMS is allowed to use. From equation (3.3), the objective function (U) can be written as

$$U = \sum_{k=1}^{K} w_k \sum_{m=1}^{M} \log_2 \left(1 + \frac{E\ h_{kk}^m\ P_k^m}{\eta^2 + \sum_{i \neq k}^{K} h_{ki}^m\ P_i^m} \right) > 0. \tag{3.5}$$

From equation (3.5), the first derivative of the objective function (U) with respect to P_k^m can be expressed as

$$U'(P_k^m) = \frac{w_k}{\ln(2)} \frac{E\ h_{kk}^m}{\eta^2 + \sum_{i \neq k}^{K} h_{ki} P_i^m + E\ h_{kk}^m\ P_k^m} > 0, \tag{3.6}$$

while second order derivative of the objective function (U) with respect to P_k^m can be obtained as

$$U''(P_k^m) = \frac{-w_k}{\ln(2)} \left(\frac{E h_{kk}^m}{\eta^2 + \sum_{i \neq k}^{K} h_{ki} P_i^m + E h_{kk}^m P_k^m} \right)^2 < 0. \tag{3.7}$$

From equations (3.6) and (3.7) it can be seen that the nonlinear optimization problem (3.3) is convex, and since the objective function is concave in the optimizing variable P_k^m that reflects the transmitting power of each FMS on each subchannel. Then we propose a distributed algorithm [10] based on Lagranigan duality that solve the optimization problem as follows in the next section.

3.3.3. Optimal Distributed Subchannel, Rate and Power Allocation algorithm

In this section, the power control algorithm is proposed to solve the optimization of (3.3). By relaxing the constraints (3.1) and (3.4) we can introduce Lagrange multiplier vectors $\boldsymbol{\mu}$ and $\boldsymbol{\lambda}$ where $\boldsymbol{\mu} = [\mu_1\ \mu_2 \ldots \mu_M]^T$, and $\boldsymbol{\lambda} = [\lambda_1\ \lambda_2 \ldots \lambda_K]^T$, and let $\mathbf{P} = [P_1^1\ P_1^2\ P_1^3 \ldots\ P_1^M\ P_2^1\ P_2^2 \ldots P_K^{M-1}\ P_K^M\ ]^T$ be the power allocation vector that interprets the transmitting power on each m subchannel of each FMS k. The corresponding Lagrangian function can be formulated as follows

$$L(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}) = \sum_{m=1}^{M} \sum_{k=1}^{K} w_k \sum_{m=1}^{M} \log_2 (1 + \frac{E\ h_{kk}^m P_k^m}{\eta^2 + \sum_{i \neq k}^{K} h_{ki}^m\ P_i^m})$$
$$+ \sum_{k=1}^{K} \lambda_k (P_k^{MAX} - \sum_{m=1}^{M} P_k^m) + \sum_{m=1}^{M} \mu_m f_m (I_m - \sum_{k=1}^{K} P_k^m h_k^m)$$

$$= \sum_{m=1}^{M} \left\{ \sum_{k=1}^{K} w_k \log_2(1+\frac{E\ h_{kk}^m P_k^m}{\eta^2 + \sum_{i \neq k}^{K} h_{ki}^m P_i^m}) - \sum_{k=1}^{K} \lambda_k P_k^m \right.$$
$$\left. +\mu_m f_m (I_m - \sum_{k=1}^{K} P_k^m h_k^m) \right\} + \sum_{k=1}^{K} \lambda_k P_k^{MAX}.$$

$$\Leftrightarrow L(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}) = \sum_{m=1}^{M} L_m(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}) + \sum_{k=1}^{K} \lambda_k P_k^{MAX}, \quad (3.8)$$

where

$$L_m(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}) = \sum_{k=1}^{K} w_k \log_2(1+\frac{E\ h_{kk}^m P_k^m}{\eta^2 + \sum_{i \neq k}^{K} h_{ki}^m P_i^m})$$
$$- \sum_{k=1}^{K} \lambda_k P_k^m + \mu_m f_m (I_m - \sum_{k=1}^{K} P_k^m h_k^m). \quad (3.9)$$

So the Lagrangian dual function can be expressed as

$$D(\boldsymbol{\lambda}, \boldsymbol{\mu}) = \max_{\mathbf{P} \geq 0} L(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}). \quad (3.10)$$

It is can be seen that different subchannel Lagrangian function $L_m(\boldsymbol{P}, \boldsymbol{\lambda}, \boldsymbol{\mu})$ are independent from each other in equations (3.8) and (3.9), so the dual function (3.10) can be decomposed into *M* independent optimization problems such as

$$\max_{\mathbf{P} \geq 0} L_m(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}). \quad (3.11)$$

From (3.11), the gradient of $L_m(\boldsymbol{P}, \boldsymbol{\lambda}, \boldsymbol{\mu})$ with respect to P_k^m can be obtained as

$$L'_m(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu}) = \frac{1}{\ln(2)} \frac{w_k\ E\ h_{kk}^m}{\eta^2 + \sum_{i \neq k}^{K} h_{ki}^m P_i^m + E\ h_{kk}^m P_k^m}$$
$$- \lambda_k - \mu_m f_m h_k^m. \quad (3.12)$$

Then the transmitting power of user *k* on subchannel m can be updated at the (t+1)th iteration time using the following equation

$$P_k^m(t+1) = [P_k^m(t) + \rho L'_m(\mathbf{P}, \boldsymbol{\lambda}, \boldsymbol{\mu})]^+ \quad (3.13)$$

where $[x]^+ = \max(0, x)$. We set equation (3.12) to zero and obtain P_k^m

$$P_k^m = \frac{w_k}{\zeta_k^m} - \frac{\eta^2}{E\ h_{kk}^m} - \frac{\sum_{i\neq k}^{K} h_{ki}^m\ P_i^m}{E\ h_{kk}^m}, \tag{3.14}$$

where

$$\zeta_k^m = \ln(2)(\lambda_k + \mu_m f_m h_k^m).$$

Letting

$$\theta_k^m = \frac{w_k\ h_{kk}^m}{\zeta_k^m} - \frac{\nabla^2}{E}$$

Equation (3.14) can be expressed as

$$\Rightarrow\ P_k^m = \frac{1}{h_{kk}^m}\left(\theta_k^m - \frac{\sum_{i\neq k}^{K} h_{ki}^m\ P_i^m}{E}\right). \tag{3.15}$$

The linear equation obtained in (3.15) can be expressed in the following matrix form

$$\begin{pmatrix} 1 & \frac{h_{2,2}^m}{E\ h_{1,1}^m} & \cdots & \frac{h_{K,K}^m}{E\ h_{1,1}^m} \\ \frac{h_{1,1}^m}{E\ h_{2,2}^m} & 1 & \cdots & \frac{h_{K,K}^m}{E\ h_{2,2}^m} \\ \vdots & \ddots & \cdots & \vdots \\ \frac{h_{1,1}^m}{E\ h_{K,K}^m} & \frac{h_{2,2}^m}{E\ h_{K,K}^m} & \frac{h_{K-1,K-1}^m}{E\ h_{K,K}^m} & 1 \end{pmatrix} \begin{pmatrix} p_1^{*m} \\ p_2^{*m} \\ \vdots \\ p_K^{*m} \end{pmatrix} = \begin{pmatrix} c_1 \\ c_2 \\ \vdots \\ c_K \end{pmatrix}$$

$$\Longleftrightarrow\ A\mathbf{p}_k^{*m} = \mathbf{c}_k, \tag{3.16}$$

where

$$c_k^m = \frac{\theta_k^m}{h_{kk}^m}.$$

The equilibrium power levels at M subchannels of the k^{th} femtocell user are obtained uniquely from equation (3.16) and given by [20]

$$P_k^{*m} = \frac{1}{h_{kk}^m}\frac{E}{E-1}\left(\theta_k^m - \frac{1}{E+K-1}\sum_{i\neq k}^{K}\theta_i^m\right), \tag{3.17}$$

where

$$\theta_i^m = \frac{w_i\ h_{ii}^m}{\zeta_i^m} - \frac{\eta^2}{E}.$$

h_{ii}^{m} represents the channel response between FMS *i* and its FBS on subchannel m, where $w_i = w_k$, and

$$\zeta_i^m = \ln(2)(\lambda_i + \mu_m f_m h_i^m).$$

According to [13], the convex optimization can be solved through its dual problem that can be formulated as

$$\min_{\lambda,\mu \geq 0} D(\boldsymbol{\lambda}, \boldsymbol{\mu}). \tag{3.18}$$

By inserting equation (3.17) into equation (3.8), and taking the derivatives with respect to λ_k and $\mu_m$we can obtain

$$\omega_k(\boldsymbol{\lambda}_k) = \sum_{m=1}^{M} \left\{ \left(\frac{w_k}{\ln(2)} \frac{Eh_{kk}^m}{\eta^2 + \sum_{i\neq k}^{K} h_{ki}^m P_i^m + Eh_{kk}^m P_k^{*m}} \nabla_{P_k^{*m}}(\lambda_k)\right) - P_k^{*m} + (\mu_m f_m h_k^m - \lambda_k) \nabla_{P_k^{*m}}(\lambda_k) \right\} + P_k^{MAX} \tag{3.19}$$

$$\varpi_m(\boldsymbol{\mu}_m) = \sum_{k}^{K} \frac{w_k}{\ln(2)} \frac{Eh_{kk}^m \nabla_{P_k^{*m}}(\mu_m)}{\eta^2 + \sum_{i\neq k}^{K} h_{ki}^m P_i^m + Eh_{kk}^m P_k^{*m}} - \sum_{k=1}^{K} \lambda_k \nabla_{P_k^{*m}}(\mu_m) + f_m\left(I_m - \sum_{k=1}^{K} P_k^{*m} h_k^m\right) - \mu_m f_m h_k^m \nabla_{P_k^{*m}}(\mu_m). \tag{3.20}$$

where $\nabla_{P_k^{*m}}(\mu_m)$ and $\nabla_{P_k^{*m}}(\lambda_k)$ are the derivatives of P_k^{*m} in (3.17) with respect to μ_m and λ_k, respectively; as follows

$$\nabla_{P_k^{*m}}(\lambda_k) = \frac{1}{h_{kk}^m} \frac{E}{E-1} \left(\frac{-\ln(2)\ w_k}{(\zeta_k^m)^2}\right) \tag{3.21}$$

$$\nabla_{P_k^{*m}}(\mu_m) = \frac{E}{(E-1)h_{kk}^m} \left(\frac{-\ln(2) w_k f_m h_k^m}{(\zeta_k^m)^2} + \frac{1}{E+K-1} \sum_{i\neq k}^{K} \frac{\ln(2) f_m h_i^m w_i}{(\zeta_k^m)^2}\right). \tag{3.22}$$

So the dual variable λ_k and μ_m can be updated as follows

$$\lambda_k(t+1) = [\lambda_k(t) - \beta(t)\psi_k(\lambda_k)]^{+} \tag{3.23}$$

$$\mu_m(t+1) = [\mu_m(t) - \beta(t)\phi_m(\mu_m)]^{+}. \tag{3.24}$$

The updating values of the variables λ_k and μ_m represents the shadow prices of FMS *k* power and subchannel *m*, respectively. Through adjusting these prices, the algorithm can coordinate the power of each FMS allocated on each subchannel.

4. COMPUTER SIMULATION AND MAIN RESULTS

The performance of the algorithm is presented in this section, where it simulates a real femtocell environment that considers cross tier and co-tier interferences to maintain MMS's communication and FMSs' data rate. In addition, it picturize whenever the FMSs are able to use the same subchannels that MMS is using, that is when b_m equal to 1's, and when they are semi-fully available, that is when b_m equal to 1's and 0's, which is called the guard system, where the system doesn't allow FMSs from occupying a the subchannel(s) that a MMS is occupying.

Given the system model in the previous section, the figures in this section addresses different number of randomly activated femtocell users, *K*=4, 50 and 100 users, simulated for 30 iterations. The MBS is located at the center and provides a coverage area within a radius of R_{c} = 2000 meters, and the FBS's coverage is estimated to be 30 meters. The subchannels shared by the FMSs and MBSs are equal to *M* = 16. The Power used by the MMS is considered to be 10 Watts, while the maximum power that can be used by a femtocell *k* user is $P_k^{MAX} = 10$ Watts. The interference tolerance of a subchannel *m* that being used by FMSs is equal to $I_m = 6 \text{ x } 10^{-14}\ Watt.$ In addition, the rate weight of each femtocell user is chosen to be normalized 1/*K*, so that the sum of all femtocell users' weight is equal to one. $\alpha_1 = 4$ and $\alpha_2 = 3$ represents the path loss exponents of outdoor and indoor communication of MMS to FMS, and FMSs transmitter to their FBS, respectively. However, the indoor exponent $\alpha_2$is always smaller than the outdoor path loss exponent $\alpha_1.$ The AWGN power is considered to be equal to $N_k^m = 3.34 \text{ x } 10^{-15}$ Watts while the cross-tier interference at the receiver of FMSs equals to $Q_k^m = h_k'^m P_M^m.$ The channel response between femtocell user *k* and its femto base station on subchannel *m* is $h_{kk}^m = \gamma d_k'^{m-\alpha_2}$, where $h_k^m = \gamma d_k^{m-\alpha_1}$is the channel response between FMS and MMS, where $\gamma = 2 \text{ x } 10^{-4}$ represents the loss factor that depends on antenna gain, where the gain is considered to equal *E* =100, while ρ is small enough to guarantee the convergence of the power update $\rho = 0.01$.

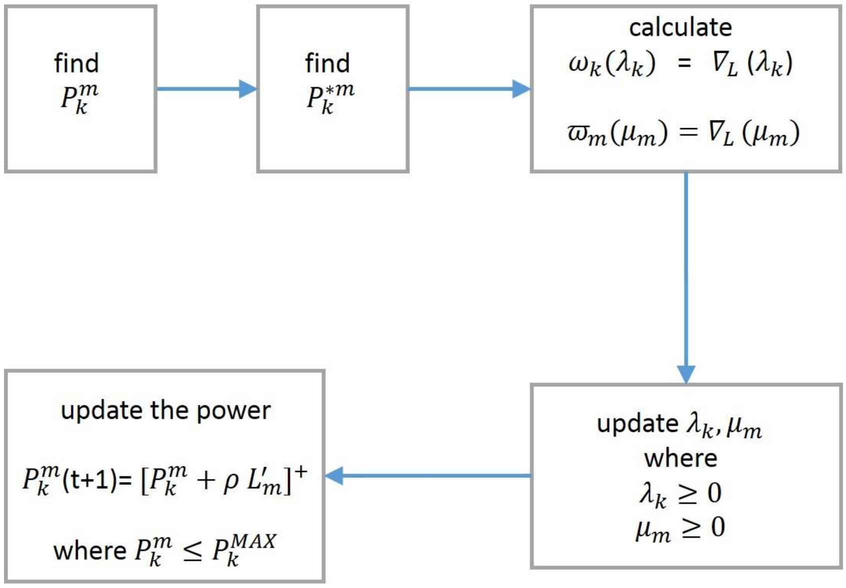

Figure 4.1 Power Update Algorithm

The following figure illustrates the process of data rate convergence of the proposed algorithm, where FMSs has the luxury of sharing MMS's subchannels; as presented in the figure (fig.4.2), the optimal results of the data rates of femtocell users is achieved after the fifth iteration.

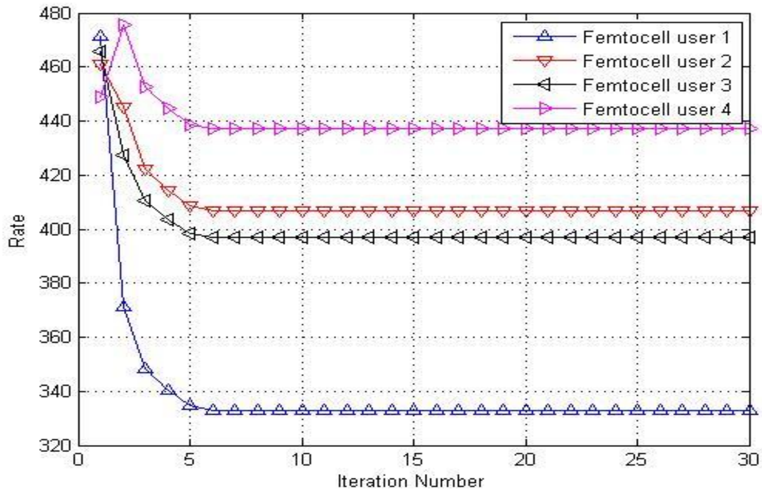

Figure 4.2 Data Rate Convergence Process for K = 4

Figure 4.3, demonstrates the increasing of the weighted rate sum of FMSs as a result of the increasing of the maximum transmitting power thresholds. The figure also shows that the proposed algorithm has a better data rate performance than the guard system, because the guard system algorithm offers a fewer available subchannels compared to the number of offered subchannels to FMSs presented in the algorithm. In this case, the offered available subchannels for the guard system are half the number offered by the proposed algorithm system.

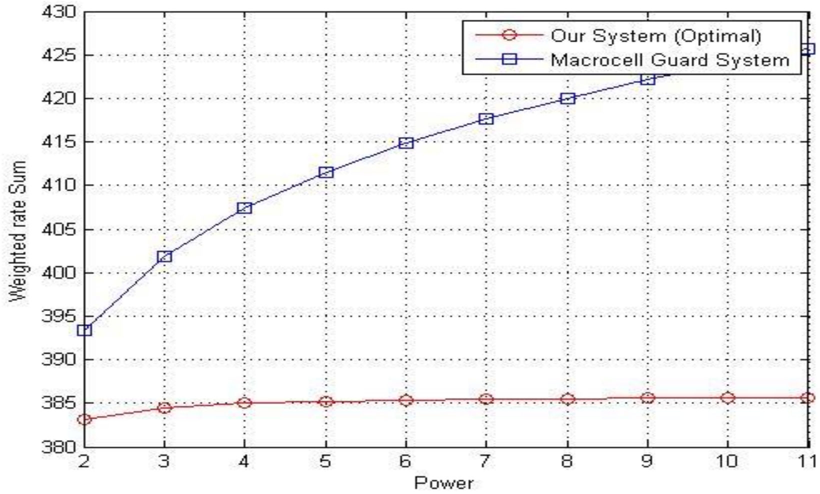

Figure 4.3 WRS as a Function of the Maximal Transmit Power for K = 4

The following figure (fig.4.4) illustrates the influence of the outdoor path loss exponent, where the outdoor exponent varies in the interval [3.6, 3.8, and 4.0] against the variation in the maximum transmitting power. It is clearly seen that the weighted rate sum increases as the outdoor exponent α_1 increases. In addition, the results compares the proposed algorithm against the guard system algorithm with half the number of subchannels offered by the system.

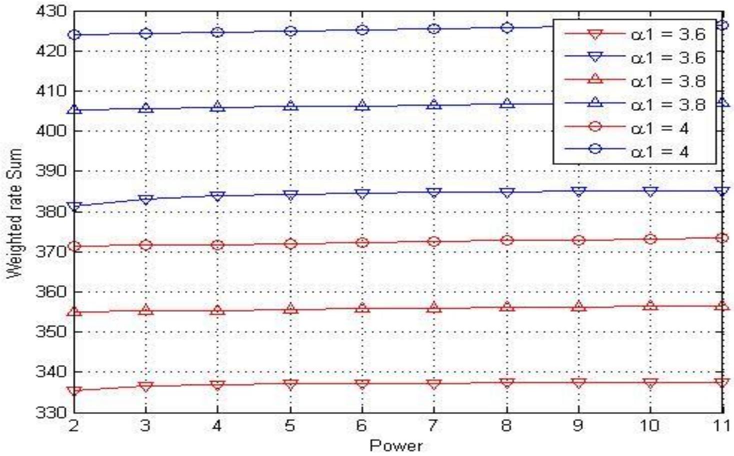

Figure 4.4 WRS as a Function of Outdoor Path Loss Component for K = 4

The following figure (figure 4.5) presents the influence of interference tolerance on the system performance. However, it can be seen that the weighted rate sum increased after the first increment, and the weighted rate sum kept on the same rate sum for the increased values of the interference tolerance.

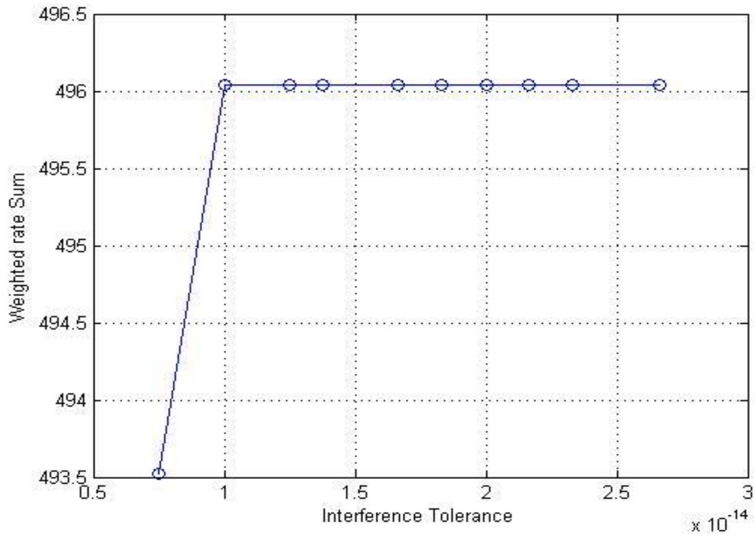

Figure 4.5 WRS as a Function of Interference Tolerance Threshold for K = 4

The following figures shows the data rate of FMSs with more active femtocell stations. As shown in figure (4.6), the algorithm offers different data rates for different FMSs. In addition, it can be clearly seen that no user has a zero data rate. Moreover, some FMSs have a very low data rate (less than 25), but still no FMS has a data rate of zero.

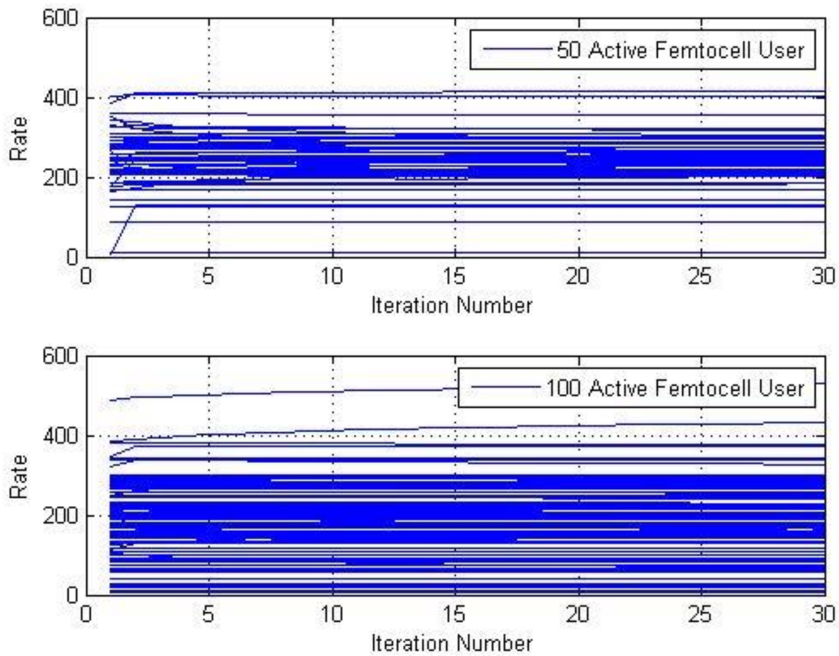

Figure 4.6 Data Rate Convergence for K = [50, 100]

Figure (4.7) illustrates the distances of the system model in the case of 50 and 100 active FMSs, where the black mark in the middle represents the MBS, the red circle represents the MMS, while the blue circles represents the FMSs.

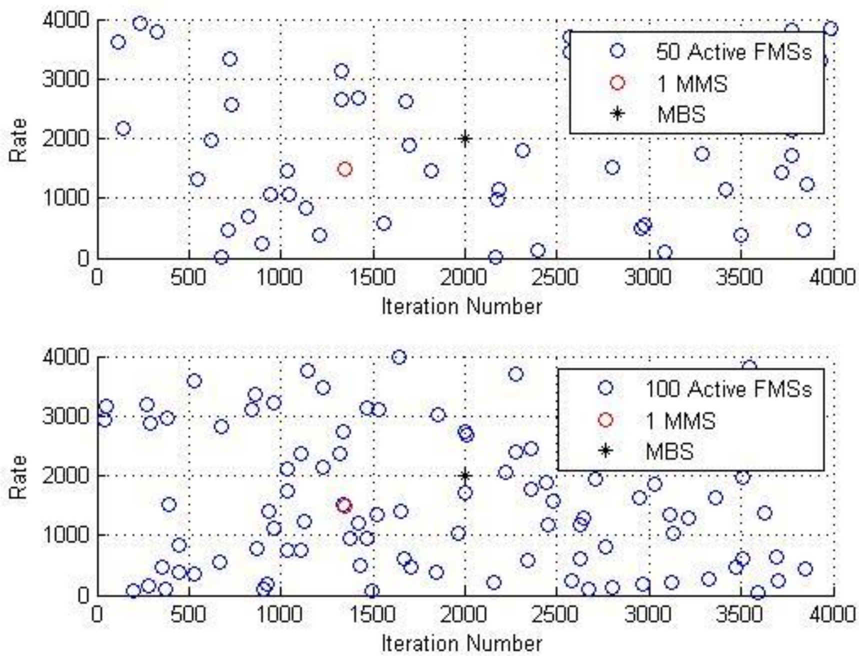

Figure 4.7 Distribution of FMSs, MMS and MBS for K = [50, 100]

From figure (4.7), the distribution shows that the active FMSs around the MMS are the FMSs shown in figure (4.6) that have a low data rate; this due to that they have a shorter distance to MMS than the other active FMSs, where they have to use a lower transmit powers than the other FMSs. In addition, the densely areas that consists of a convergent FMSs have a lower data rate than the distant FMSs, which addresses that the main problem femtocell faces is the distances between FMS and MMS, and the distances among FMSs.

5. CONCLUSIONS

Femtocell is invented to solve the issue of indoor users that suffers from an efficient data rate. Since the femtocell tier and the macrocell tier share the same frequencies, an interference mitigation to solve this issue. Power control algorithms were invented in the past to solve other type of wireless communication interferences issues, where this dissertation studies the performance of an adaptive algorithm that concentrates on mitigating the cross and co-tier interferences experienced in a coverage area that has randomly activated femtocells. The simulation results presented in this thesis addresses a power control mechanism that concerns about the data rates, and interference mitigation. The proposed system assumes an M subchannel shared by the mediums, that the algorithm iteratively allocates the powers of femtocell mobile stations on each subchannel that provides a decent data rate in a recognized covered area.

A comparison is also presented within another system called the guard system that prevents the femtocell mobile stations from using the same subchannels that macrocell mobile stations are using. In this thesis, two constraints were discussed to mitigate the interference and enhance the data rate of the femtocell mobile stations. The first constraint discusses the interference tolerance of a femtocell mobile user on a specific channel where it consists of the transmitting power of a femtocell user multiplied with the channel response from the transmitter of the femtocell user to the receiver of the macrocell mobile station. The other constraint concerns about the data rate as a weighted rate sum of the system, where no femtocell mobile station can exceed its maximum transmitting power.

The results shows that the weighted rate sum of a sparsely distributed femtocell mobile stations model have an optimal data rate at the sixth iteration. In addition, a weighted rate sum comparison with the guard system model, where the proposed model proves better results. Moreover, the results also shows that a weighted rate sum increasing when the maximum transmitting powers used by the femtocell mobile users increases, when the outdoor path loss exponent increases, and when the interferences tolerance increases. Also, the study shows the other aspects that this model offers, where it demonstrates that in a densely model no femtocell mobile station has a data rate of zero. The values of the data rates presented are mainly affected by the position of the femtocell user. In other words, the distance between the femtocell user and its femtocell base station, the distance of femtocell user among other femtocell users, and the distance between a femtocell user and the macrocell user, which the latter is one of the main constraints of this study.

From [31], a network-based solution cooperated with our algorithm, the future work of this study may include investigation about altering the downlink, uplink times in the femtocell-macrocell topology. In [31] the femtocells uses only the MC's downlink time, and splits it into downlink and uplink times, where the FC listens to the environment in the MC's uplink time to adjust its powers in the transmitting times. The future work can be developed with the use of our algorithm that applies the MC's downlink time into FC's uplink time, and the MC uplink time into the FC downlink time; since this topology is not using the frequencies currently being used by the macrocell, it cares more about the co-tier interference alleviation.

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Curriculum Vitae

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