

الاية

أعوذ بالله من الشيطان الرجيم

بسم الله الرحمن الرحيم

اللَّهُمَّ الَّذِينَ آمَنُوا لِوَفْقِهِمْ وَالَّذِينَ أُوثُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ (

صدق الله العظيم

[سورة المجادلة: الآية 11]

DEDICATION

We present this thesis to our parents, to our lecturers, who broadened our minds and concepts concerning the science and electronic engineering Also to our super-visor, Dr. Ibrahim Khider and to our colleagues and all who concerned help us to developing this project .We hope this project may add new knowledge , information's and techniques for the welfare of mankind.

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ABSTRACT

Long term evolution is the standard that the Third-generation Partnership Project developed to be an evolution of UMTS, in Heterogeneous and Homogeneous networks.

One of the main problem in LTE networks is interference between cells, which decreased the signal to interference and noise ratio as well as throughput for users whom in range extension and cell edge. it solved by using Almost Blank Sub-frames technology which sent blank sub-frames or mutt frames

The objective of this thesis is interference management for Long term evolution networks especially in heterogeneous networks.

The throughput of this thesis has been increased especially at cell edges and/or range extension while the Almost Blank Sub-frames ratio has been increased, tacked 0.3 ratio as initial value and noticed the maximum throughput at 0.7 ratio also founded that more than 0.7 ratio throughput decreased.

المستخلص

التطور علي المدى الطويل للشبكات القياسي الذي طور مشروع الشراكة للجيل الثالث ليكون نظام الاتصالات النقالة العالمي ، وذلك للشبكات المتجانسة وغير المتجانسة .
احد المشاكل الاساسية في التطور علي المدى الطويل للشبكات هو التداخل بين الشبكات الذي يسبب ضعف في الطاقة الإنتاجية بالنسبة للمستخدمين الموجودين في المدى الموسع وفي حافة الخليه

تم حلها باستخدام تقنية الترددات شبه الفارغة التي تقوم على ارسال بعض الإطارات الفارغه من مجموع الإطارات التي ترسلها المحطة ذات القدره العاليه وذلك ما يسمى بالإطارات الصامته .
الهدف من هذه الاطروحة هو ادارة التداخل في شبكات المدى الطويل خصوصاً في الشبكات غير المتجانسه .

تمت زيادة الطاقة الانتاجية في هذه الاطروحة خصوصاً في حافة الخليه وتمت زيادة نسبة الترددات شبه الفارغة واستخدم 0.3 كنسبة تجريبية لابتدائه للإطارات شبه الفارغة و وجد أنه كلما زادت نسبتها زادت نسبه الاشاره الى التداخل والضجيج وبالتالي زادت القدره الإنتاجية وأخيراً وجد ان استخدام نسبة 0.7 تؤدي الى الوصول لاقصى قدره انتاجيه وتبدا بالنقصان عند زيادة النسبه اكثر من ذلك .

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LIST OF ABBREVIATIONS

3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
ABS	Almost Blank Sub-frames
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CA	Carrier Aggregation
CRS	Cell Specific Reference
CQI	Channel Quality Indicator
CSG	Closed Subscriber Group
CDF	Cumulative Density Function
CoMP	Coordinated Multi Point
CRS	Common Reference Symbols
CRE	Cell Range Extension
CPRI	Common Public Radio Interface
DSL	Digital Subscriber Line
DL	Downlink
E-UTRAN	Evolved UMTS Terrestrial Radio Access Networks
EICIC	Enhanced Inter-Cell Interference Coordination
eNB	Evolved NodeB
EV-DO	Evolution-Data Optimized

FAPs	Femto Access Points
FUE	Femto User Equipment
FEICIC	Further Enhanced Inter-Cell Interference Coordination
FER	Frame Error Rate
FDM	Frequency Domain Multiplexing
FFR	Fractional Frequency Reuse
FMC	Fixed Mobile Convergence
HSPA	High Speed Packet Access
HetNets	Heterogeneous Networks
HeNet	Homogeneous Networks
HeNBs	Home Evolved Node Bs
HII	High Interference Indicator
HeNB	Home Evolved NodeB
HARQ	Hybrid Automatic Repeat Request
ICI	Inter-Cell Interference
IMT	International Mobile Telecommunication
LTE	Long Term Evolution
LA	Link Adaptation
LCS	Location Services
MUE	Macro User Equipment
MATLAB	Matrix Laboratory
MIMO	Multiple-Input and Multiple-Output
MBMS	Multimedia Broadcast Multicast Services

OI	Over-load Indication
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
OBSAI	Open Base Station Architecture Initiative
PDCCH	Physical Downlink Control Channel
PCFICH	Physical Control Format Indicator Channel
PHICH	Physical Hybrid ARQ Indicator Channel
PSS	Primary Synchronization Signals
PBCH	Physical Broadcast Channel
PS	Packet Scheduling
PFR	Partial Frequency Reuse
QoS	Quality of Service
RRM	Radio Resource Management
RNTP	Relative Narrowband Transmit Power
RRHs	Radio Remote Heads
RREs	Radio Re-mote Equipment's
RE	Range Extension
SINR	Signal to Interference plus Noise Ratio
SFR	Soft Frequency Reuse
SON	Self Organizing Network
SSS	Secondary Synchronization Signals
SCM	Spatial Channel Model
SLS	System Level Simulator

TDM	Time Domain Multiplexing
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System

Chapter One

Introduction

Chapter One

Introduction

1.1 Preface

The Third-generation Partnership Project (3GPP) started working on solutions to fulfill the need for high data rates and came up with HSPA which is currently used in 3G phones for the before mentioned applications. In order to ensure the competitiveness of its standards in the future, 3GPP developed the Long Term Evolution (LTE) to be the 4th generation of mobile telephony [1]. LTE as defined by the 3GPP is the evolution of the 3rd generation of mobile communications (UMTS).

The main goal of LTE is to introduce a new radio access technology with a focus on high data rates, low latency and packet optimized radio access technology, LTE is also referred to as E-UTRAN (Evolved UMTS Terrestrial Radio Access Networks). In December 2008, the LTE specification was published as part of release 8 and the first implementation of the standard was deployed in 2009. The first release of LTE, namely release 8, supports radio network delay less than 5ms and Multiple Input Multiple Output (MIMO) antenna techniques which allow achieving very high data rates. Later on in December 2009 release 9 has been introduced with extensions to various features that existed in release 8 such as Closed Subscriber Group (CSG) and Self Organizing Network (SON). It added also new features such as Location Services (LCS) and Multimedia Broadcast Multicast Services (MBMS) [1].

Finally release 10,11 has been introduced in March 2011-2012 which is also called LTE-Advanced and it added new features such as carrier aggregation, relaying and heterogeneous deployments.

Heterogeneous deployments refer to deployments where we have base stations with different transmission powers and coverage areas sharing, fully or partially, the same set of frequencies and having an Overlapping geographical coverage. An example of Heterogeneous networks is having a Pico-eNB placed in the coverage area of a Macro-Enb Heterogeneous networks, also called HetNets, were supported by release 8 and 9 but release 10 introduced improved inter-cell interference handling making HetNet scenarios more robust. The rest of this report will focus on HetNets and HetNet also the Enhanced Inter-Cell Interference Coordination (eICIC) used by release 10 to combat the interference caused by the Macro-eNBs to the Pico-eNB users. Pico-eNB is a low transmitting power base station that has limited coverage and Macro-eNB is the normal base station which is called eNB (short for evolved node B.) in LTE. Homogeneous networks in nature most nodes have very few connections and a few nodes have many connections that make interference between cells or small node [1].

1.2 Problem Statement

The problem in cellular system in LTE it is the interference between cells. in network the type of interference Co-tier interference it is interference occurs between neighboring cells in homogenous networks and cross-tier interference it is interference occurs between small cell in range of macro cell with same frequency and different power in heterogeneous .

1.3 Aim and Objectives

The aim of this thesis is interference management for LTE networks.

The objectives are:

- To study and understand the types of interference.
- To enhance interference management.
- To use realistic validation of a (high performance) Macro/Pico interference management scheme.
- To simulate ABS technology.
- To evaluate the performance for heterogeneous networks.

1.4 Methodology

A MATLAB application simulator Monte Carlo simulations that performs verify the results of equations by intering the assuming parameters in it and provide illustrations for cellular system also provide relations between the assuming parameters .

1.5 Thesis Outlines

This thesis contain five chapters present a background for LTE networks and the most technologies which used for interference management

Chapter.2. Presents a background of LTE depicts the main features, enhancements and the most techniques which use to management the interference.

Chapter.3. Applies the equations and techniques that are used to solve the problem, reduce interference, get results and provides a description of the model simulations and tool.

Chapter.4. Presents the results obtain from the simulation model and discuss it.

Chapter.5. Summarizes the results of the thesis and future recommendations.

Chapter Two

Literature Review

Chapter Two

Literature Review

2.1 Background

2.1.1 Homogeneous Networks (HeNets)

The wireless cellular networks it is typically deployed as homogeneous networks using wide area macro cells that provide coverage for several square kilometers by using high power transmitters and high mounted antennas patterns, receive noise limit and also similar backhaul connectivity to the data network. Further, all base stations offer unrestricted access to user terminals in the network and are able to serve approximately the same number of UEs which carry similar data how's with similar QoS requirements [3]. The macro base stations are carefully located according to a network planning and properly set up in order to get as maximum coverage as possible and control the possible interference among different base stations [3]. Cellular system deployment has reached practical limits in many dense urban areas while data traffic only continues to increase. This fact leaves cellular operators with few options to increase one of the most relevant metric: area spectral efficiency. Unfortunately, radio link improvements including coding or multiple antenna techniques are approaching theoretical limits [1]. As a result, a more flexible deployment model is needed for operators to enhance broadband user experience in a cost effective way. The most straightforward approach in order to efficiently deal with this continuous traffic demand is the use of advanced

network topology, bringing the network closer to the user terminals. As a result, Heterogeneous Networks (HetNets) have been introduced in LTE-Advanced standardization and are expected to be one of the major performance enhancement enablers. Picocells are usually deployed to eliminate coverage holes in a homogeneous system and improve the capacity of the network [4]. The coverage area of picocells usually varies between 40–75 m. Picocells consist of omi-directional antennas with about 5 dBi antenna gain providing significant indoor coverage to the UE in public places such as airports and shopping malls [2]. On the other hand, short-range (10~30 m) and low-power (10~100 mW) home base stations, commonly known as femtocell or femto access points (FAPs), which operate in the licensed spectrum owned by the mobile operator, enable fixed mobile convergence (FMC) service by connecting to the cellular network via broadband communications links (e.g., digital subscriber line, DSL) [2]. Due to several advantages such as improved indoor coverage, higher datarate, better QoS, plug-and-play deployment, and self-organization. In recent years, different types of femtocells have been designed and developed based on various air interface technologies, services, standards, and access control strategies. Due to the flexibility in spectrum allocation, LTE-Advanced femtocells, which are referred to as home evolved Node Bs (HeNBs), will use orthogonal frequency division multiple access (OFDMA) as the air interface technology. Example of homogeneous illustrated in Figure 2.1 [3].

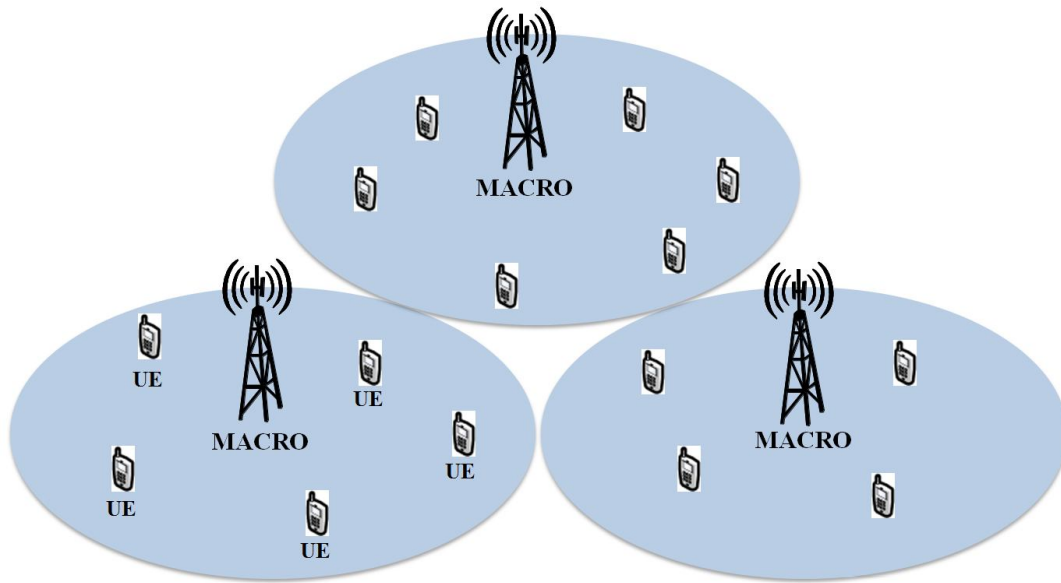


Figure 2.1. homogeneous network.

2.1.2 Heterogeneous Networks (HetNets)

Heterogeneous deployments refer to deployments where we have base stations with different transmission powers and coverage areas sharing, fully or partially, the same set of frequencies and having an overlapping geographical coverage. An example of Heterogeneous networks is having a Pico-eNB placed in the coverage area of a Macro-eNB. Heterogeneous networks, also called HetNets, were supported by release 8 and 9 but release 10 introduced improved inter-cell interference handling making HetNet scenarios more robust. Heterogeneous illustrated in Figure 2.2.

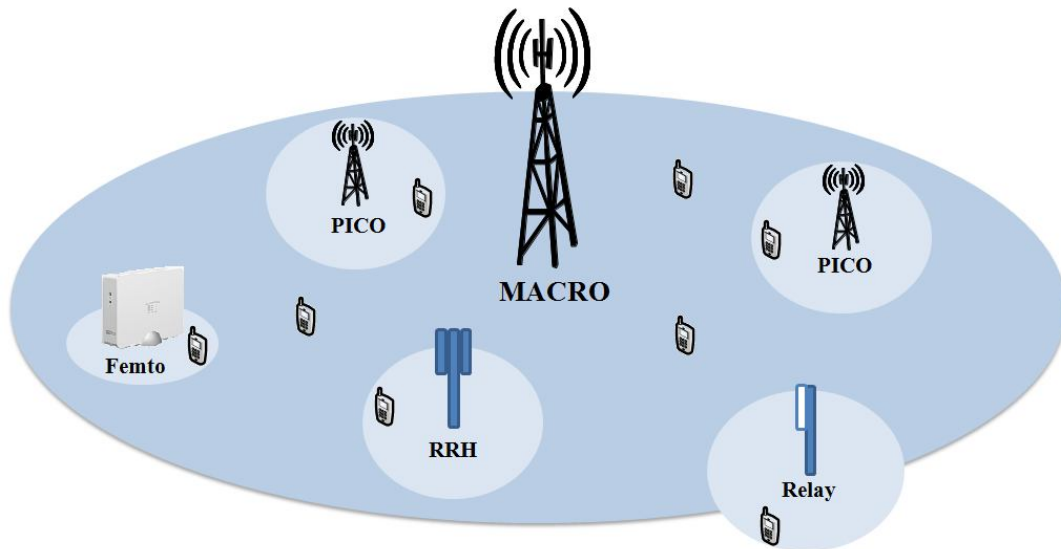


Figure 2.2. Heterogeneous network.

2.1.3 Range extension and associated problems

Cell selection in LTE is based on terminal measurements of the received power of the downlink signal or more specifically the cell specific reference (CRS) downlink signaling. However; in a heterogeneous network we have different types of base stations that have different transmission powers including different powers of CRS [5]. This approach for cell selection would be unfair to the low power nodes (Pico-eNBs) as most probably the terminal will choose the higher power base stations (Macro-eNBs) even if the path loss to the Pico-eNB is smaller and this will not be optimal in terms of:

- Uplink coverage: as the terminal has a lower path loss to the Pico-eNB but instead it will select the Macro-eNB.
- Downlink capacity: Pico-eNBs will be under-utilized as fewer users are connected to them while the Macro-eNBs could be overloaded even if Macro-eNBs and Pico-eNBs are using the same resources in terms of

spectrum, so the cell-splitting gain is not large and the resources are not well utilized.

- Interference: due to the high transmission power of the Macro-eNBs, then the Macro-Enb transmission is associated with a high interference to the Pico-eNB users which denies them to use the same physical resources. As a solution for the first 2 points cell selection could be dependent on estimates of the uplink path loss, which in practice can be done by applying a cell-specific offset to the received power measurements used in typical cell selection. This offset would somehow compensate for the transmitting power differences between the Macro-eNBs and Pico-eNBs; it would also extend the coverage area of the Pico-eNB, or in other words extend the area where the Pico-eNB is selected. by expanding the coverage of pico base stations and subsequently increase cell splitting gains [5]. We will refer to this concept as “Range Extension” which is illustrated in Figure 2.3.

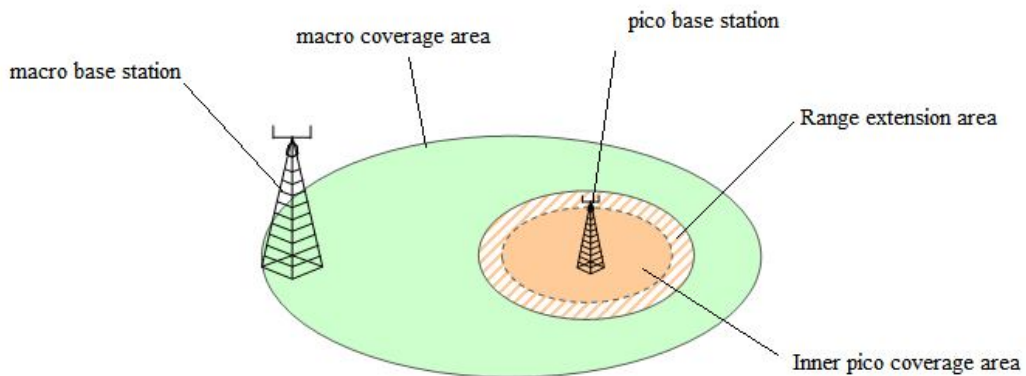


Figure 2.3 Macro-Pico Scenario with increased pico cell area coverage using range Extension.

Range extension advantages:

- 1) Applying range extension would maximize the achievable uplink SINR which in turn maximizes the uplink data rate.
- 2) The terminal transmit power would be reduced as the path loss to the Pico-eNB is lower than the one to the Macro-eNB so the interference to other cells would be reduced and the uplink system efficiency would be improved.
- 3) It also allows more users to be connected to the Pico-eNB, thus increasing the cell splitting gain.
- 4) Since the Macro-eNB transmits to fewer users then the interference it applies on the Pico-eNB is reduced and the Pico-eNBs can reuse the resources more efficiently so the downlink system efficiency is maximized as well [5].

Interference effects associated to range extension:

Due to the difference in transmission powers of the Macro-eNBs and the Pico-eNBs, in the range extension area, illustrated in Figure 2.3, where the Pico-eNB is selected by the terminal while the downlink power received by that terminal from the Macro-eNB is much higher than the power it receives from the Pico-eNB, this makes the users in the range extension area more prone to interference from the Macro-eNB. So along with the benefits of range extension comes the disadvantage of the high inter-cell interference that the Macro layer imposes on the users in the range extension area of the Pico layer [12]. As it illustrated in Figure 2. 4.

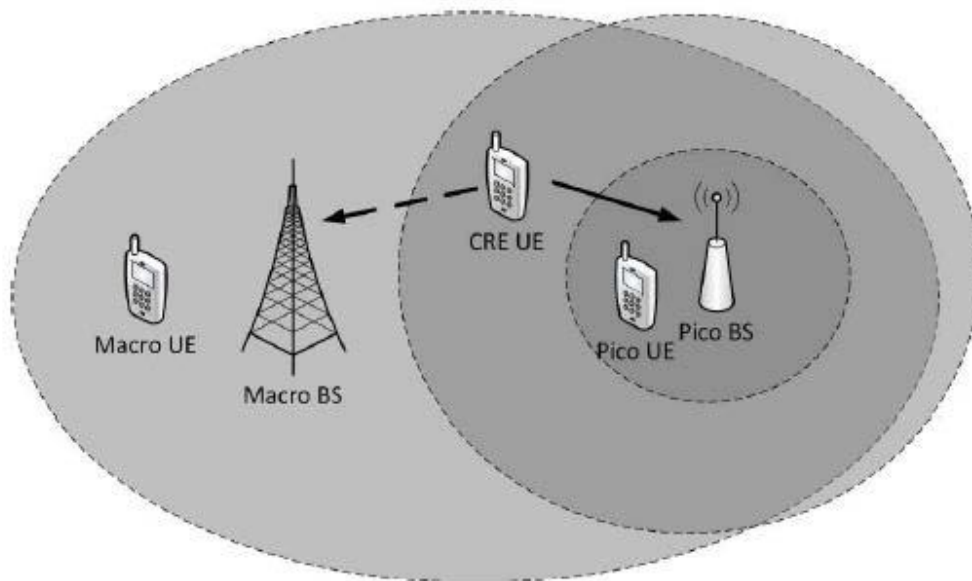


Figure 2.4. Interference effects associated to range extension.

2.1.4 Type of Interference:

- **Co-tier interference:**

This type of interference occurs between neighboring femtocells or Macrocells. For example, a femtocell UE device (aggressor) causes uplink co-tier interference to the neighboring femtocell BSs (victims). On the other hand, a femtocell BS acts as a source of downlink co-tier interference to the neighboring femtocell UE as illustrated in Figure 2.5 [1].

- **Cross-tier interference:**

This type of interference occurs between femtocells or Picocells and macrocells. For example, picocell UE (referred to as CRE UE) and macrocell UE act as sources of uplink cross-tier interference to the serving macro BS and nearby HeNBs, respectively. On the other hand, the serving

macro BS and HeNBs cause downlink cross-tier interference to the CRE UE and nearby, respectively such as illustrated in Figure 2.5 [1].

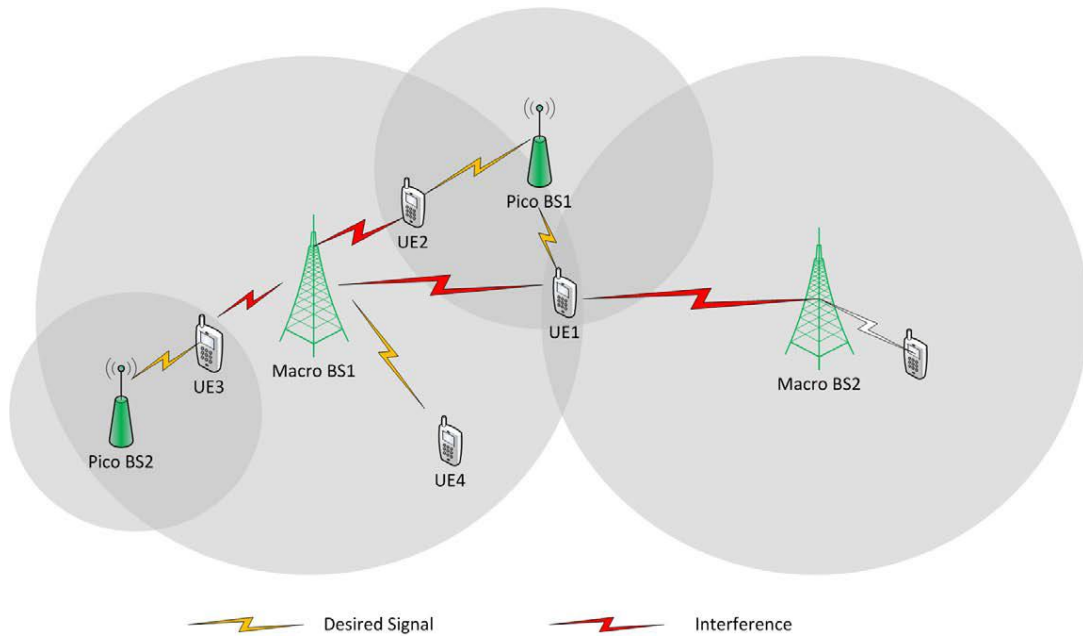


Figure 2.5 .Cross-tier and Co-tier interference.

2.1.5 Orthogonal frequency Divition Multiple Access

In OFDMA-based femtocell networks, co-tier/cross-tier and uplink/downlink interference occur only when the aggressor (or the source of interference) and the victim use the same subchannel. Therefore, it is essential to adopt an effective and robust interference management scheme that will mitigate co-tier interference and reduce cross-tier interference considerably in order to enhance the throughput of the overall network. Different techniques such as cooperation among MeNB and HeNBs and collaborative frequency scheduling, formation of groups of HeNBs and

exchange of information (path loss, geographical location, etc.) among neighboring HeNBs , power control , and intelligent spectrum access have been considered in the recent literature to reduce co-tier and cross-tier interference.

2.2 Related work:

2.2.1. Interference mitigation schemes

As mentioned before, LTE standard is designed for frequency reuse 1 (to maximize spectrum efficiency), which means that all the neighbor cells are using same frequency channels and therefore there is no cell-planning to deal with the interference issues. Thus, there is a high probability that a resource block scheduled to cell edge user, is also being transmitted by neighbor cell, resulting in high interference and eventually low throughput or call drops. Besides, heterogeneous networks require some sort of interference mitigation, since small cells and macro cells are overlapping in many scenarios. Inter cell interference mitigation schemes can be grouped under two categories: static and dynamic schemes (see Fig. 2.6) [2].

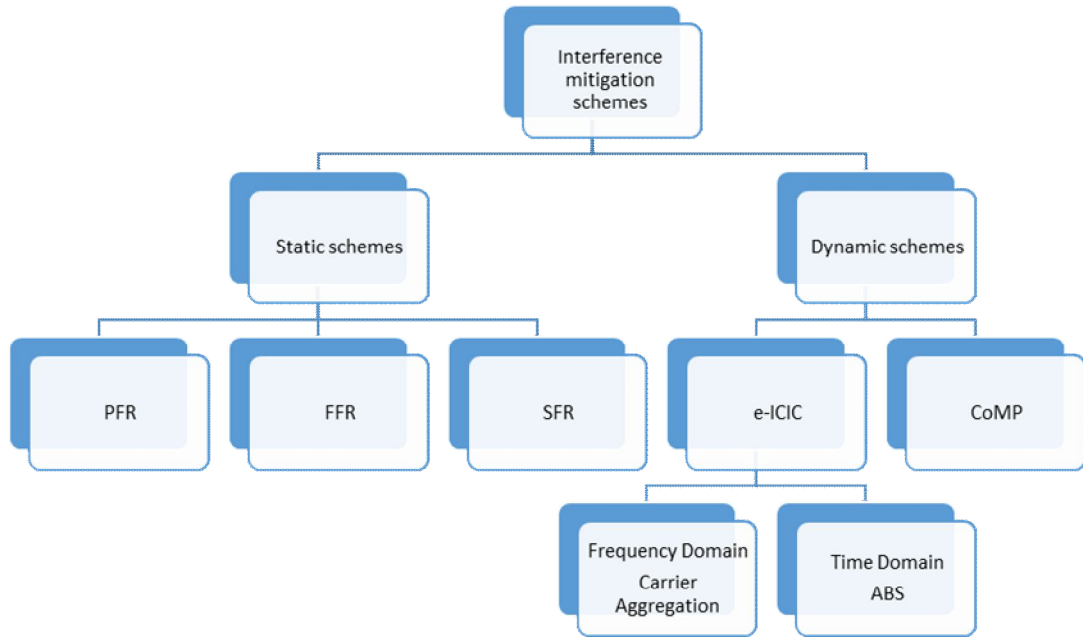


Figure 2.6. Interference mitigation schemes

2.2.2 Static Schemes: Release 8/9 ICIC

Inter-cell interference coordination was first introduced by 3GPP Release 8 LTE to deal with interference issues at cell-edge by mitigating interference on traffic channels only. It has the task to manage frequency radio resources (notably the radio resource blocks) such that inter-cell interference is kept under control. ICIC is inherently a multi-cell Radio Resource Management (RRM) function that needs to take into account information (e.g. the resource usage status and traffic load situation) from multiple cells. The preferred ICIC method may be different in the uplink and downlink [4]. ICIC function is located in the eNB. The coordination between cell sites is achieved by exchanging messages between eNBs over X2 interface. Frequency-domain ICIC over downlink in Release 8 is based on controlling the downlink cell power for resources. This is achieved by sending Relative Narrowband Transmit Power (RNTP) message as often as

every 200 ms . This message contains information whether or not the frequency time resource is limited by transmit power. When a neighbor eNB listens to this message, it can avoid scheduling on the indicated resources. Two messages are defined for uplink interference coordination: High Interference Indicator (HII) and over-load indication (OI) exchanged between eNBs as often as every 20 ms.

HII is used to communicate, on which frequency time resources and eNB is going to schedule cell edge users. By listening to this message, a neighbor eNB can avoid scheduling cell edge users in the indicated resources. This can, therefore, result in reduced uplink interference for both of the cells. The action to be taken by an eNB when it receives HII message is implementation specific. An eNB sends Overload Indicator message to indicate the level of interference experience in different frequency time resources to neighbor eNB. Three levels of interference are defined: Low, Mid and High. When an eNB receives overload indicator message, it can change the scheduling pattern to free the resources indicated in the overload indicator message, therefore, reducing the interference for cell edge users. Static schemes usually fall into one of three broad categories: traditional hard fractional frequency reuse (FFR), soft frequency reuse (SFR) , and partial frequency reuse (PFR) [7].

2.2.3 Fractional Frequency Reuse (FFR)

To avoid the limitations of the traditional frequency reuse schemes, the fractional frequency reuse scheme is introduced to obtain a frequency reuse factor between 1 and 3 [12] . FFR divides the whole available frequency bands into two groups, one for cell center users and the other for cell edge users. In the first group, resources are used with a reuse factor

equal to one. This means that all cell center users in adjacent cells can be scheduled with the same resources. The second group is contrarily divided into three subsets [9], which allows a reuse factor equal to three for adjacent cell edges as shown in Fig 2.7.

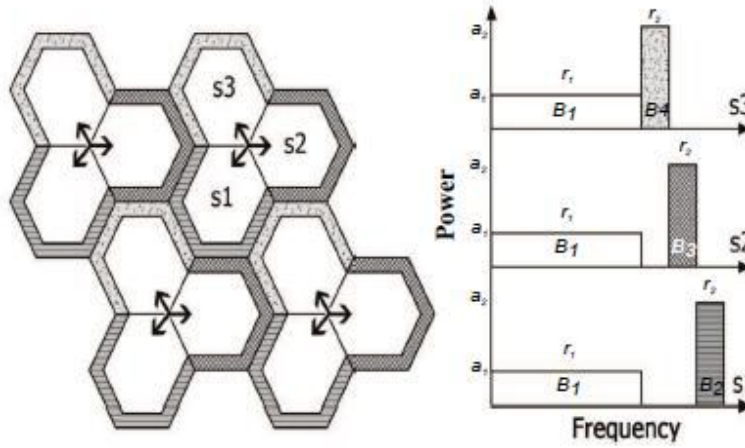


Figure. 2.7. Fractional Frequency Reuse (FFR)

2.2.4 Partial Frequency Reuse (PFR)

It is clear that using the same FRF value for the entire cell is not bandwidth-efficient. One way to improve the cell-edge SINR, while maintaining a good spectral efficiency, is to use a frequency reuse factor greater than unity for the cell-edge regions and a reuse factor of unity for the cell-center regions. In a homogeneous network, the cell center regions have equal areas. The idea of PFR is to restrict portion of the resources so that some frequencies are not used in some sectors at all. The effective reuse factor of this scheme depends on the fraction of unused frequency [9]. The PFR is also known as FFR with full isolation (FFR-FI), as users at cell-edge are fully protected (isolated) from adjacent cells interference. An example for sites with 3 sectors is shown in Fig.2.8.

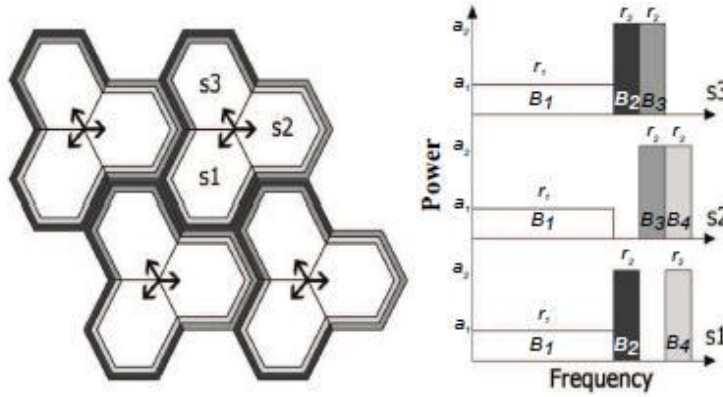


Figure.2.8. Partial Frequency Reuse (PFR)

2.2.5 Soft Frequency Reuse (SFR)

The term soft reuse is due to the fact that effective reuse of the scheme can be adjusted by the division of powers between the frequencies used in the center and edge bands. SFR makes use of the concept of zone-based reuse factors in the cell-center and cell-edge areas. Unlike the PFR; however, frequency and power used in these zones are restricted [13]. In particular, a frequency reuse factor of 1 is employed in the central region of a cell, while frequency reuse factor greater than 1 at the outer region of the cell close to the cell edge. In fact, when the mobile station is near the antenna of the base station, the received power of the wanted user signal is strong, and the interference from other cell is weak. So at the inner part of the cell, all the sub-carriers can be used to achieve high data rate communication. For example, consider the 3-sector cell sites shown in Fig.2.9, the cell-edge band uses 1/3 of the available spectrum which is orthogonal to those in the neighboring cells and forms a structure of cluster size of 3. The cell-center band in any sector is composed of the frequencies used in the outer zone of neighboring sectors [9]. The benefits of the soft

frequency reuse scheme include the following:

- Improved bit rate at cell edge;
- High bit rate at the cell center;
- Avoid interference at the cell edge, so the following procedure is easier:
channel estimation, synchronization, cell selection and reselection

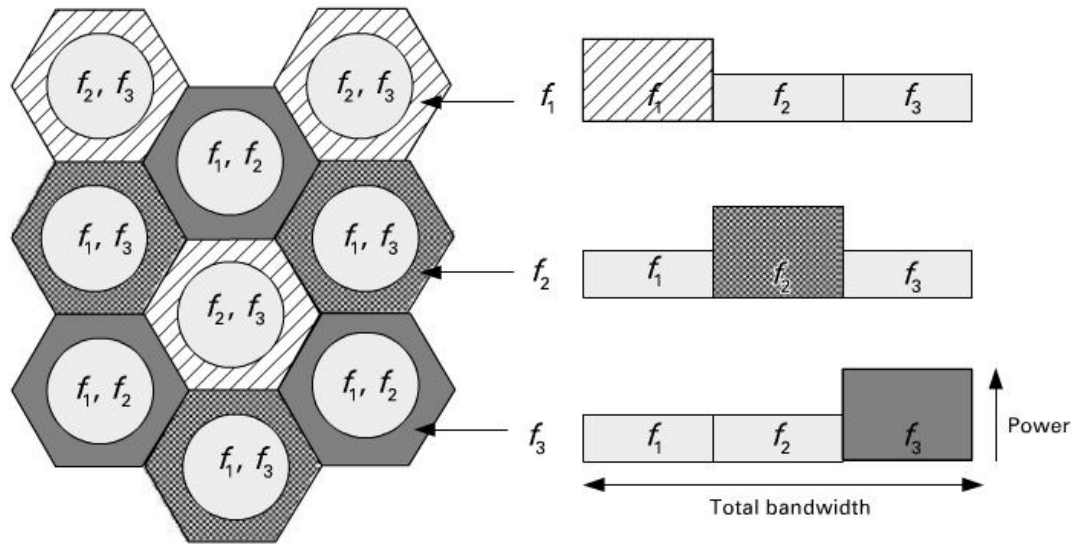


Figure.2.9. Soft Frequency Reuse (SFR)

2.2.3 Dynamic Schemes

2.2.3.1 Enhancements Inter-cell Interference Release 10: E-ICIC

In ICIC specifications, only homogeneous network scenario was examined. To deal with interference issue in heterogeneous deployments such as overlaying Macro and Femto cells, enhanced ICIC (e-ICIC) was standardized by 3GPP Release 10. Several enhancements were made to overcome the limitations of previous ICIC schemes. The e-ICIC mitigates interference on traffic and control channels. Besides, e-ICIC uses power, frequency and also time domain to mitigate intra-frequency interference in

heterogeneous networks. In such networks, two major scenarios for severe inter cell interference should be highlighted: Macro-Pico scenario with Cell Range Extension (CRE) and Macro-Femto scenario with Closed Subscriber Group (CGS). Extending the coverage of a cell by means of connecting a UE to cell that is weaker than the strongest detected cell is referred to as CRE. Indeed, cell selection in LTE is based on terminal measurements of the received power of the downlink signal. However; in a heterogeneous network we have different types of base stations that have different transmission powers including different powers of downlink signal. This approach for cell selection would be unfair to the low power nodes (Pico-eNBs) as most probably the terminal will choose the higher power base stations (Macro-eNBs) even if the path loss to the Pico-eNB is smaller and this will not be optimal in terms of uplink coverage, downlink capacity and interference. As a solution for the first two points cell selection could be dependent on estimates of the uplink path loss, which in practice can be done by applying a cell-specific offset to the received power measurements used in typical cell selection. This offset would somehow compensate for the transmitting power differences between the Macro-eNBs and Pico-eNBs; it would also extend the coverage area of the Pico-eNB, or in other words extend the area where the Pico-eNB is selected. This area is called Range Extension^{||} and is illustrated in Fig.2.3. Due to the difference in transmission powers of the Macro-eNBs and the Pico-eNBs, in the range extension area, illustrated in Figure 2.10, where the Pico-eNB is selected by the terminal while the downlink power received by that terminal from the Macro-eNB is much higher than the power it receives from the Pico-eNB, this makes the users in the range extension area more prone to interference from the Macro-eNB. So along with the benefits of range extension comes

the disadvantage of the high inter-cell interference that the Macro layer imposes on the users in the range extension area of the Pico layer. Fig.2.10 illustrates the comparison of 2 users connected to the Pico-eNB where:

- User 1 is placed close to the Pico-eNB so we will call it center Pico user, this is not affected very much by the Macro-eNB interference as the downlink received power from the Pico-eNB is higher than the one received from the Macro-eNB.
- User 2 is placed farther from the Pico-eNB, in the range extension area, and as discussed before this user endures a severe interference from the Macro-eNB [8] .

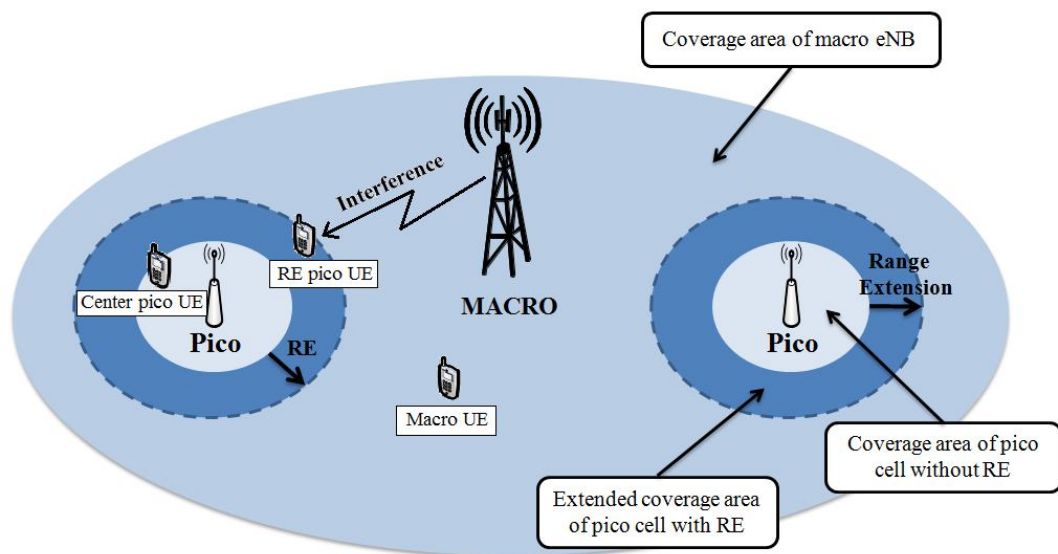


Fig.2.10 the comparison of 2 users connected to the Pico-eNB.

2.2.3.2 Inter-cell interference available solutions

The enhanced Inter-Cell Interference Coordination (eICIC) in heterogeneous networks introduced in LTE-Advanced so without an efficient inter-cell interference scheme the range extension concept loses its advantage and efficiency. The problem with ICIC schemes in releases 8

and 9 was that they were only considering data channels and did not focus on the interference between control channels, so LTE Release 10 solves this problem. The solutions are mainly divided into frequency domain solutions such as carrier aggregation and time domain solutions such as almost blank subframes (ABS), and they will be discussed in details in the following [10].

2.2.3.3 Frequency domain multiplexing ICIC scheme

The main FDM interference cancellation method used in LTE-Advanced is carrier aggregation.

As mentioned before the previous releases of LTE have introduced a lot of flexibility in terms of bandwidth as it allows operating in bandwidths ranging from 1 MHz to 20 MHz in both paired and unpaired modes. In LTE release 10 the transmission bandwidth can be further , the main idea is to aggregate several component carriers and jointly use them for transmission to and from single extended using " carrier Aggregation " terminals. Up to 5 transmission components can be aggregated whether they belong to the same frequency range or not and this feature allows the transmission bandwidth to reach 100 MHz, it also allows to make use of the fragmented spectrum, as operators with fragmented spectrum can use this feature to offer high data-rates by combining all the small spectrum fragments into a sufficiently large component [14]. It is one of the most important features of LTE Advanced and it basically enables LTE-Advanced user equipment (UE) to be connected to several carriers simultaneously. Carrier aggregation not only allows resource allocation across carriers but also allows scheduler based fast switching between carriers without time consuming handovers, which means that a node can schedule its control information on a carrier

and its data information on another carrier. An example of that concept in a HetNet scenario is to partition the available spectrum into, 2 separate component carriers, and assign the primary component carrier (f1) and the second component carrier (f2) to different network layers at a time as shown in Figure 2.11 [5].

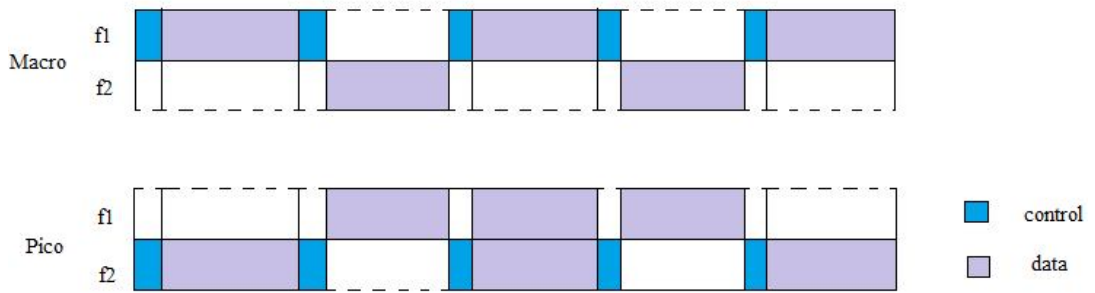


Figure 2.11: Illustration of eICIC based on carrier aggregation

In the example we have 2 component carriers' f1 and f2 where 5 subframes are shown in each carrier. There are 2 cases, the case of Macro layer usage and the case of Pico layer usage; the subframes are distributed in control part, the blue part, and data part. The control part in the example only illustrates the PDCCH, PCFICH and PHICH11 at the beginning of the subframes [5].

2.2.3.4 Time domain multiplexing ICIC scheme:

When a picocell is located in the center zone of a macrocell, it uses the entire frequency band. The interference problem between the macrocell and picocell still exists. Therefore, we solve the cross-tier interference, by applying the Almost Blank Subframes (ABS) in the time domain [5]. The aggressor macrocell uses ABS, which doesn't transmit a signal during some subframe for the victim pico user, as depicted in Figure 2.12. Therefore, the

picocell can avoid interference, by transmitting a signal during the ABS of the macrocell. In this approach transmissions from Macro-eNBs inflicting high interference onto Pico-eNBs users are periodically muted (stopped) during entire subframes, this way the Pico-eNB users that are suffering from a high level of interference from the aggressor Macro-eNB have a chance to be served. However this muting is not complete as certain control signals are still transmitted which are:

- Common reference symbols (CRS) which will be explained later
- Primary and secondary synchronization signals (PSS and SSS)
- Physical broadcast channel (PBCH)
- SIB-113 and paging with their associated PDCCH.

These control channels have to be transmitted even in the muted subframes to avoid radio link failure or for reasons of backwards compatibility, so muted subframes should be avoided in subframes where PSS, SSS, SIB-1 and paging are transmitted [5]. Since these muted subframes are not totally blank they are called Almost Blank Subframes (ABS).

The basic idea is to have some subframes during which the Macro-eNB is not allowed to transmit data allowing the range extension Pico-eNB users, who were suffering from interference from the Macro-eNB transmission, to transmit with better conditions [5]. The outline of ABS has been specified by the 3GPP in . ABS have specific patterns that are configured and communicated between the eNBs over the X2 interface. These patterns are signaled in the form of bitmaps of length 40 subframes, i.e. spanning over 4 frames and they can be configured dynamically by the network using self-optimizing networks (SON) feature to optimize the ABS ratio according to some criterion that can be the cell-edge users throughput or load balancing

for instance and of course keeping in mind the above mentioned subframes that should be avoided [9].

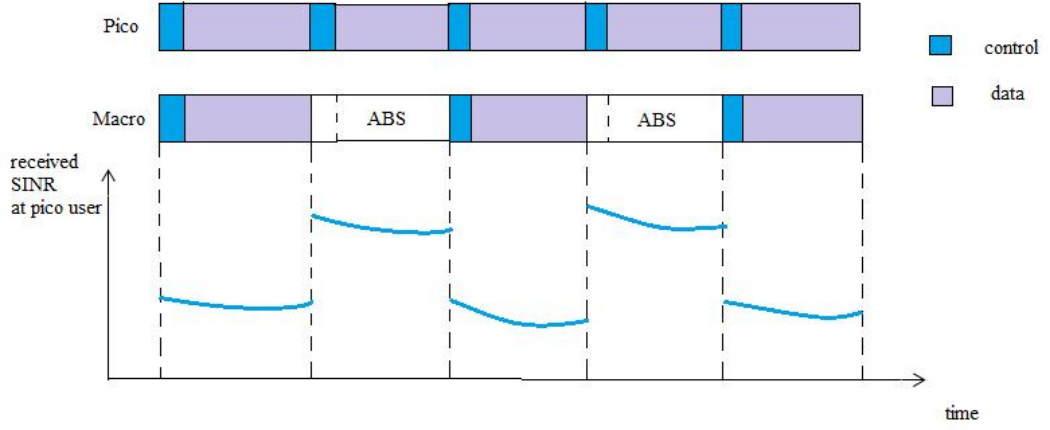


Figure 2.12. TDM ICIC using ABS

-formula to calculate the ABS ratio to maximize the performance

In this section we will deduce a closed form expression for the ABS (Almost Blank Subframes) allocation percentage or ratio¹⁴ that maximizes the performance of the network in terms of cell-edge users capacity. As was stated before the ABS configuration is communicated between the nodes using a 40 subframes pattern, so by optimizing the ABS ratio we mean optimizing the number of subframes that are considered as ABS in this pattern. In the following example a round robin scheduler is considered where Macro-eNB users and center PicoeNB users are only allowed to be scheduled in the non-ABS while the range extension Pico-eNB users are only allowed to be scheduled in the ABS. The constraint on the center Pico-eNB users is introduced for simplicity and to allow the range extension users some fairness in using the ABS because in reality ABS are shared between center and range extension Pico-eNB users and it becomes harder to determine which users are scheduled in the ABS. First we start by an

introduction about round robin scheduler and why it is used in this example. Round robin is a simple scheduling method that is based on assigning the resources to the terminals in turn, one after another, which means that all the users have equal chances to be scheduled without considering their CQI (channel quality indicator) [5].

2.2.3.5 Closed Subscriber Group

A closed subscriber group (CSG) is a limited set of users with connectivity access to a Femto cell. When a Femto cell is configured in CSG mode, only those users included in the Femto cell access control list are allowed to use the Femto cell resources. When considering CSGs, yet another challenge for interference management arises if UEs are in the coverage area of a HeNB, typically well shielded from the macro-eNB, but are not allowed access to it. This creates complex high-interference scenarios in both transmission directions that cannot easily be solved. In the downlink such a macro-UE is the victim being exposed to heavy interference from the HeNB, whereas in the uplink the macro-UE is the aggressor severely disturbing transmissions to the HeNB [7].

2.2.3.6 Coordinated Multi Point Release 11: CoMP

LTE-Advanced continues to evolve. New CA configurations are added (additions of new bands for CA are not bound to specific releases) and there are new features introduced in coming releases of the 3GPP specifications, such as Coordinated Multi Point (CoMP) introduced in R11 as shown in figure 2.13 [3]. The main reason to introduce CoMP is to improve network performance at cell edges. The basic idea of CoMP is to transform inter cell interference into a useful signal, especially in cell edges

where performance may be degraded. In CoMP, a number of transmit points (TX) provide coordinated transmission in the downlink, and a number of receive points (RX) provide coordinated reception in the uplink. A TX/RX-point constitutes of a set of co-located TX/RX antennas providing coverage in the same sector. The set of TX/RX-points used in CoMP can either be at different locations, or co-sited but providing coverage in different sectors, they can also belong to the same or different eNBs. CoMP can be performed in several ways, and the coordination can be done for both homogenous networks as well as heterogeneous networks. When CoMP is used additional radio resources for signaling is required e.g. to provide UE scheduling information for the different DL/UL resources .There are two methods for CoMP technology deployment: the distributed control based on independent con-figuration of each eNB and the centralized control based on Radio Remote Heads (RRHs) also called Radio Re-mote Equipment's (RREs) [3] .The RRH concept constitutes a fundamental part of a state-of-the-art base station architecture. RRH-based system implementation is driven by the need to reduce both CAPEX and OPEX consistently, which allows a more optimized, energy-efficient, and greener base deployment. For example, the Open Base Station Architecture Initiative (OBSAI) and the Common Public Radio Interface (CPRI) standards introduced standardized interfaces separating the Base Station server and the remote radio head (RRH) part of a base station by an optical fiber With the distributed control, signaling is transmitted over X2 interface between eNBs to ensure inter cell co-ordination. Therefore, delay and overhead problems could be generated. However, in the centralized control, several RRHs are connected through optical fiber which transports base band signals between the different cells and the central eNB. Consequently,

the radio resource management of all cells is exclusively performed by the central eNB which considerably reduces the eNBs configuration complexity. Nevertheless, the RRHs number should be limited in order to maintain a certain level of processing load at the central eNB.

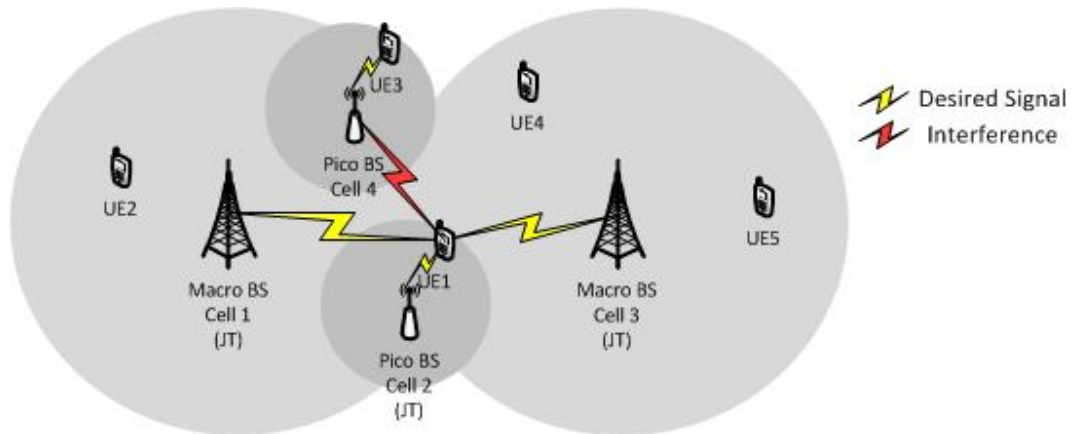


Figure 2.13. CoMP in Release.11

2.2.4 Radio Resource Management

Radio Resource Management (RRM) is used in LTE-Advanced to assure that the available radio resources are utilized as efficiently as possible. In order to do that, it includes strategies for controlling different parameters such as transmit power, handover measures, modulation scheme, error coding scheme and channel allocation [8]. In LTE-Advanced, a dynamic RRM is considered, meaning that the radio network parameters are adaptively adjusted to the traffic load, user positions, QoS requirements, etc. For that purpose, Link Adaptation (LA) and other objects like the Packet Scheduling (PS) or Hybrid Automatic Repeat Request (HARQ) play such an important role as it will be further described in this section. However, in a heterogeneous deployment scenario, the different scale

transmission power levels of the eNBs make this selection decision not be a trivial task. Given the considered scenario with both macro and pico eNBs, if the cell decision is still based on the downlink RSRP, the larger coverage of macro cells can limit the advantages of using cell-splitting by bringing most UEs towards macro cells even though they may not have enough resources to serve these UEs efficiently, while pico cells may not be delivering service to any UE. Further, this fact will result in only few UEs being served by the pico cells due to their much lower transmit power. The RSRP-based cell selection can therefore lead to unbalanced cell load for HetNet deployments, thus overloading macro-cells. In order to solve this macro eNB overloading and force more UEs to be served by the pico eNB, a positive offset can be applied to the RSRP measured from pico cells, expanding their coverage area and subsequently increasing cell splitting gains [8]. Mathematically it can be expressed as follows,

$$\text{Selected cell} = \arg \max \{ \text{RSRP}_{\text{macro}}; \text{RSRP}_{\text{pico}} + \text{REg} \}$$

We will refer to this concept as Range Extension (RE). This bias in the cell selection decision allows more UEs to be pushed to the pico layer as shown in Figure.2.14 [8].

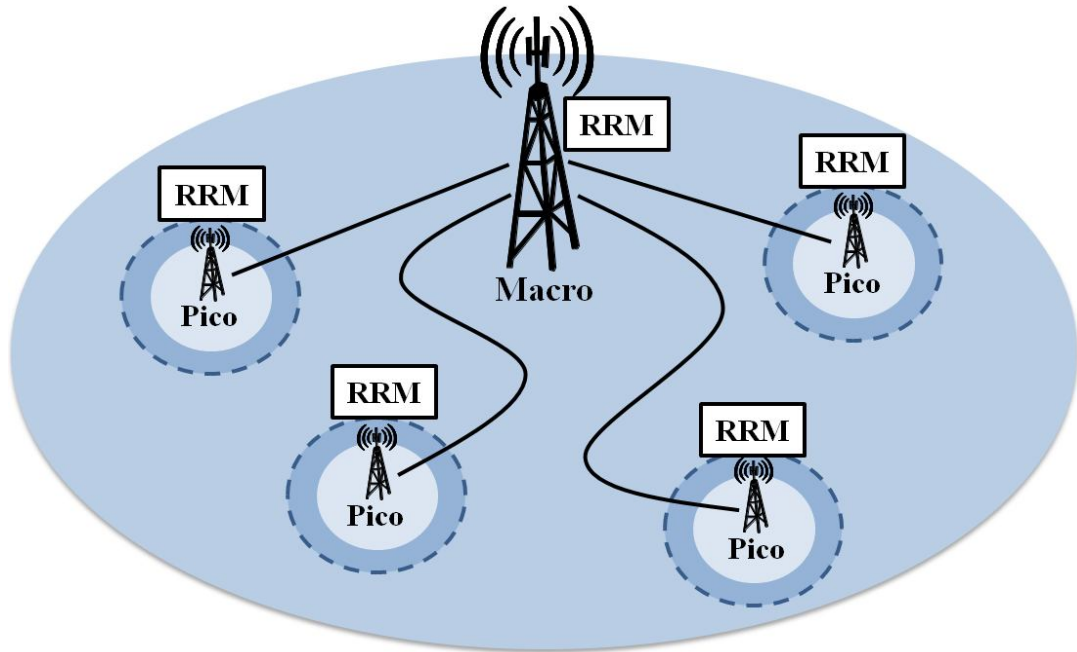


Figure.2.14. Distributed Architecture - Explicit RRM at each eNB

The concept of RE enables an optimal association of UEs throughout the coverage area, which will lead to enhanced system performance and load reduction from the macro eNB at the same time. However, it will be necessary to carry out methods to reduce the downlink interference caused by macro cells to the UEs served by the pico eNB in the extended coverage area. In addition, the RE technique requires careful evaluation when deciding on the offset values and only low values of RE up to 6dB are recommended to be used in co-channel deployments without any explicit interference management [2].

Interference Management .The interference management in HetNets is a non-trivial task and plays an important role to get an optimal overall performance. In particular, due to a large number of heterogeneous cells that could exist in a certain area, inter-cell interference becomes a challenging subject in these scenarios. According to the considered scenario in Figure 2.15 with both macro and pico base stations, the main DL inter-cell interference problem that may occur for the co-

channel deployment is the DL macro-eNB interference to pico UEs. Basically, a UE connected to a pico eNB placed close to a macro eNB can suffer interference from the macro because of the different transmit power between macro and pico eNBs. Among others, the commented interference problem may result in a strong degradation of the overall HetNets performance, being necessary the use of interference coordination schemes in order to decrease the interference and guarantee its proper operation [8]. As depicted in Figure 2.15, a homogeneous cellular system is a network consisting of base stations in a planned layout and a group of user terminals, with all the base stations having similar transmit power levels, antenna [8].

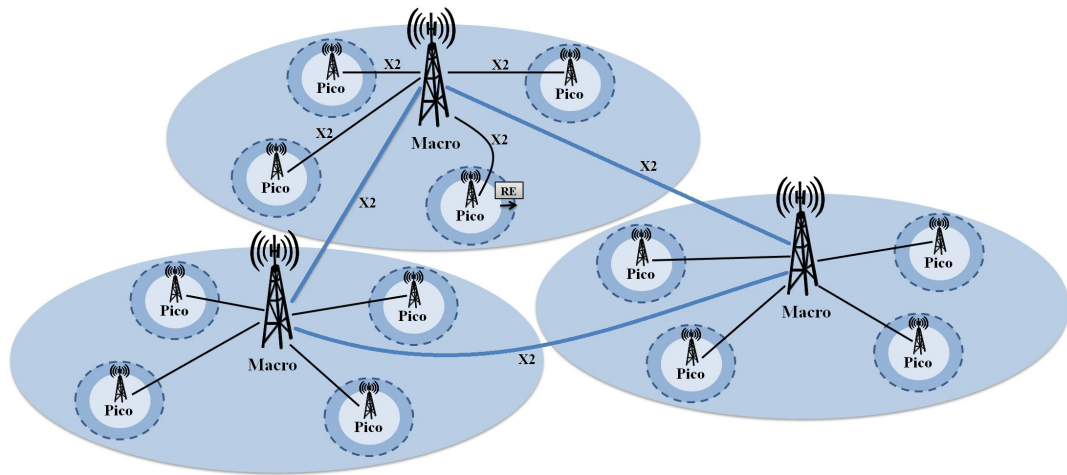


Figure 2.15 : Macro - Pico Deployment

For the depicted scenario, several clusters are considered. Introducing pico eNBs within an existing macro cell network provides coverage improvements by offloading users from the macro to the pico eNB, taking advantage of the RE. This, however, added to the difference in the transmission power of the macro and the pico eNBs, will bring some inter-cell interference problems for users on the whole extended area of the pico

eNB. These problems have to be solved in order to not suffer degradation in the overall system performance.

In order to achieve that, a loose coordination between macro and pico eNBs is carried out over the X2 interface. Also, UE measurement restrictions in

Release 10. In this first approach, a distributed architecture is used, where explicit modeling of major RRM algorithms such as packet scheduling, HARQ or LA, are performed at each eNB (i.e. each eNB makes them separately for the UEs under its coverage area) as shown in Figure 2.15. As a result, only light signaling and coordination between the macro and pico eNB is carried out through open access X2 interface. Therefore, this architecture is attractive for HetNet cases where the number of cells can increase significantly.

In Figure.2.15 the basic muting coordination between macro and pico eNBs so as to take the proper scheduling decisions. Furthermore, for this scenario, two different types of subframes are distinguished in the macro eNB: normal subframes (i.e. normal transmission) and mandatory ABS (i.e. only mandatory information is transmitted). The number of normal subframes and mandatory ABS in each frame is semi-static. Furthermore, for simplicity, we conceive all macro eNBs using the same ABS muting pattern [8] .

2.2.5 Optimization of the RE and ABS muting ratio

The use of RE and eICIC techniques for both balancing the load in the network and managing interference problems are the main features adopted in the heterogeneous network deployment under study. However, setting optimal values of RE and ABS muting ratio is not a trivial task. In

order to explain further how these settings are chosen, the macro - pico scenario with different possible values of RE is considered [8].

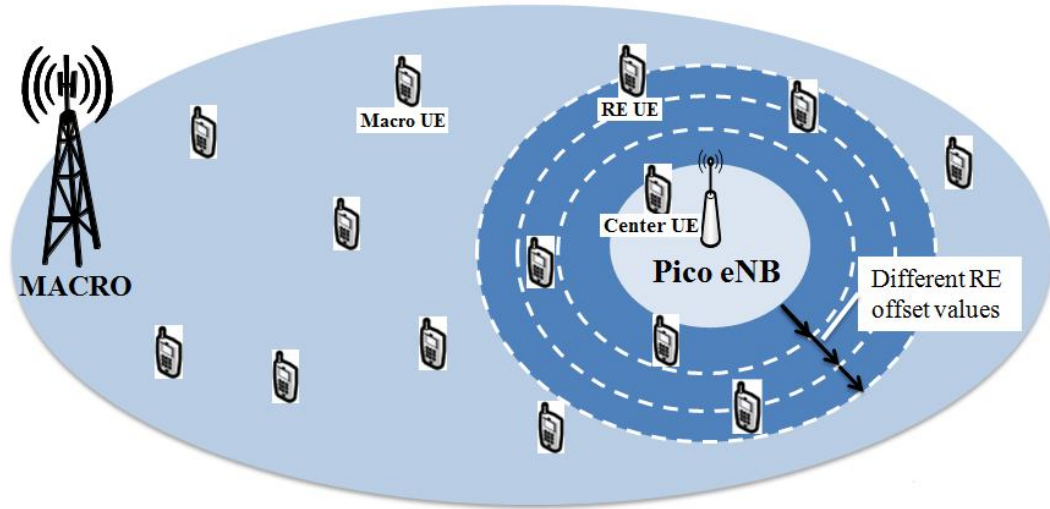


Figure 2.16. Macro - Pico Scenario with different RE values (RE increasing in the direction of the arrow)

As deduced from Figure 2.16, different levels of offloading at the macro eNB can be achieved depending on the RE. In fact, higher values of RE push more UEs to connect to the pico eNB and, therefore, a higher offloading of the macro eNB is achieved. This fact generates, however, more interference from the macro eNB to those UEs in the extended coverage area (i.e. RE pico UEs). Since RE pico UEs are only scheduled during mandatory ABS in the macro eNB, the number of mandatory ABS (i.e. TDM muting ratio) in the macro eNB should increase or decrease accordingly with the RE in the pico eNB and, consequently, with the number of cell-edge UEs in the cluster.

On the other hand, an inappropriate configuration of the RE and TDM muting ratio will cause degradation in the overall network performance. Imagine the case with an increased number of UEs in the cluster as the one illustrated in Figure 2.16. Since the number of UEs is high, more offloading from the macro to the pico eNB is recommended. In that case, a high value of RE is desirable to get the most of the pico eNB. Regarding that case, a high value of RE is desirable to get the most of the pico eNB. Regarding the number of mandatory ABS, suppose that a low ABS muting ratio is defined in the macro eNB. In that case, even though we have offloaded the macro eNB, the new UEs connected to the pico eNB (cell-edge UEs) will barely be scheduled since there are not enough mandatory ABS subframes, resulting in an unsuitable situation which will cause a worst overall performance. To sum up, it can be concluded that the optimal setting of RE at the pico eNB and ABS muting ratio at the macro eNB are closely related and depending on the actual load in the system, where the load is defined as number of UEs [8].

Chapter Three

Modeling and Simulation

Chapter Three

Modeling and Simulation

In this chapter provide a full description and apply the equations and techniques that are used to solve the problem. Then start firstly by giving an overview of the Monte-Carlo LTE Simulator [24] used as a powerful LTE System Level Simulator (SLS). Then describe the models that are used to reduce the interference in LTE networks .There are two models used in this chapter.

3.1. System Level Simulation Description

The approach that is typically used in the development of SLS is the so called Monte-Carlo approach . Also using the Raptor simulator to validate the formula using different channel models, users distributions, Pico-eNBs numbers and range extension values. The results that have been obtained using the simulator in each step have been used to evaluate these technologies, their benefits, their disadvantages and the assumed solution to handle them. LTE networks deployment improves the system performance overall, coverage, capacity, system throughput as well as SINR values, and allows for more efficient spectrum reuse. This results in allowing higher data rates. This means that several independent snapshots or photos of the system are evaluated in order to obtain statistics about the global system behavior.

3.2. Mathematical Models:

Considering a simple setup having a 1 cell network with the following features:

- a. This cell contains 1 Macro-eNB and a certain number N_{pico} of Pico-eNBs. The Pico-eNBs are randomly distributed in the cell.
- b. The users are randomly distributed throughout the cell area.
- c. All Pico-eNBs have the same number of users in the range extension area.
- d. If consider a channel model that is only impaired by additive white Gaussian noise (AWGN) and interference, then the i^{th} user capacity will be according to the following equation

$$C_i = \frac{\text{number of subframes}}{\text{number of users}} * BW \log_2(1 + ||h_i|| SINR_i) \quad (3.1)$$

Where h_i is the channel gain, SINR_i is the signal to interference and noise ratio and BW is the bandwidth which is considered to be 1 Hertz through the whole example for simplicity, also the number of subframes is assumed to be 1. The following notation will be used in the deduction.

Table 3.1. Descriptions and Symbols

Descriptions	Symbols
Macro-eNB transmission power	p_1
Pico-eNB transmission power	p_2
Channel gain from Macro-eNB to the i^{th} user	$(h_{m_us})_i$
Channel gain from the k^{th} Pico-eNB to the i^{th} user	$(h_{p_us})_{k,i}$
number of user per Macro-eNB	N_m
number of Pico-eNBs	N_{pico}
number of center Pico-eNB use per Pico-eNB	N_{p_c}

number of range extension use per Pico-eNB	N_{p_re}
Almost blank subframes ratio	α (Alpha)
the noise in the system	N0

As explained before, cell selection is based on the downlink reference signal power measurements so the users attached to the Macro-eNB (N_m) have a higher downlink power coming from the Macro-eNB than the Pico-eNBs, While center Pico-eNB users (N_{p-c}) receive the reference signals from the Pico-eNB with a higher power than the signals coming from the Macro-eNB. Finally for the range extension Pico-eNB users (N_{p-re}), although they receive the reference signals from the Macro-eNB with a higher power but due to the range extension offset, that was explained before, these users are attached to the Pico-eNB. So using the above notation the capacity for the users attached to the different nodes can be formulated as follows starting by the i^{th} Macro-eNB user capacity in equation (3.2).

$$(C_m)_i = \frac{1}{N_m} \log_2(1 + \|(h_{m-ue})_i\|^2 (SINR_m)_i)(1 - \alpha) \quad (3.2)$$

$$(SINR_m)_i = \frac{p_1}{N_0 + p_2 \sum_{k=1}^{N_{pico}} \|(h_{p-ue})_{k,i}\|^2} \quad (3.3)$$

Then the capacity of the i^{th} center Pico-eNB user attached to the k^{th} Pico-eNB

$$(C_{p,c})_{i,k} = \frac{1}{N_{p-c}} \log_2(1 + \|(h_{p-ue})_{i,k}\|^2 (SINR_{p-c})_{i,k})(1 - \alpha) \quad (3.4)$$

$$(SINR_{p,c})_{i,k} = \frac{p_2}{N_0 + p_1 \|(h_{m-ue})_i\|^2 + p_2 \sum_{\substack{j=1 \\ j \neq k}}^{N_{pico}} \|(h_{p-ue})_{j,i}\|^2} \quad (3.5)$$

And finally the i^{th} range extension Pico-eNB user attached to the k^{th} Pico-eNB

$$(C_{p-re})_{i,k} = \frac{1}{N_{p-re}} \log_2 (1 + \|(h_{p-ue})_{i,k}\|^2 (SINR_{p-re})_{i,k}) \alpha \quad (3.6)$$

$$(SINR_{p-re})_{i,k} = \frac{p_2}{N_0 + p_2 \sum_{\substack{j=1 \\ j \neq k}}^{N_{pico}} \|(h_{p-ue})_{j,i}\|^2} \quad (3.7)$$

Can plot the users capacity in equations (3.2), (3.4) and (3.6) as a function of α , so by choosing one user from each group (Macro, center Pico and range extension Pico) and specifying values for the different parameters (channel gains, p_1 , p_2 , N_m , N_{p-c} and N_{p-re}).

So in order to maximize the cell edge users capacity then need to find the intersection point between the lowest range extension capacity line, corresponding to the range extension user having the lowest capacity, and the first line it intersects with which is the lowest Macro-eNB or center Pico-eNB user capacity line, corresponding to the Macro-eNB or center Pico-eNB user having the lowest capacity.

So can define the intersection point, which is basically found by a search over α , using the following criterion:

$$\min\{(C_m)_i(\alpha), (C_{p-c})_{i,k}(\alpha)\} = (C_{p-re})_{i,k}(\alpha) \quad (3.8)$$

As shown in figure 4.10.

In this case we will not consider the center Pico-eNB capacity line, so will only focus on the range extension and Macro-eNB users as in reality center Pico-eNB users are not affected by the ABS ratio, but here assume that center Pico-eNB users are only allowed to transmit during non-ABS to make the scheduler simpler and giving the Macro-eNB user and Pico-eNB range extension user an equal chance to be scheduled.

Will denote the Macro-eNB user having the lowest capacity by user “m” having the following capacity

$$(C_m)_m = \frac{1}{Nm} \log_2(1 + \|(h_{m-ue})_m\|^2 (SINR_m)_m) (1 - \alpha) \quad (3.9)$$

$$(SINR_m)_m = \frac{p_1}{N_o + p_2 \sum_{k=1}^{N_{pico}} \|(h_{p-ue})_{k,m}\|^2} \quad (3.10)$$

We will denote the range extension user having the lowest capacity by user “n” and assuming that this user belongs to the k^{th} Pico-eNB with the following capacity

$$(C_{p-re})_{n,k} = \frac{1}{N_{p-re}} \log_2(1 + \|(h_{p-ue})_{n,k}\|^2 (SINR_{p-re})_{n,k}) \alpha \quad (3.11)$$

$$(SINR_{p-re})_{n,k} = \frac{p_2}{N_o + p_2 \sum_{\substack{j=1 \\ j \neq k}}^{N_{pico}} \|(h_{p-ue})_{j,n}\|^2} \quad (3.12)$$

The intersection point can be acquired analytically by equating equations (3.9) and (3.11) in order to find the optimum alpha that maximizes the cell edge capacity as follows

$$\begin{aligned} \frac{1}{Nm} \log_2(1 + \|(h_{m-ue})_m\|^2 (SINR_m)_m) (1 - \alpha) = \\ \frac{1}{N_{re}} \log_2(1 + \|(h_{p-ue})_{n,k}\|^2 (SINR_{p-re})_{n,k}) \alpha \end{aligned} \quad (3.13)$$

And by reordering the previous equation we get the following equation which can be considered as the optimal value of α in order to optimize the 0% worst user throughput.

$$\alpha = \frac{1}{1 + \frac{N_m \log_2(1 + \|(h_{p-ue})_{n,k}\|^2 (SINR_{p-re})_{n,k})}{N_{re} \log_2(1 + \|(h_{m-ue})_m\|^2 (SINR_m)_m)}} \quad (3.14)$$

Since the m^{th} Macro-eNB user capacity is given by eq. (3.9) so considering that only this Macro-eNB user gets all the resources all the time then the capacity would be given by the following expression, i.e. putting the number of users to 1 in eq 3.1

$$(C_{macro-max})_m = \log_2(1 + \|(h_{m-us})_m\|^2 (SINR_m)_m) \quad (3.15)$$

Which can call the maximum Macro-eNB user capacity, so $(C_{macro-max})_m$ is the same as $(C_m)_m$ but only assuming that the Macro-eNB is only serving this user m , this is why it is called $(C_{macro-max})_m$ because this is the maximum capacity that this user can reach. And doing the same for the n^{th} range extension Pico-eNB user

$$(C_{re-max})_n = \log_2(1 + \|(h_{p-us})_{p,n}\|^2 (SINR_{p-re})_{n,k}) \quad (3.16)$$

Then can be expressed as

$$\alpha = \frac{1}{1 + \frac{N_m(C_{re-max})_n}{N_n(C_{macro-max})_m}} \quad (3.17)$$

From this equation we can clearly see that alpha depends on 2 factors:

The ratio between the number of Macro-eNB use to the number of range extension use per Pico-eNB.

The ratio between the maximum capacity of a range extension user $(C_{re-max})_n$ and the maximum capacity of a Macro-eNB user $(C_{macro-max})_m$.

Focusing on the second factor and trying to simplify it, starting with the maximum Macro-eNB user capacity

$$(C_{macro-max})_m = \log_2(1 + \|(h_{m-us})_m\|^2 \frac{p_1}{N_0 + p_2 \sum_{k=1}^{N_{pico}} \|(h_{p-us})_{k,m}\|^2}) \quad (3.18)$$

Since the noise value is very small we can neglect it also assuming the value of P_1 to be very large so $(\|(h_{m-us})\|^2 p_1)$ is much bigger than the term in the denominator then can approximate the previous equation to

$$(C_{macro-max})_m = \log_2(\|(h_{m-us})_m\|^2 \frac{p_1}{p_2 \sum_{k=1}^{N_{pico}} \|(h_{p-us})_{k,m}\|^2}) \quad (3.19)$$

Normally most users attached to the Macro-eNB are placed close to it, although some Macro-eNB users are placed very close to the Pico-eNB due to the high transmission power of the Macro-eNB but will consider only the users closer to the Macro-eNB, who are the majority, and assuming that the interference to these users is dominated by one or at most two Pico-eNBs while the rest cause negligible interference. Under this assumption can approximate the interference term $p_2 \sum_{k=1}^{N_{pico}} \|h_{pk-m}\|^2$ with a constant (I) since it is assumed to be independent on the number of Pico-eNBs and is dominated by the interference caused by the closest 1 or 2 interferer Pico-eNBs.

$$(C_{macro-max})_m = \log_2(\|(h_{m-us})_m\|^2 \frac{p_1}{I}) \quad (3.20)$$

Since $C_{macro-max}$ is assumed to be independent on N_{pico} so it can be considered as a constant and can be denoted by C_1 . Now focusing on the second term which is $(C_{re-max})_n$.

$$(C_{re-max})_n = \log_2(1 + \|(h_{p-us})_{k,n}\|^2 (SINR_{k-n})) \quad (3.21)$$

Inserting the $SINR_3$ expression

$$(C_{re-max})_n = \log_2(1 + \|(h_{p-us})_{k,n}\|^2 \frac{p_2}{N_0 + p_2 \sum_{\substack{j=1 \\ j \neq k}}^{N_{pico}} \|(h_{p-us})_{j,n}\|^2}) \quad (3.22)$$

Assuming that we have a very large N_{pico} then N_0 can be neglected, considering that $P_2 \neq 0$, and the interference term in the denominator would be larger than the numerator so the previous equation can be approximated to

$$(C_{re-max})_n = \frac{\|(h_{p-us})_{k,n}\|^2}{\sum_{\substack{j=1 \\ j \neq k}}^{N_{pico}} \|(h_{p-us})_{j,n}\|^2} \quad (3.23)$$

Where k is the serving Pico-eNB for the range extension user. Since the Pico-eNBs are distributed randomly in the cell so $(h_{p-us})_{k,n}$ and $(h_{p-us})_{j,n}$ can be considered as independent and identically distributed (IID) random variables. Also since are trying to optimize the capacity and assuming a large N_{pico} so optimizing C_{re-max} would be the same as optimizing its expected value so can replace C_{re-max} by $E[C_{re-max}]$ as follows

$$E[(C_{re-max})_n] = E\left[\frac{\|(h_{p-us})_{k,n}\|^2}{\sum_{\substack{j=1 \\ j \neq k}}^{N_{pico}} \|(h_{p-us})_{j,n}\|^2}\right] \approx \frac{E[\|(h_{p-us})_{k,n}\|^2]}{E[\sum_{\substack{j=1 \\ j \neq k}}^{N_{pico}} \|(h_{p-us})_{j,n}\|^2]} \quad (3.24)$$

Since all the values of $(h_{p-us})_{j,n}$ can be considered as independent identically distributed (IID) random variables having the same mean value and C_{re-max} can be expressed as

$$(C_{re-max})_n \approx \frac{E[\|(h_{p-us})_{k,n}\|^2]}{\sum_{\substack{j=1 \\ j \neq k}}^{N_{pico}} E[\|(h_{p-us})_{j,n}\|^2]} \quad (3.25)$$

$E[\|(h_{p-us})_{k,n}\|^2]$ can be considered as a constant value so

$$(C_{re-max})_n \approx \frac{E[\|(h_{p-us})_{k,n}\|^2]}{(N_{pico}-1)E[\|(h_{p-us})_{j,n}\|^2]} \quad (3.26)$$

And finally the term $\frac{E[\|(h_{p-us})_{k,n}\|^2]}{E[\|(h_{p-us})_{j,n}\|^2]}$ can be considered as a constant and can

be denoted by C_2 and since N_{pico} is assumed very large so $N_{pico} - 1 \approx N_{pico}$ and C_{re-max} can be expressed as

$$(C_{re-max})_n \approx \frac{C_2}{N_{pico}} \quad (3.27)$$

Finally

$$\frac{(C_{re-max})_n}{(C_{macro-max})_m} \approx \frac{C_2}{C_1 N_{pico}} \quad (3.28)$$

So α can be expressed as

$$\alpha \approx \frac{1}{1 + \frac{N_m}{N_{re}} \frac{C_2}{C_1 N_{pico}}} \quad (3.29)$$

Where $N_{re} * N_{pico}$ is equal to the total number of range extension users which can be denoted by N_{re_total} .

Finally α is expressed by

$$\alpha \approx \frac{1}{1 + \frac{N_m}{N_{re_total}} \frac{C_2}{C_1}} \quad (3.30)$$

So if the values of C_2 and C_1 are assumed to be approximately equal, which will be shown in the following sections, then can introduce α_{opt} which is considered, according to simulations, to be the optimized value that gives the optimal or suboptimal value of α and is expressed by:

$$\alpha_{opt} \approx \frac{1}{1 + \frac{N_m}{N_{re_total}}} \quad (3.31)$$

This means that the ABS ratio α is proportional to the ratio between the number of users attached to the Macro-eNB and the total number of range extension users attached to the Pico-eNBs.

3.3 Simulations validating the previous results

In this section a small MATLAB system simulator that performs Monte Carlo simulations [24] will be introduced to verify the results in the previous section specifically equations (3.29) and (3.31) as they are considered the most important results in the deduction. The simulations consist of a 1 cell network with a Macro cell at a predefined position and a specific number of Pico-eNBs and users are dropped randomly throughout the cell area.

The path loss is calculated according to 2 models, the ITU channel model and the Spatial Channel Model (SCM) which will be explained in details in the following.

- ITU channel model: we will use the urban Macro-eNB (UMa), for Macro-eNB users, and urban micro (UMi), for Pico-eNB users, models in [6].

Assuming that all users have line of sight to the serving base station so the path loss in dB for Macro-eNB users will be calculated according to

$$PL = 22 \log_{10} d + 28 + 20 \log_{10} f_c$$

for $d < 160m$ (3.32)

$$PL = 40 \log_{10} d + 7.8 - 18 \log_{10} h_{BS} - 10 \log_{10} 18 h_{uT} + 20 \log_{10} f_c$$

for $d > 160m$ (3.33)

Where d is the distance between the user and the node $h_{BS} = 24m, h_{uT} = 0.5m$ and $f_c = 1GHz$.

And for Pico-eNB users the path loss is given as

$$PL = 22 \log_{10} d + 28 + 20 \log_{10} f_c$$

for $d < 120m$ (3.34)

$$PL = 40 \log_{10} d + 7.8 - 18 \log_{10} h_{BS} - 10 \log_{10} 18 h_{uf} + 20 \log_{10} f_c$$

for $d > 120m$ (3.35)

Where d is the distance between the user and the node $h_{BS} = 9m, h_{uT} = 0.5m$ and $f_c = 1GHz$.

Spatial channel model: This model will be calculated according to the equations in [10] and assuming no line of sight for both Macro-eNB and Pico-eNBs.

For the Macro-eNB users the path loss in dB is given by

$$PL[dB] = (44.9 - 6.55 \log_{10} h_{BS}) + \log_{10} \left(\frac{d}{1000} \right) + 45.5 + (35.46 - 1.1 h_{MS}) \log_{10} f_c - 13.82 \log_{10} h_{BS} + 0.7 h_{MS} + c \quad (3.36)$$

where h_{BS} is the base station antenna height in meters, h_{MS} is the MS antenna height in meters, f_c the carrier frequency in MHz, d is the distance between the BS and the user in meters, and C is a constant which is equal to 3dB for urban Macro-eNB. These parameters are set to $h_{BS} = 32m, h_{MS} = 1.5m$, $f_c = 1900$ MHz. And the path loss for Pico-eNB users is given by

$$PL = -55.9 + 38 \log_{10} d + [24.5 + 1.5 \left(\frac{f_c}{925} \right)] \log_{10} f_c \quad (3.37)$$

Where $f_c = 1900$ MHz

The idea is to use the Monte Carlo method to compare the optimum alpha, given by equation (14), with the deduced alpha in (3.29) and (3.31). In order to do that, an average of 100 drops, with a random realization for the positioning of the Pico-eNBs and users for each drop, will be used to calculate an average value of alpha and this process will be repeated 500 times so that we will have 500 calculated alpha for each equation at the end then we compare the results.

3.3.1 Validating the alpha expression for equation (3.29)

In this section we will validate the α expression given by equation (3.29), the idea is to calculate the value of α according to equations (3.29) and the optimum value of α according to equation (3.14), this process will be iterated 500 times, as explained before, so at the end we will have 2 vectors of α , each consisting of 500 values, that we can compare and if the values in both vectors are approximately equal, then equation (3.29) can be validated to give an optimal value for α .

Since in the deduction we assume having a large number of Pico-eNBs, we will drop 100 Pico-eNBs and 200 users randomly and α will be calculated according to equations (3.14) and (3.29) and both values will be compared, listed in Table 2 are the parameters used in this simulation.

Table 3.2. Parameters and Values

Parameters	Values
Cell area	50m x 50m
Macro-eNB position	X:0 Y:25
Pico-eNBs positions	Random but keeping a minimum distance of 10 m from the Macro-eNB.
Users positions	Random
Macro-eNB transmitting power	40 W
Pico-eNB transmitting power	1 W
Number of drops	100

3.3.2 Validating the alpha expression for equation (3.31)

In this section we will validate α expression given by equation (3.31), the idea is to calculate the value of α according to equations (3.31) and the optimum value of α according to equation (3.14), this process will be iterated 500 times, as explained before, so at the end we will have 2 vectors of α , each with 500 values, that we can compare and if the values in both vectors are close enough then equation (3.31) can be validated to give an optimal value for α .

For this part we use a more realistic example where we drop 6 Pico-eNBs placed randomly in the cell, in addition 200 users are dropped randomly throughout the cell area. The simulation parameters are listed in Table 3.3.

Table 3.3 Parameters and Values

Parameters	Values
Cell area	50m x 50m
Macro-eNB position	X: 0 Y: 250
Pico-eNBs positions	Random but keeping a minimum distance of 70 m from the Macro-eNB and the other Pico-eNBs.
Users positions	Random
Macro-eNB transmitting power	40 W
Pico-eNB transmitting power	1 W
Number of drops	100

3.4 System simulation assumptions

The criterion that we focus on optimizing is the cell-edge users throughput while keeping a fair level of average throughput.

The simulation assumptions are listed in the following table 3.4:

Table 3.4 Parameter and Description

Parameter	Description
Network topology	21 cell network (i.e. 7 three-sector sites)
Number of user's	30 user's per cell

Number of Pico-eNBs	From 2 to 10 per cell depending on the tested scenario and all the Pico- eNBs are outdoors and located at predefined locations
Deployments	Configuration 129 and 4b30 [7]
Traffic model	Full buffer 31
Range extension offset	From 0 to 18 dB depending on the scenario
Downlink scheduling	Proportional fair scheduler [2]
Carrier frequency	2 GHz
Path loss mode	ITU Channel Model and Spatial Channel Model (SCM)
Downlink link adaptation	Ideal link adaptation ³²
CRS interference modeling	Assuming perfect CRS interference cancellation.
Total bandwidth	20 MHz
Antenna tilting	According to TR36.819- 12 degrees for Macro-eNB, 0 degrees for Pico- Enb

Chapter Four

Simulation Results and Discussion

Chapter Four

Simulation Results and discussion

This section is for the simulation results and discuss it. Start by introducing the simulator used in this section which is the Raptor simulator, there are two model, ITU channel model and Spatial Channel Model. Finally presenting the simulations in different subsections.

4.1 The Raptor and Monticarlo simulators

All the simulations in this project are performed using a simulator called 'Raptor' which is a property of Ericsson. Raptor is an LTE-Advanced system simulator which means that it performs physical layer simulations. The simulator is divided into 3 parts:

- 1) Input parameter files: MATLAB files containing all the simulation parameters that will be used as input to the simulator.
- 2) Main simulator: the main body of the simulator which is developed in C++ and this simulator generates MATLAB result files.
- 3) Graphical interface: MATLAB graphical interface that processes the MATLAB result files to illustrate the results in the form of CDFs, bar charts and scatter plots as will be shown in the next section.

Contributed mainly in creating input parameter files and optimizing the graphical interface to show more illustrative plots.

4.2 ITU channel model

Start by the ITU channel model. Figure 4.1 represents the PDFs of the 500 alpha values calculated from equations (3.14) and (3.29). And it shows that the PDFs are concentrated at very close values.

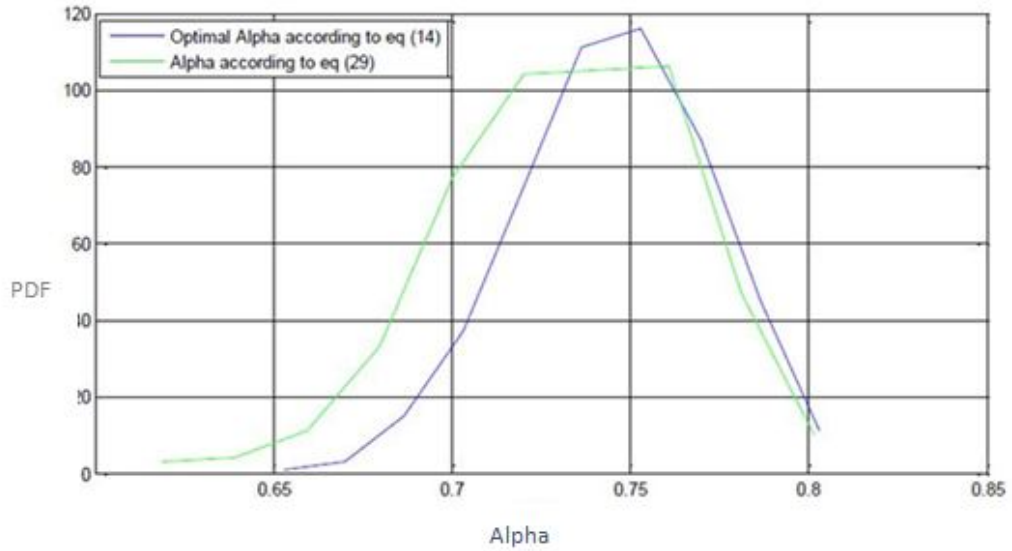


Figure 4.1: PDFs of Alpha

Figure 4.2 represents a plot of the alpha value in both cases for 500 iterations; each iteration is an average of 100 drops. If we compare both values at any of the 500 measurements will see that the difference between them is always less than 0.1 which means that the value of alpha calculated in equation (3.29) gives the optimal or the suboptimal value of the ABS ratio. It can be seen from these results that the result from equation (3.29) can be validated to give the optimal or suboptimal ABS ratio for the ITU channel model.

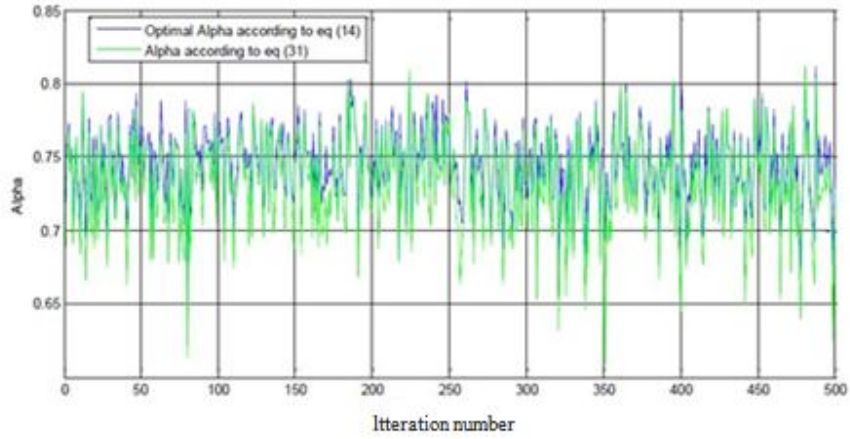


Figure 4.2: Plot of the 100 values of Alpha

4.3 Spatial channel model

In this part will repeat the previous simulation but using the Spatial Channel Model instead of the ITU channel model. Figure 4.3 represents the PDFs of the results from equations (3.14) and (3.29). And it shows that the pdfs are concentrated at very close values.

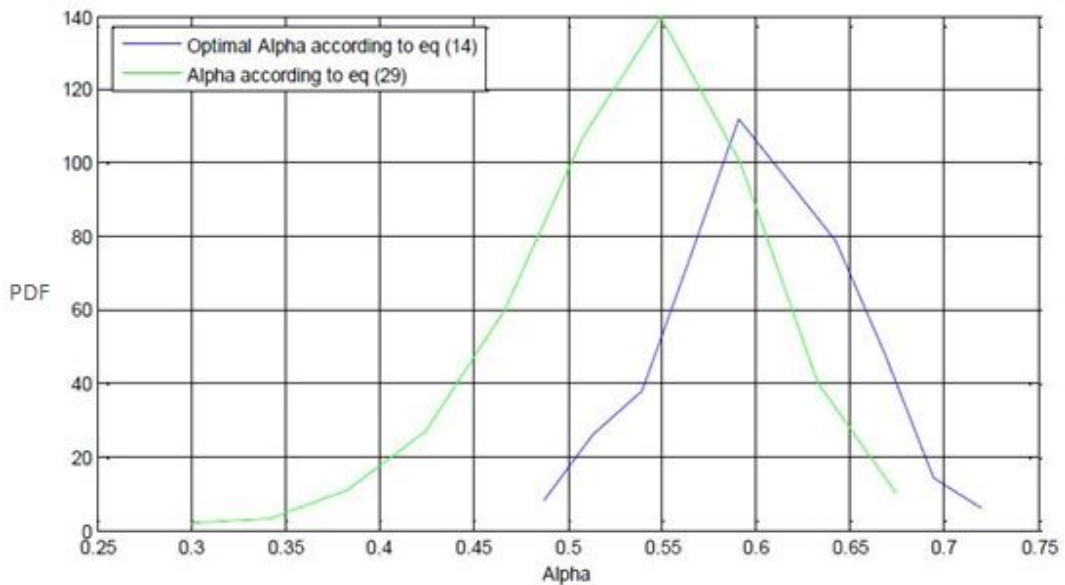


Figure 4.3: PDFs of Alph

Figure 4.4 represents the plot of the alpha value in both cases for 500 iterations; each iteration is an average of 100 drops. If we compare both values at any of the 500 measurements we will see that the difference between them is always less than 0.1 which means that the value of alpha calculated in equation (3.29) gives the optimal or the suboptimal ratio of ABS. It can be seen from these results that the result from equation (3.29) can be validated to give the optimal or suboptimal ABS ratio for the spatial channel model.

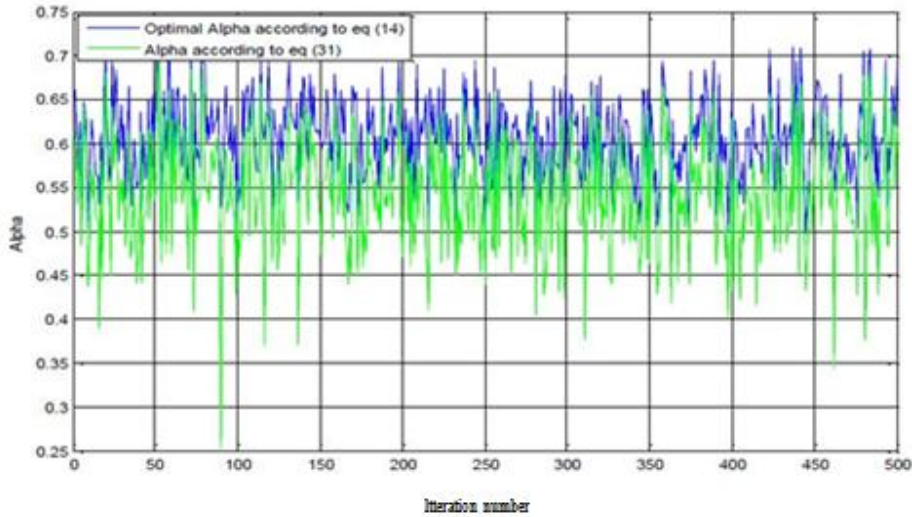


Figure 4.4: Plot of the 100 values of Alpha

In this section equation (3.29) has shown to be giving results very close to those of equation (3.14) which, in turn, shows that equation (3.29) gives the optimal ABS ratio in terms of cell edge user's throughput in the case of the ITU channel model and spatial channel model. It is also worth noting that the difference between the alpha values according to equation (3.29) and equation (3.14) is higher in the case of Spatial Channel Model compared to

the ITU channel model and this is due to the fact that the path loss in the case of SCM is lower than in the case of ITU channel model, which means that the interference in the ITU case is higher, so by putting the values of the channel gains according to SCM in equation (3.14) will get a larger value of alpha.

4.4 ITU channel model

Start by the ITU channel model. Figure 4.5 represents the PDFs of the results from both equations. And it shows that the PDFs are almost coinciding.

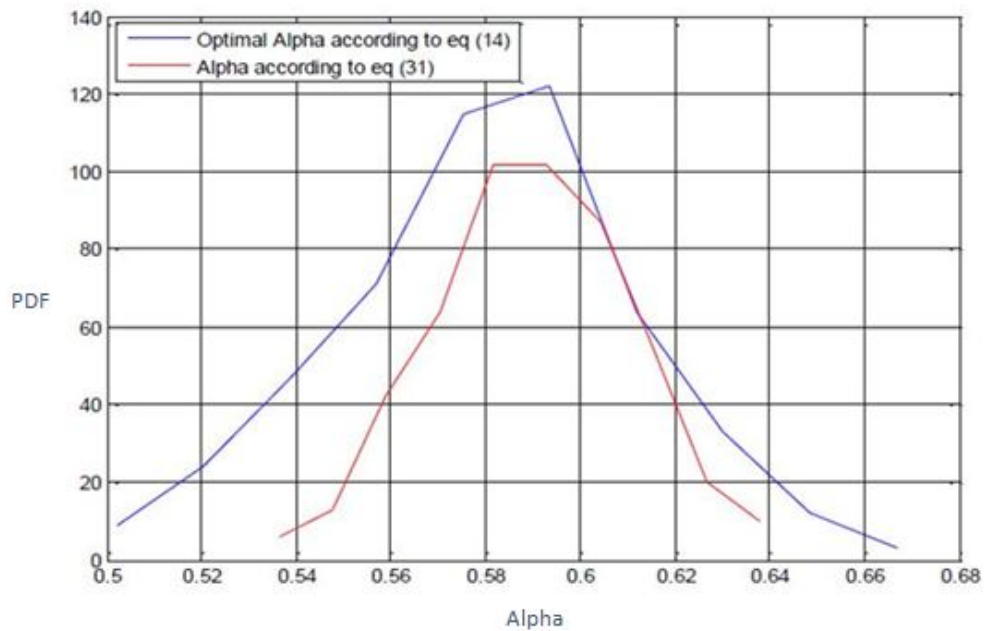


Figure 4.5: PDFs of Alpha

Figure 4.6 represents the plot of the alpha value in both cases for 500 iterations, each iteration is a 100 drops.

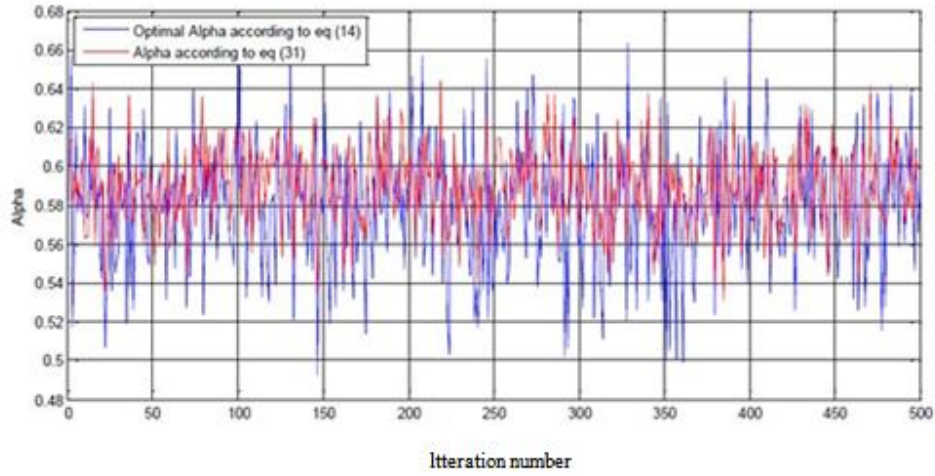


Figure 4.6: Plot of the 100 values of Alpha

These results show that the result in equation (3.31) is very close to the optimum value given by (3.14) when using the ITU channel model therefore it can be validated.

4.5 Spatial Channel Model (SCM)

In this part we will repeat the previous simulation but using the spatial channel model instead of the ITU channel model. Figure 4.7 represents the PDFs of the results from equations (3.14) and (3.31). And it shows that the PDFs are concentrated at very close values.

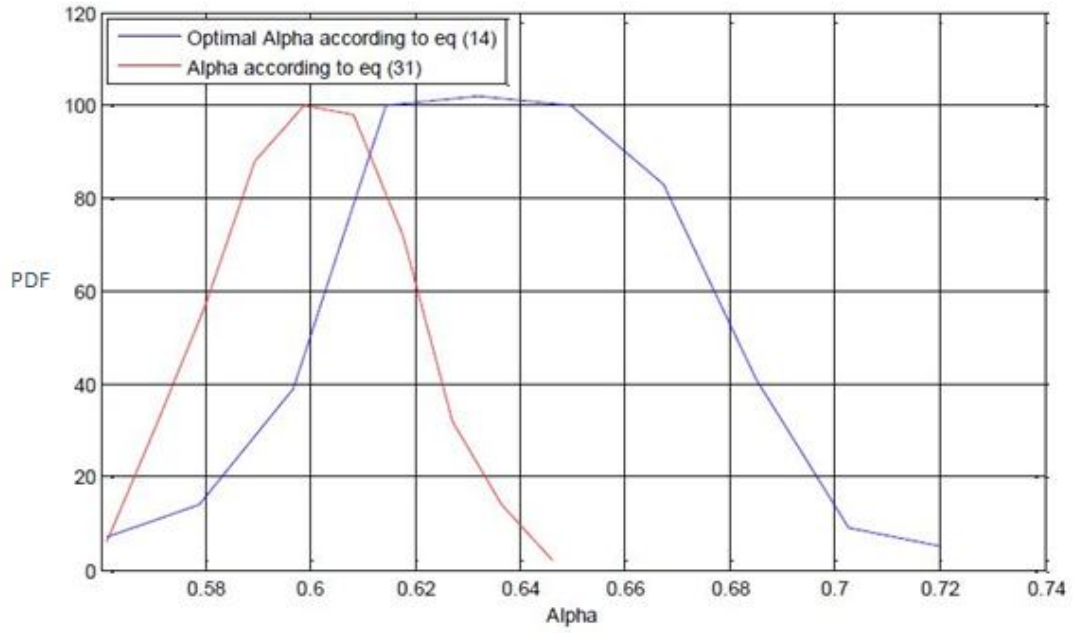


Figure 4.7: PDFs of Alpha

Figure 4.8 represents the plot of the alpha value in both cases for 500 iterations, each iteration is an average of 100 drop and as seen the values resulting of both equations are very close.

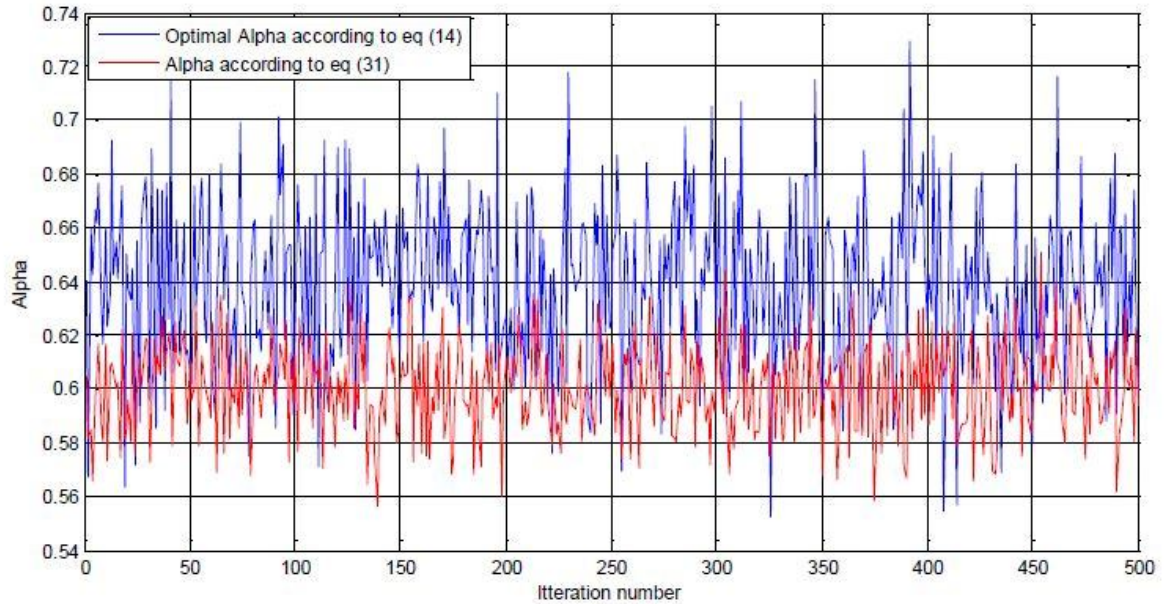


Figure 4.8 : Plot of the 100 values of Alpha

These results show that the result in equation (3.31) is very close to the optimum value given by (3.14) when using the spatial channel model therefore it can be validated. Same as the previous case, the difference between the alpha values according to equation (3.31) and equation (3.14) is higher in the case of Spatial Channel Model compared to the ITU channel model and this is due to the fact that the path loss in the case of SCM is lower than in the case of ITU channel model, which means that the interference in the ITU case is higher, so by putting the values of the channel gains according to SCM in equation (3.14) we get a larger value of alpha. To summarize, it has been shown that the theoretical deductions in equations (3.29) and (3.31) can be validated to give optimal or suboptimal results for the ABS ratio using Monte-Carlo simulations. In the following section an example that is a special case of the general model used in the deduction will be introduced to elaborate more on the theoretical results.

Can plot the users capacity in equations (3.2), (3.4) and (3.6) as a function of α , so by choosing one user from each group (Macro, center Pico and range extension Pico) and specifying values for the different parameters (channel gains, p_1 , p_2 , N_m , N_{p-c} and N_{p-re}) we get the plot in Figure 4.9

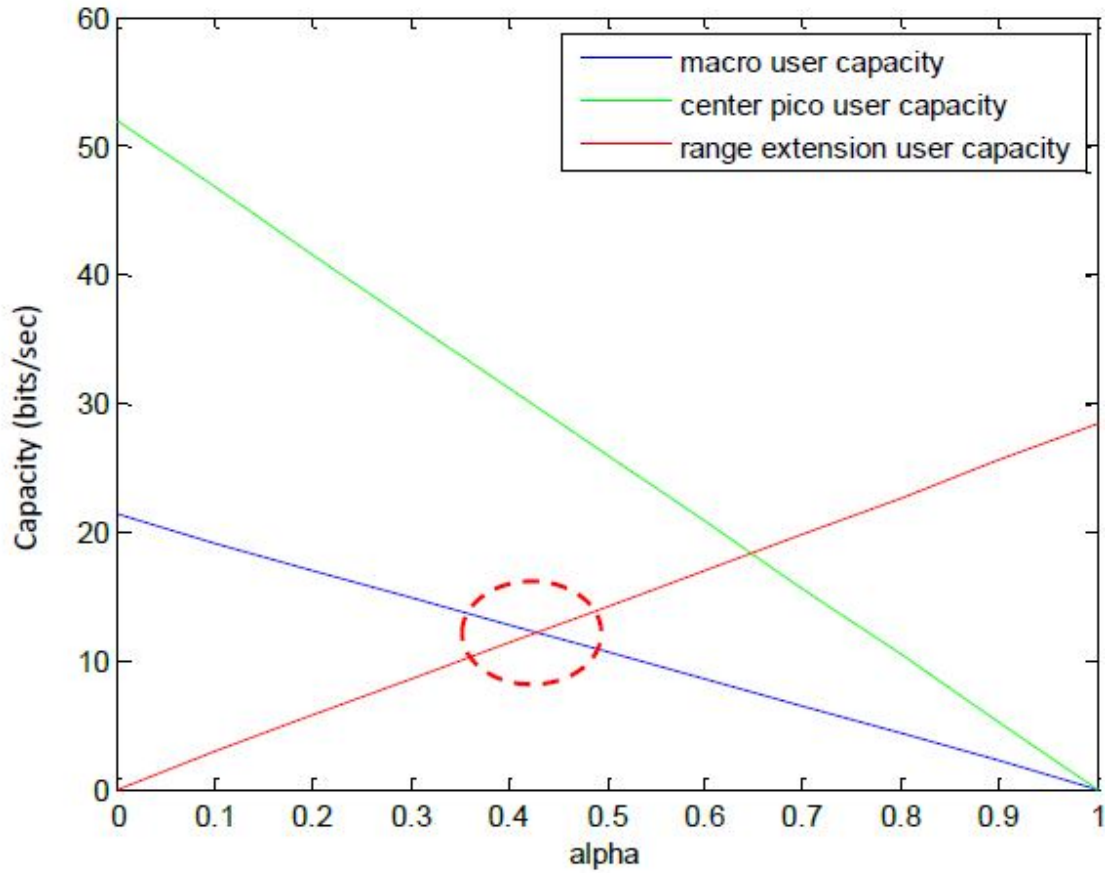


Figure 4.9: Plot of the capacity of Macro-eNB, center Pico-eNB and range extension users against α

Figure 4.10 represents the users who experience a decrease of throughput, the losers, when adding the Pico layer. The majority of the losers are Macro-eNB users (the red ones). also seen from Figure 4.10 these users are all cell edge users, as they have the lowest throughput, which means that they have low signal to interference and noise ratio (SINR) channel with the Macro-eNB and this makes them more prone to interference coming from the Pico-eNBs. So although the interference from the Pico-eNBs is small it can still affect low SINR Macro-eNB users.

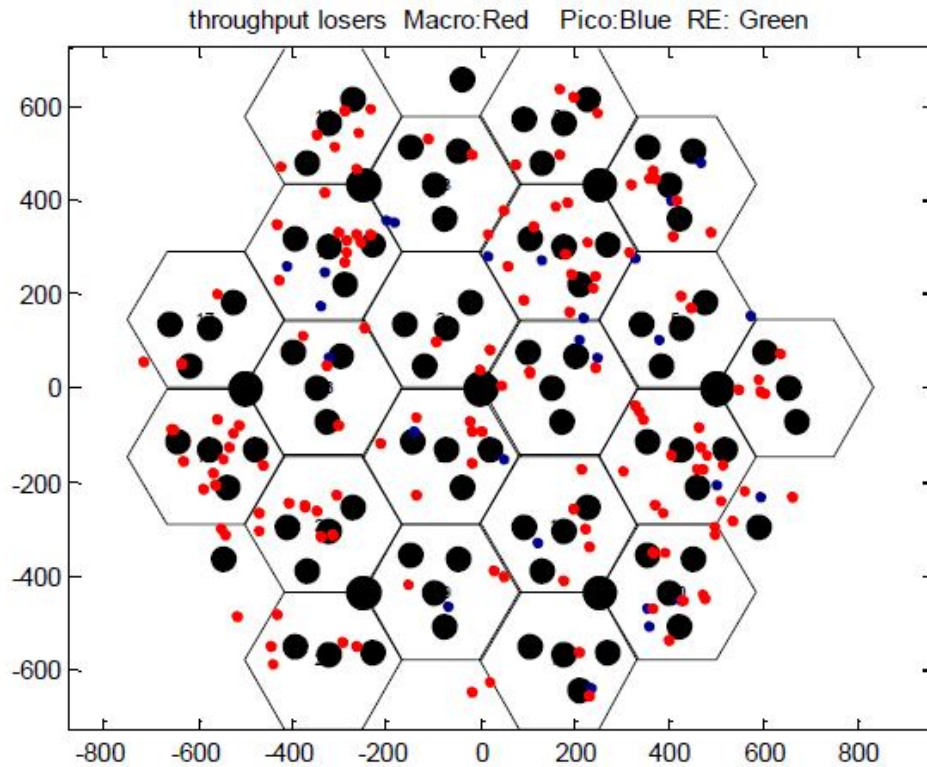


Figure 4.10: Illustration of the users experiencing a decrease of throughput after adding the Pico-eNB layer, Macro-eNB users (red) and Pico-eNB users (blue)

As a conclusion, adding the Pico-eNB layer increases the throughput for the majority of users except the Macro-eNB cell edge users which are affected by the interference coming from the Pico-eNBs.

4.6. Same example with the addition of an 8 dB range extension to the Pico-eNBs in the Macro+Pico case

Here we are comparing the following 2 scenarios:

- 1) Macro-eNB only deployment: we only have 1 Macro-eNB per cell

- 2) Macro-eNB + Pico-eNB + range extension deployment: we have 1 Macro-eNB and 4 Pico-eNBs per cell and applying an 8 dB range extension to the Pico-eNBs.

Figure 4.11 represents the users that are losing throughput when adding the Pico layer with range extension. As seen, most of the losers are range extension users, which means that these users suffer from a high interference from the Macro-eNBs. This shows the importance of using almost blank subframes (ABS) to protect the range extension users from the high interference coming from the Macro-eNBs.

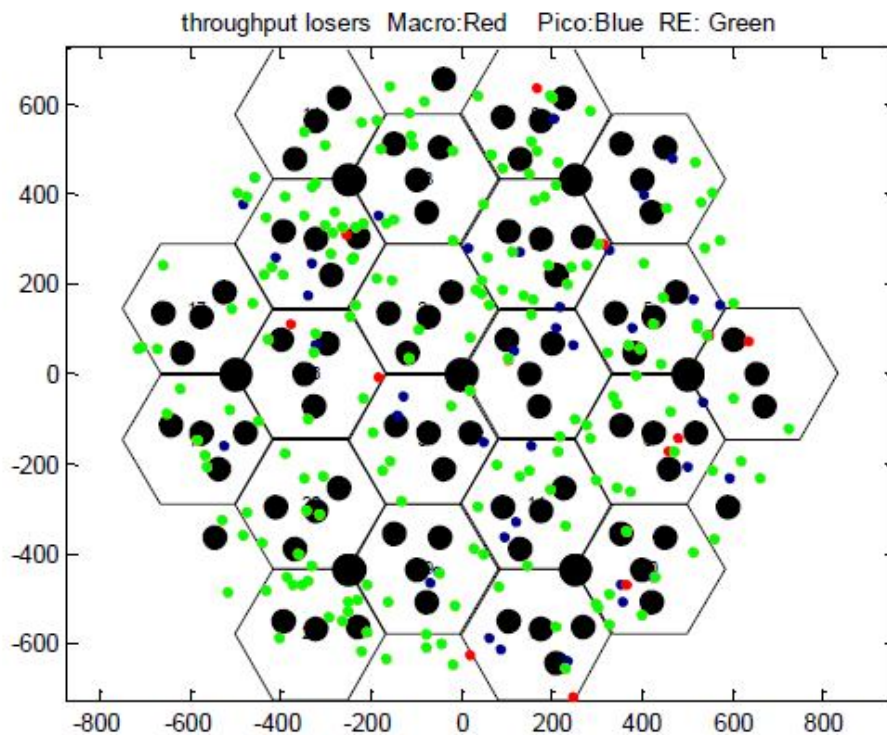


Figure 4.11 : Illustration of the users losing throughput after adding the Pico-eNB layer with range extension, Macro-Enb users (red), Pico-eNB users (blue) and range extension users (green)

4.7 Simulations demonstrating the benefits of using ABS

Through this example we will compare 2 scenarios:

- 1) Macro-eNB + Pico-eNB + range extension deployment
- 2) Macro-eNB + Pico-eNB + range extension + ABS of ratio (0.3), from equation (3.31), deployment.

Figure 4.13. Same as before, is showing the users whose throughput has decreased due to the use of an ABS ratio of 0.3. As seen most of these users are Macro-eNB users (red ones). This can be explained by the fact that after applying ABS the Macro-eNB users are only allowed to use 70% of the available sub-frames which, in turn, decreases the Macro-eNB user's throughput.

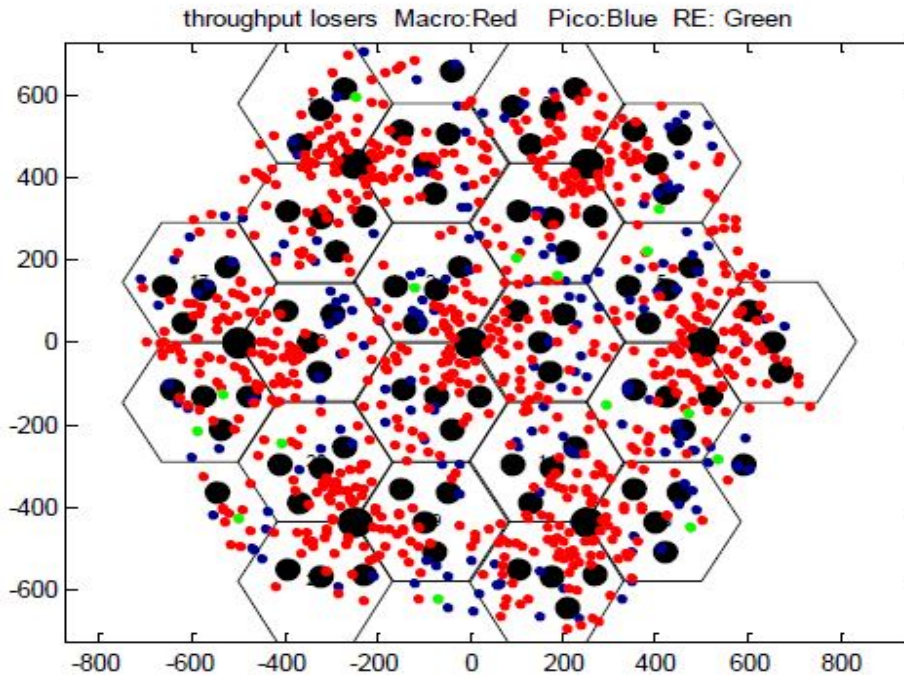


Figure 4.12 : Illustration of the users losing throughput after applying ABS, Macro-eNB users (red), Pico-eNB users (blue) and range extension users (green)

Figure 4.13 illustrates the normalized throughput of the cell edge users in the four cases (Macro only ,Macro + Pico, Macro + Pico + RE and Macro + Pico + RE + ABS), where the percentage represents the difference of each case with the (Macro only) case. We see that the fourth case (Macro + Pico + RE +ABS) has the best cell edge throughput.

Also the (Macro + Pico) case has a higher cell edge throughput than the (Macro+Pico+RE) case which shows that using range extension without ABS is not effective as range extension users suffer from a high interference level from the Macro-eNB.

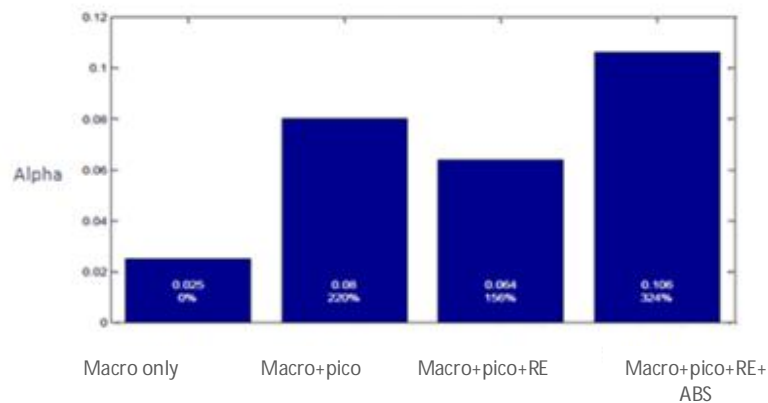


Figure 4.13: Cell edge throughput for the 4 cases.

Finally Figure 4.14 shows the normalized throughput per user for the 4 cases it can be seen that the 3 cases having the Pico-eNB layer have almost equal throughput while the Macro-eNB only case has a very low normal throughput.

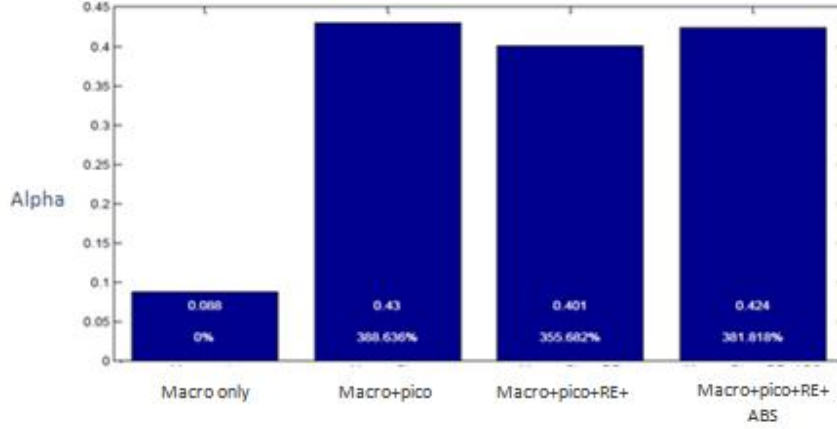


Figure 4.14: Normalized throughput per user for the 4 cases.

4.8. Simulations validating the ABS ratio formula for different users and Pico-eNBs distributions.

In this section we will present simulations validating the ABS ratio formula given by equation (3.31)

$$(\alpha_{opt} \approx \frac{1}{1 + \frac{N_m}{N_{re_tot}}})$$

(3.31)

That was deduced in section 4.2. The strategy will be to test several Pico-eNBs and users distributions with different range extension values and check if the formula holds. The results from equation (3.30) will be compared to the results from the same equation but using the maximum number of range extension users per cell (N_{re_max}) instead of the total number of range extension users (N_{re_tot}) per cell. The new equation is given by:

$$\alpha \approx \frac{1}{1 + \frac{N_m}{N_{re_max}}} \quad (3.30)$$

We will focus on the ITU channel model but at the end of the section some results for the Spatial Channel Model (SCM) will be shown to validate the theory for this model. As mentioned before the criterion to be optimized is the normalized throughput of the cell edge users and the average throughput per user, in general the formula gives the optimal or the suboptimal solution Which is acceptable as well as will be seen in the results. Each simulation consists of 5 drops, 2 seconds in total, and this is done to have enough information in order to get reliable results, so since we have 30 users per cell per drop then 1 drop will consist of 630 users and each simulation will consist of 3150 users. For each simulation the following 11 cases will be compared

1. No range extension
2. No ABS
3. ABS=0.1
4. ABS=0.2
5. ABS=0.3
6. ABS=0.4
7. ABS=0.5
8. ABS=0.6
9. ABS=0.7
10. ABS=0.8
11. ABS=0.9

Figure 4.15 represents the normalized user throughput and it shows minor changes between all the cases except the last 3 cases where the difference

with the no range extension case is between 5.7% and 8.2% but these cases have very low cell edge throughput. This is explained by the fact that we have a low

number of range extension users and the ABS ratio is very high (70% to 90%) so this allows the range extension users to be scheduled more frequently and to have a very high throughput, which explains the high normal throughput, while the number of Macro-eNB users is much higher and they are only allowed

to be scheduled in (10% to 30%) of the subframes so they have a very low throughput and most of the cell-edge users are Macro-eNB users, which explains the low cell edge throughput.

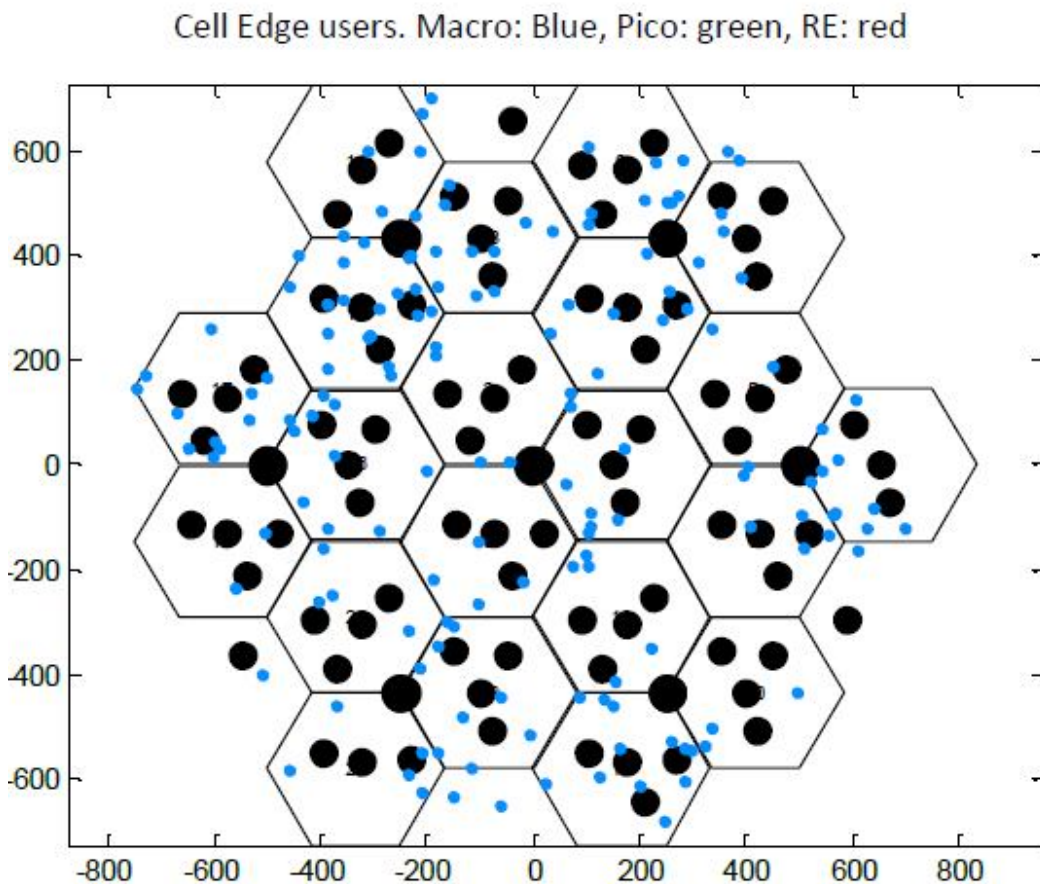


Figure 4.15: Cell edge users distributed among the 3 groups (Macro-eNB, center Pico-eNB and range extension) depending on the color.

Figure 4.16 represents the throughput CDF for the 11 cases, it can be seen that the ABS=20% case has the highest throughput for the first 10% users and maintaining a moderate throughput for the rest of the users while for the ABS=90% case it has the lowest throughput for the first 30% users, which are mostly Macro-eNB users, while it has the highest throughput for the 40% to 95% users and since the main criteria to optimize is the cell edge throughput it is very obvious that the optimum ABS value is 20% as given by the formula in (3.31).

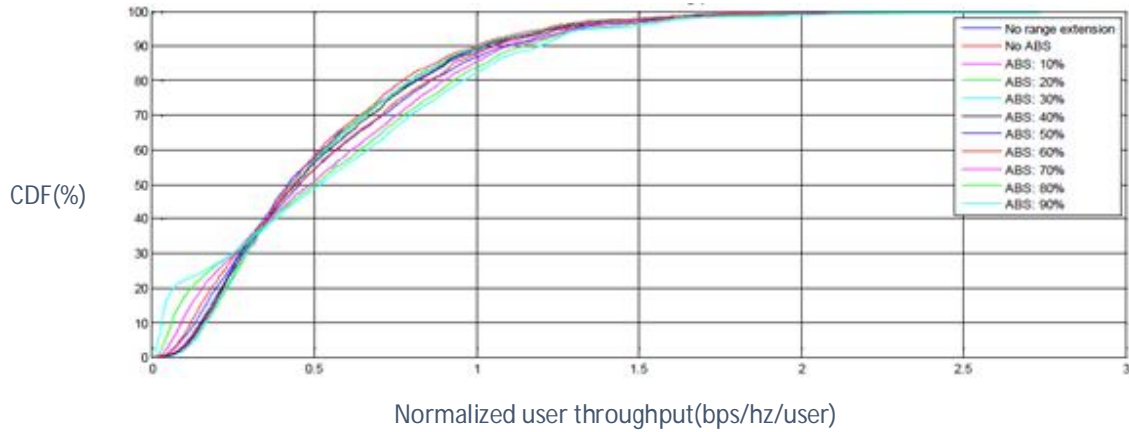


Figure 4.16 : throughput CDFs

As seen from Figure 4.17 and Figure 4.18, the α values and the resulting throughput according to equation (3.31) are far from the optimal values. The α values and the resulting throughput according to equation (3.31) are very close to the optimal α values and the resulting throughput according to simulations except for the range extension values 12 dB and 18 dB where there is an 0.1 difference between the optimum alpha value and the value calculated by equation (3.31) which is translated to a slight difference in the

resulting throughput and in that case the result from equation (3.31) is considered as a suboptimal solution as it has the closest value to the optimal solution.

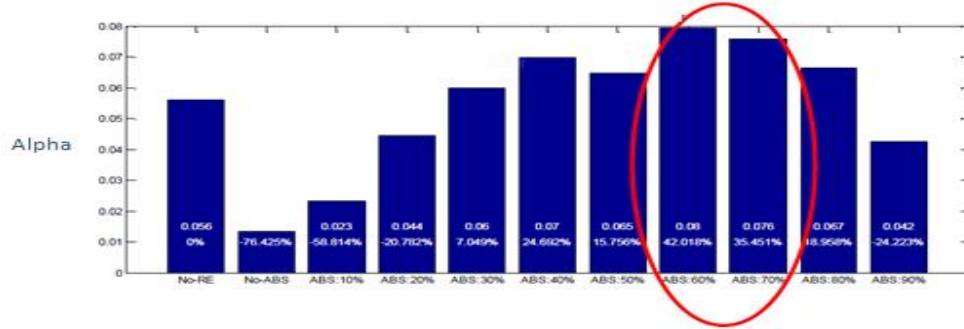


Figure 4.17: Normalized cell edge users throughput

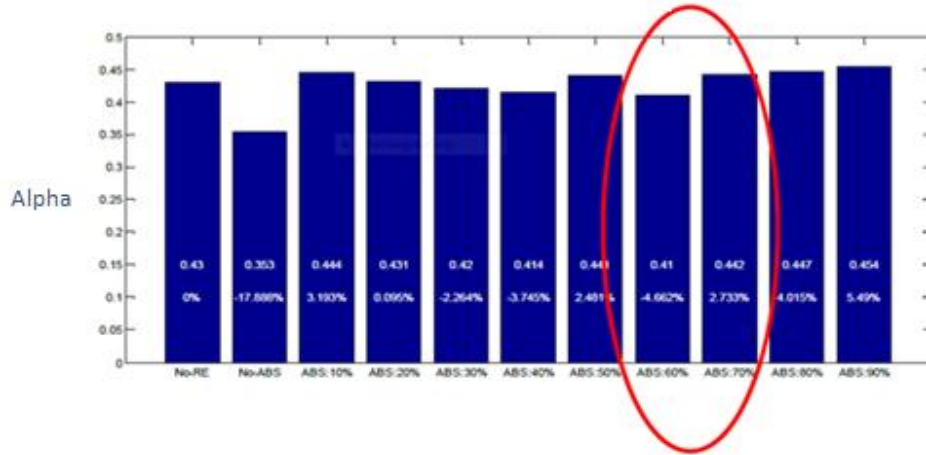


Figure 4.18: Normalized user throughput

4.9. Range extension performance

In this section we will study the benefits of having a high range extension value. will consider a case having (4 Pico-eNBs, configuration 4b and 18 dB range extension). If we consider the optimized value of the ABS ratio according to equation (3.31) (ABS=70%) we see that it has a high cell

edge users normalized throughput in Figure 4.19 and a high normalized throughput as well in Figure 4.20 .

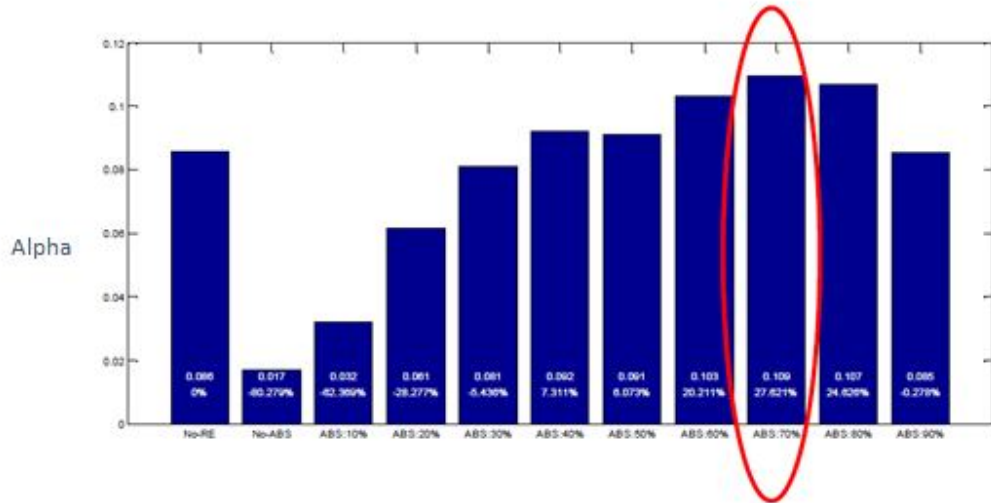


Figure 4.19: Normalized cell edge users throughput

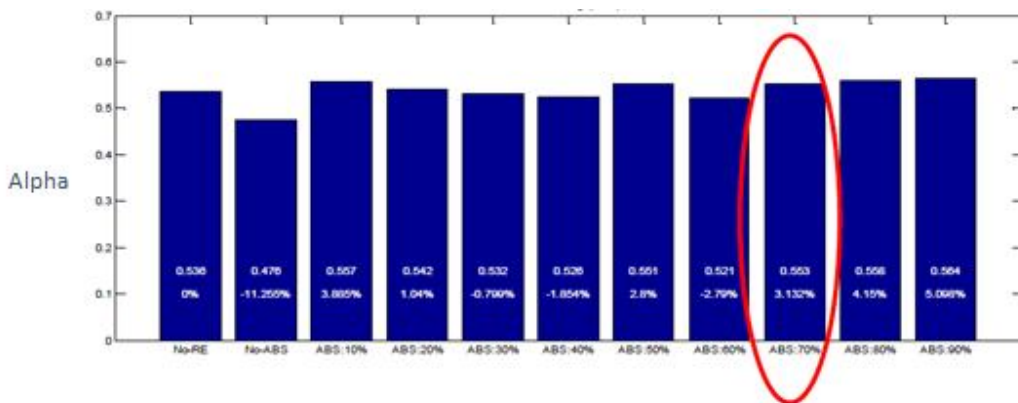


Figure 4.20: Normalized user throughput

Chapter Five

Conclusion and Recommendations

Chapter Five

Conclusion and Recommendations

5.1. Conclusions

In this thesis, heterogeneous networks have been evaluated as a part of LTE-Advanced features to meet IMT-Advanced requirements, benefits from HetNets, and enhanced ICIC techniques (ABS) have been implemented to solve the cross-tier interference in the time domain.

All these steps have been simulated using a Matlab system simulator that performs Monte Carlo simulations. Also system simulations using the Raptor simulator have been performed to validate the formula using different channel models, users distributions, Pico-eNBs numbers and range extension values. The results that have been obtained using the simulator in each step have been used to evaluate this technology, their benefits, their disadvantages and the assumed solution to handle them. LTE networks deployment improves the system performance overall, coverage, capacity, system throughput as well as SINR values, and allows for more efficient spectrum reuse. This results are providing higher data rates and maximum ABS ratio.

5.2. Recommendations

Developing flexible and forward-looking technologies such as Further Enhanced Inter-Cell Interference Coordination (FEICIC) and Almost Blank Subframes with flexible carrier aggregation. Future work will be focusing on the radio channel characteristics can be different at different frequency carriers.

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