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Performance Evaluation of Interference Management in Long Term Evolution-Advanced Networks using Almost Blank Subframes

تقييم اداء ادارة التداخل في شبكات التطور طويل الامد المتقدم باستخدام الاطار الفرعي شبه الفارغ

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الآية

قال تعالى :

بسم الله الرحمن الرحيم

لَقَدْ أَرْسَلْنَا رُسُلَنَا بِالْبَيِّنَاتِ وَأَنزَلْنَا مَعَهُمُ الْكِتَابَ
وَالْمِيزَانَ لِيَقُومَ النَّاسُ بِالْقِسْطِ ۖ وَأَنزَلْنَا الْحَدِيدَ فِيهِ
بَأْسٌ شَدِيدٌ وَمَنَافِعُ لِلنَّاسِ وَلِيَعْلَمَ اللَّهُ مَن يَنصُرُهُ وَرُسُلَهُ
بِالْغَيْبِ ۚ إِنَّ اللَّهَ قَوِيٌّ عَزِيزٌ ﴿٢٥﴾

صدق الله العظيم

سورة الحديد الآية(٢٥)

Dedication

To Prophet Mohammed 'Peace be upon him'.

To my beloved parents.

To all Electronic Engineering Students.

Acknowledgement

First Alhamdulillah that with his blessing this work is fulfilled

All thanks and appreciation for my supervisor **Dr. FathElrahman** for his patience with me . I appreciate the countless hours and the efforts he dedicated to guide me through this thesis

Abstract

Long-Term Evolution (LTE) allows operators to use new and wider spectrum and complements 3G networks with higher data rates, lower latency and a flat, IP based architecture to deal with sudden increase in demand for mobile broadband services and to further improve the broadband user experience in a ubiquitous and cost-effective manner 3GPP has been working on various aspects of the LTE Advanced standard. The enhanced Inter-Cell Interference Coordination (eICIC) in heterogeneous networks introduced in LTE-Advanced solve the problem of inter cell interference, which become a challenge. Since the resources of wireless network are limited due to the limitation on the spectrum and limited frequencies that is distributed on the network which limit the resources. The main aim of this project is to compare the time domain intercell interference reduction methods which are represented in ABS and RP-ABS , therefor the time domain eICIC was selected then a simulation was done using matlab in order to evaluate the performance of the two methods , an evaluation between these techniques were done in term of QoS parameters such as (SINR, Throughput, Spectrum efficiency, Transmission Delay and Outage probability) . The main results that was found that the reduction of the RP-ABS is efficient compared to the ABS about 11.25% , 3.2% , 30.5% , 10.3% , 90% on average in SINR, Throughput, Spectrum efficiency, Transmission Delay and Outage probability respectively.

المستخلص

نظام التطور طويل الأمد للاتصالات الخلوية يتيح للمشغلين استخدام طيف جديد وأوسع وتم عن طريق شبكات الجيل الثالث بمعدلات بيانات أعلى ووقت استجابة أقل ومعمارية مستندة إلى بروتوكول الإنترنت للتعامل مع الزيادة المفاجئة في الطلب على خدمات النطاق العريض المتنقل ولزيادة تحسين خدمات النطاق العريض و تجربة المستخدم في كل مكان وبطريقة فعالة من حيث التكلفة يعمل مشروع شراكة الجيل الثالث على جوانب مختلفة من معايير التطور طويل الامد المتقدم . إن تنسيق التدخل بين الخلايا المحسَّن في الشبكات غير المتجانسة التي تم إدخالها في شبكات التطور طويل الامد المتقدمة يحل مشكلة تداخل الخلايا الداخلية ، والتي اصبحت تحديًا بسبب محدودية موارد الشبكة اللاسلكية بسبب القيود المفروضة على الطيف والترددات المحدودة والموزعة على الشبكة . يتمثل الهدف الرئيسي من هذا المشروع في مقارنة طرق الحد من التداخل بين الخلايا باستخدام حلول المجال الزمني الممثلة في اطار ثانوي فارغ تقريبا و تخفيض قوة اطار ثانوي فارغ تقريبا ، تم إجراء محاكاة باستخدام برنامج الماتلاب من أجل تقييم أداء الطريقتين و تم إجراء تقييم بين هذه التقنيات من خلال عناصر جودة الخدمة ممثلة في نسبة الطاقة المرسلة الي التداخل والضجيج ، الإنتاجية ، كفاءة الطيف ، تأخر الإرسال و احتمال الانقطاع . النتائج الرئيسية وجدت أن تقليل التداخل عن طريق تخفيض قوة اطار ثانوي فارغ تقريبا فعال اكثر من اطار ثانوي فارغ تقريبا حوالي ١١,٢٥ ٪ ، ٣,٢ ٪ ، ٣٠,٥ ٪ ، ١٠,٣ ٪ ، ٩٠ ٪ في المتوسط في نسبة الطاقة المرسلة الي التداخل والضجيج ، الطاقة الإنتاجية ، الكفاءة الطيفية ، تأخيرِ الإرسالِ واحتمال الانقطاع على التوالي.

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3GPP	Third Generation Partnership Project
ABS	Almost Blank Subframe
BS	Base Station
CA	Carrier Aggregation
CCO	Coverage and Capacity Optimization
CDMA	Code Division Multiple Access
CET	Cell-Edge throughput
CRE	Cell Range Extension
CSB	Cell Selection Bias
dB	Decibels
DL	Downlink
eICIC	Enhanced Inter-Cell Interference Coordination
eNB	Evolved Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-UTRAN	Evolved Terrestrial Radio Access Network
FDD	Frequency Division Duplex
GMT	Geometric Mean user Throughput
GSM	Global System for Mobile Communications
HetNet	Heterogeneous Network
HSPA	High Speed Packet Access
ICIC	Inter-Cell Interference Coordination
ITU	International Telecommunication Union
LTE	Long Term Evolution
MAB	Multi-Armed-Bandit

MUT	Mean User Throughput
OFDMA	Orthogonal Frequency Division Multiple Access
PC	Power Consumption
PRB	Physical Resource Block
PS	Processor Sharing
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RB	Resource Block
RE	Resource Element
RF	Radio Frequency
RNC	Radio Network Controller
RP-ABS	Reduce Power Almost Blank Subframe
SINR	Signal to Interference and Noise Ratio
SON	Self-Organizing Network
TDD	Time Division Duplex
UA	User Association
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System

Chapter One

Introduction

1.1 Preface

Long term evolution (LTE) is the standard that the Third-generation Partnership Project (3GPP) developed to be an evolution of UMTS. The existing technologies such as 3G UMTS and 4G LTE are upcoming the theoretical limitations in terms of spectral efficiency. Since spectrum has become a limited resource a new ways have developed to improve the network performance [1]. The LTE networks method consists of complementing the Macro layer with low power nodes such as Micro or Pico base stations. LTE improve the capacity and data rate in the areas covered by these low power nodes because they are distributed depending on the Urban with generate higher traffic. Since cell selection for the users is based on the downlink power level and due to the transmitting power differences between Macro and Pico nodes. The limited spectrum became a problem on the high speed datarate communication system because it requires a high usage of the limited resources which increases the ICI intercell interference, thus the eICIC solution was developed to solve the problem. The time domain Enhanced Inter-Cell Interference Coordination (eICIC) techniques specified in LTE Rel. 10 standard improves the throughput of picocell-edge users by protecting them from macrocell interfering. On the other hand, it also reduces the collective capacity in macrocell because the macro base station (MBS) does not transmit data during certain subframes known as almost blank subframes [2].

The problem of intercell interference was solved by using Almost blank Subframes (ABSFs) which is a part of Enhanced Inter-Cell Interference Coordination (eICIC) framework[3] as means to combat extreme co-channel cross-tier interference in heterogeneous network (HetNet) scenarios. HetNet scenarios are generally cellular network scenarios that cover different type of low-power nodes, such as base stations (BSs), relays or remote radio heads, as motivated to the old macrocell tier. HetNet scenarios that are definitely targeted to benefit from ABSFs are groupings of macrocells with closed access femtocells (macro/femto) and macrocells with open access picocells (macro/pico)[4].

1.2 Problem Statement

The frequency reuse in LTE-A increases the interference which results in degradation of the network performance. To reduce interference there are so many mechanisms including Almost Blank Subframes (ABS) and Reduced Power Almost Blank Subframes (RP-ABS). So there is a need to compare the selected interference mitigation mechanisms to explore their strength and weaknesses under various conditions.

1.3 Proposed Solution

The proposed solution is to compare between Almost Blank Subframes (ABS) and Reduced Power Almost Blank Subframes (RP-ABS) for reduce the interference in LTE-Advanced .

1.4 Aims and Objectives

The main aim of this research to compare Almost Blank Subframes (ABS) and Reduced Power Almost Blank Subframes (RP-ABS).

The comparison consider the following performance metrics :

- SINR.
- Throughput is overall.
- Transmission delay.
- Spectral Efficiency.
- Outage probability .

1.5 Methodology

In order to fulfill the aim of the thesis a research background were obtained in heterogeneous network architecture, the scenarios of picking the places of the Macro-cells, All of the scenarios includes a problem of inter-cell interference which requires to be enhanced using enhanced inter-cell interference coordination eICIC in time domain as a reference taken for this study that includes two methods the almost blank sub-frame (ABS) and the reduced power almost blank sub-frame (RP-ABS). To evaluate the performance of a heterogeneous network ABS and RP-ABS, five performance metrics were measured and evaluated (SINR, throughput, spectral efficiency, and transmission delay and outage probability).

By using Matlab software to simulate the performance of a network consisting of one macro cell and some Pico cell, the performance metrics were evaluated for ABS and reevaluated for RP-ABS. The results were obtained and the system enhancement percentage was calculated.

1.6 Thesis Outlines

This thesis composed of five chapter their outlines are as follow: Chapter One: Is an introduction that covers the statement of the problem, the proposed solution and the objectives of the study. Chapter Two: Presents the literature review of LTE-Advance and its key features, heterogonous networks (motivation, design options, low power nodes type, advantages and disadvantages) also present related work ABS and RP-ABS. Chapter Three: Presents the methods of Almost Blank Subframes (ABS) and Reduced Power Almost Blank Subframes (RP-ABS), also provides the performance mathematical model and the simulation scenario used to measure the performance of the network. Chapter Four: Provide the simulation parameters and discussion of the results obtained from each simulation scenario also provide a comparison for the ABS and RP-ABS. Chapter Five: Provide the conclusion of the work done and the recommendation.

Chapter Two

Literature review

2.1 Background

Wireless communications was developed in the second generation (2G) systems of the early 1990s, which first represent the digital cellular technology, through the placement of third generation. The early 3G systems, of which there were five, did not directly run into the ITU. 2 Mbps peak data rate targets in applied deployment although they did in theory. However, there have been developments and improvements to the standards since then that have carried organized systems closer to and now well beyond the original 3G targets toward the 4th generation (LTE) [5].

2.2 Long Term Evolution-Advanced (LTE-A)

The Long-Term Evolution (LTE) is called “4G”, or referred to as LTE-Advanced. The true 4G evolution step, with the first release of LTE (release 8) then being categorized as “3.9G”. The work on LTE was initiated in late 2004 with the overall aim of providing a new radio-access technology focusing on packet-switched data only. The first phase of the 3GPP work on LTE was to explain a set of performance and capability targets for the LTE. This included targets on peak data rates, user/system throughput, spectral efficiency, and control/user-plane latency [5].

2.2.1 LTE-A Requirements

3GPP set a standard requirements for LTE-Advanced system to adapt the demands of the Radio Access Technology (RAT). The most important requirements are defined as follows [6]:

a) Scalable architecture with simplified implementation.

b) Seamless mobility, ensuring the Quality of Service (QoS) for higher speeds.

c) Reduced delays in transmission and connection procedures.

d) Increased user data rates, taking into consideration the cell-edge throughputs.

e) Enhanced Inter-Cell Interference (ICI) mitigation schemes.

f) Reduced cost per bit, with a guaranteed spectral efficiency.

g) Flexible and efficient spectrum usage in all allocated bands.

h) Optimal power consumption, especially for UEs.

2.2.2 LTE-A Architecture

Radio-Access Network (RAN) and the Core Network (CN) was revisited, including the split of functionality between the two network parts. This work was known as the System Architecture Evolution (SAE) and resulted in a flat RAN architecture, as well as a new core network architecture referred to as the Evolved Packet Core (EPC). Together, the LTE RAN and the EPC can be referred to as the Evolved Packet System (EPS). The RAN is responsible for all radio-related functionality of the overall network including scheduling, radio-resource handling, retransmission protocols, coding and various multi-antenna schemes.

The EPC is responsible for functions not related to the radio interface but needed for providing a complete mobile-broadband network. This includes authentication, charging functionality, and setup of end-to-end connections. Handling these functions separately, instead of integrating them into the RAN, is beneficial as it allows for several radio access technologies to be served by the same core network [5].

a) Core Network

The EPC is a radical evolution from the GSM/GPRS core network used for GSM and WCDMA/HSPA. EPC supports access to the packet-switched domain only, with no access to the circuit switched domain. It consists of several different types of nodes.

The Mobility Management Entity (MME) is the control-plane node of the EPC. Its responsibilities include connection/release of bearers to a terminal, handling of IDLE to ACTIVE transitions, and handling of security keys.

The Serving Gateway (S-GW) is the user-plane node connecting the EPC to the LTE RAN. The S-GW works as a mobility anchor when terminals move between eNodeBs, as well as a mobility anchor for other 3GPP technologies (GSM/GPRS and HSPA).

The Packet Data Network Gateway (PDN Gateway, P-GW) connects the EPC to the internet. Allocation of the IP address for a specific terminal is handled by the P-GW, as a quality-of-service enforcement according to the policy controlled by the PCRF.

The Home Subscriber Service (HSS) node, a database containing subscriber information [5].

b) Radio-Access Network

The LTE radio-access network uses a flat architecture with a single type of node – the eNode-B. The eNode-B is responsible for all radio-related functions in one or several cells. It is important to note that an eNode-B is a logical node and not a physical implementation. One common implementation of an eNode-B is a three-sector site, where a base station is handling transmissions in three cells, although other implementations can be found as well, such as one baseband processing unit to which a number of remote radio heads are connected. The eNode-B is connected to the EPC by means of the S1 interface, more specifically to the S-GW by means of the S1 user-plane part, S1-u, and to the MME by means of the S1 control-plane part, S1-c. One eNode-B can be connected to multiple MMEs/S-GWs for the purpose of load sharing and redundancy.

The X2 interface, connecting eNode-Bs to each other, is mainly used to support active-mode mobility. This interface may also be used for multi-cell Radio Resource Management (RRM) functions such as Inter-Cell Interference Coordination (ICIC). The X2 interface is also used to support lossless mobility between neighboring cells by means of packet forwarding. The X2 interface is also used to support lossless mobility between neighboring cells by means of packet forwarding [5].

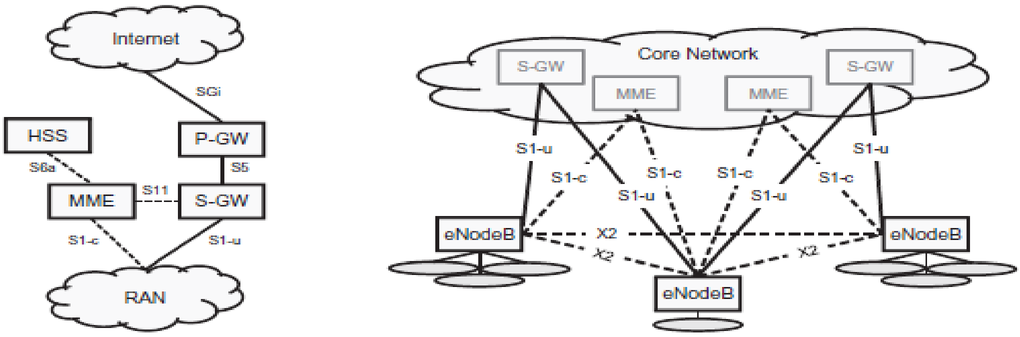

Figure 2.1: Core-network (EPC) architecture and Radio-access-network interfaces [5].

2.2.3 LTE-A Frame Structure

LTE-A supports either FDD or TDD modes, and two types of frame structure are standardized by 3GPP TS 36.211 [7]:

a) **Frame structure type 1:** where the radio frame is divided into ten equally-sized subframes of 1 millisecond time span, each subframe is composed of two time slots (0.5 ms). Therefore, one radio frame (10 ms) contains 20 time slots. Each radio frame has 307200 Ts (the basic time unit), which is 30.72 MHz, so one Ts equals 1/ (15000×2048) seconds. Figure 2-2 illustrates the radio frame structure type 1.

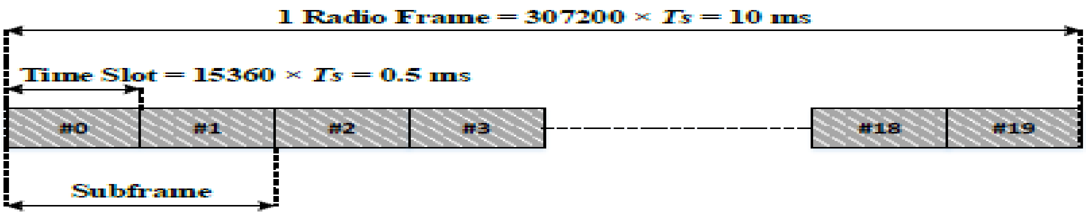

Figure 2.2: Radio Frame Structure (type1)[7]

b) **Frame structure type 2:** in this type, the radio frame is divided into two equal half frames, where each half is divided into five equal subframes of 1-millisecond size. Two types of subframes are defined in this frame, as shown in Figure 2-3: special and non-special subframes. The special subframes are subdivided into Downlink Pilot Timeslot (DwPTS), Guard Period (GP), and Uplink Pilot Timeslot (UpPTS), which exist in both halves of the radio subframe.

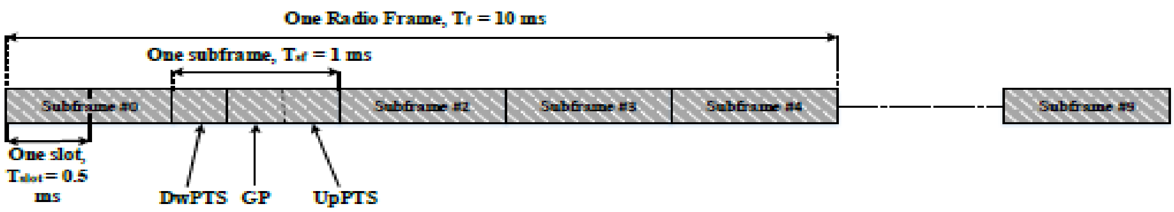

Figure 2.3: Radio Frame Structure (type 2)[7]

2.2.4 LTE-A Physical Resource Block (PRB)

LTE-A systems simplify the resource allocation by grouping Resource Elements (REs), which are considered the smallest unit of the frame and contain a single complex value of data from a physical channel or signal, into a larger group known as Resource Blocks (RBs). An RB is well-defined as the smallest unit that can be allocated to a user by an eNB's scheduler of the eNB. It represents a time-frequency grid of REs (as shown in Figure 2-4), where each PRB spans 180 kHz and consists of 12 consecutive subcarriers (15 KHz width each) in frequency-domain and

7 OFDM symbols in time domain. However, in the case of using an extended prefix, the number of OFDM symbols will be 6 rather than 7[8].

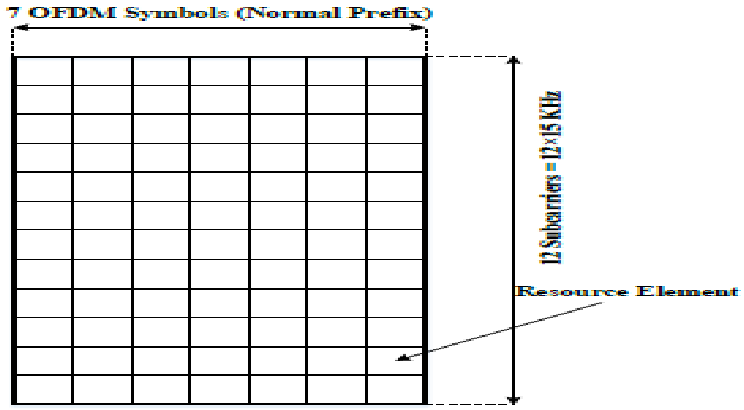

Figure 2.4: Physical Resource Block (PRB)[8]

2.3 Heterogeneous Deployment of LTE-A

HetNet is one of the most efficient solutions for achieving optimum spectrum and network efficiencies. HetNets have referred to the deployment of different radio access techniques within the same coverage area (Inter-RAT implementation), while in this thesis the term “HetNet” indicates the heterogeneous deployment of LTE-Advanced system where the regular High Power Cells (Macro cells) are overlaid by Low Power Cells, forming a multi-tier network (as shown in Figure 2-5). Such implementation is used to enhance network capacity and/ or network coverage in different deployment scenarios. Furthermore, such types of network can improve both average and cell-edge users throughputs [9].

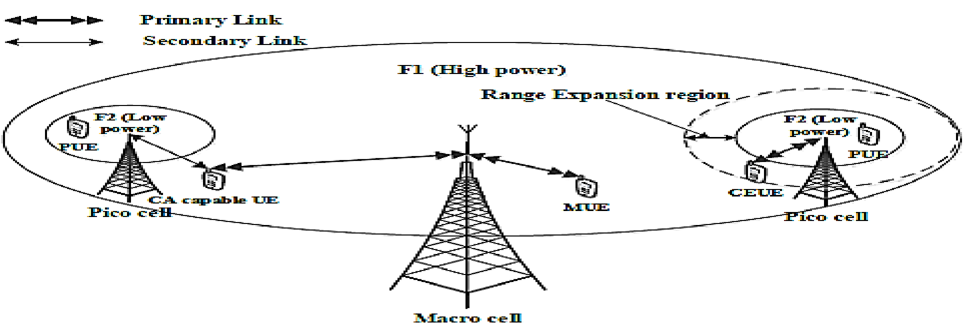

Figure 2.5: Heterogeneous deployment in LTE-Advanced network[9]

These low-power cells include Micro cells, Pico cells, Femto cells, and Remote Radio Heads (RRHs), where the classification of cells is mainly based on transmit power, coverage area, physical size, and backhaul and radio propagation characteristics [10]. Seven types of cells are classified, where cell radius of type A and type B represent a Macro cell and Micro cell respectively, according to ITU-R, as shown in Table 2-1.

Table 2-1: Cell Classification according to ITU-R [11]

Type	A	B	C	D	E	F	G
Cell Radius (m)	289	115	92	69	46	23	11
Tx power (dBm)	46	30	28	26	22	16	10
Antenna height (m)	60	26	24	22	20	18	16

Type C cell size=80% of type B; likewise, types D, E, F, and G cell sizes are 60%, 40%, 20%, 10% respectively compared to type B [11].

2.3.1 Advantages of Heterogeneous Networks

The goals of deploying HetNets are to offload data from the possibly congested Macro cells toward the LPCs, to achieve enhancements for outdoor/ indoor coverage, more spectrum reuse, and to increase the network throughput for cell-edge users. Moreover, it provides better link quality and low power consumption by reducing the path between the transmitter and the receiver [12].

The new physical layer design of LTE introduces a flexible resource partitioning among cells of different power classes, to achieve the optimum resource utilization. However, interference is a critical issue that affects the operation of HetNets, so advanced techniques for interference management should be carefully chosen. In LTE Release 8, ICIC technique is used to mitigate the downlink interference between cells [13]. Consequently, ICIC techniques were enhanced efficiently in the next successive releases mainly to support co-channel deployment in heterogeneous networks.

Since there is no X2 interface defined between Macro/ Femto cells to enable interference coordination techniques, interference management for co-channel deployment can be done through Operation and Maintenance (OAM) and power control techniques (in Release 10) to minimize the link failure due to interference. Studies on Release 12 and onward focus on network densification to meet the increasing demands for high-speed applications without affecting the scarce spectrum. In turn, such deployments require the development of the number of radio and protocols solutions to achieve that gain [14].

2.3.2 Carrier Frequency Allocation

Due to some regulatory limitations and heavy usage of the recent spectrum, most heterogeneous deployments focus on same-frequency operations (intra-frequency) wherein Macro/ low-power cell layers share the same carrier frequency(s).

Where different scenarios for heterogeneous deployment are suggested:

a) Macro/ low-power cells share the same carrier frequencies (Intra-frequency).

b) Macro/ low-power cells use different carrier frequencies (Inter-frequency).

c) Deployment of only low-power cells sharing one or more carrier frequencies.

Thus, using different carrier frequencies for both layers (Macro/ low-power cells) has less complexity as it does not require a centralized architecture or tight coordination between layers. However, such enhancement comes with the price of multiple carriers' usage, and Inter-frequency handover, which consumes more time and terminal battery life

[15]. On the other hand, Intra-frequency deployment is spectrum efficient sine it can provide better resources partitioning [16] but it is more challenging to mitigate the cross-tier interference and mobility management between cells using the same carrier frequencies. These two challenges require a robust UE solution to overcome such interference in heterogeneous deployment. The availability of higher frequency bands (e.g. 3.5 GHz) can support better spectrum usage by using separate spectrums for each layer, which leads to minimized interference between the two network layers. Frequency-separated deployments can be used to exploit both duplex schemes (FDD/TDD) to achieve better performance. Dynamic TDD is possibly beneficial in local area coverage, where the network can dynamically choose between UL and DL according to the instantaneous needs [17].

2.3.3 HetNet Components

HetNets follow the same architecture of any LTE-A network (as described in section LTE-A Architecture). However, several types of cells with different characteristics could be deployed in such networks, forming a multi-tier network [18]:

a) **Macro cells**: refer to the conventional eNBs, which are installed by operators to provide open access to all users subscribed to the network. This type of cell has a high transmit power of up to 46 dBm and covers a wide area of a few kilometers. It is utilized to serve thousands of users with a minimum guaranteed data rate and tolerable delay.

b) **Pico cells**: they are fully-fledged eNBs with low transmit power (23-30 dBm), deployed by operators to improve network capacity/ coverage for either indoor or outdoor environment. They provide open access for all users of the network when Macro cell capabilities are insufficient for dense areas.

c) **Femto cells**: this term describes the low-power cells (up to 23 dBm) used to provide unplanned deployment by users for indoor environments (e.g. office, mall, etc.). This type of cell features some access restrictions for certain users, as they are deployed by the customers, and they utilize other types of backhauling (e.g. DSL) to reach the mobile network.

d) **Relay nodes**: refer to the access points used to route the data from Macro cells to the users to extend the coverage in new areas. They use wireless backhaul to connect the Macro cells and have limited capabilities as compared with other low-power cells.

2.3.4 Technical Challenges in HetNets

As a result of different power characteristics of cells (e.g. transmit power, power control settings), HetNet has several challenges, which have significant impacts on the potential achieved performance of this type of deployment. Based on the literature, the most major challenges can be outlined as follows [19] :

a) Imbalanced coverage between UL/DL: transmit power disparity between the Macro cell and low-power cell is one of the biggest problems in HetNets, where the best DL cell and the best UL cell for a certain UE may be different, as a result of different output power for each cell. Moreover, each cell may have a different UL power control setting. Due to a larger transmit power of Macro cell, handover boundaries are shifted closer to the low-power cell, which can lead to severe UL interference as a result of Macro user impact on low-power cell.

b) More frequent handover due to smaller footprints of low-power cells, which leads to more signaling overhead. Signaling overhead could be minimized by using an RRC inactivity timer. A shorter RRC inactivity timer leads to less handover signaling overhead compared to connection setup overhead.

c) Interference from Macro cell to low-power cells which causes underutilization in low-power cells (which is the most effective challenge for many deployments).

d) Cell selection (especially for UE in CE region).

e) UL interference due to shifted handover boundaries toward the low-power cells.

f) Mobility robustness: due to the more frequent handover, heterogeneous deployment leads to more handover failure (HOF), which has a negative impact on the Quality of Service.

g) Backhauling limitations between the Macro cell and low-power.

2.3.5 Interference Scenarios in HetNets

Despite the significant benefits of deploying HetNets to increase the network capacity or to extend the coverage in a cost-effective way, the inter-cell interference is the largest challenge in such networks when using co-channel deployment. Figure 2-6 describes the possible inter-cell interference in an LTE-A network with cells of different classes .

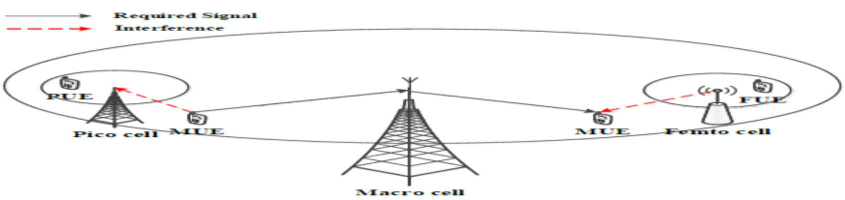

Figure 2.6: Interference Scenarios in HetNets[20]

Uplink (UL) interference: Normally, the Macro UE (MUE) receives high transmit power from the serving Macro cell, and at the same time it transmits with high power in UL as well. For Macro/ Pico cells co-channel deployment, both cells share the same radio resources, so the Pico cell close to that Macro cell receives high UL interference from all MUEs located in its proximity [20].

Downlink (DL) interference: The main DL interference in HetNets is caused by Femto cells of CSG access because they still have high transmit power on MUEs in their neighborhood while they reject those UEs from accessing their resources. There is another possible DL interference coming from Pico cells towards the MUEs in their vicinity.

2.3.6 Transmission Mode (CSG, OSG, HSG)

Several access modes are identified in LTE-A HetNets to regulate the UEs access to the network:

a) **Closed Subscriber Group (CSG)**: It is the most restricted access mode, which is mainly defined for the Femto cells. In this mode, only predefined UEs have the exclusive permission to connect the Femto cell [21].

b) **Open Subscriber Group (OSG)**: Where all UEs in the network has the right to connect the open access cells.

c) **Hybrid Subscriber Group (HSG)**: In this mode, the highest priority access is for the predefined UEs; subsequently, the rest of the UEs can access that cell according to the available resources.

2.3.7 Cell Range Expansion (CRE)

Conventionally, cell selection in LTE systems is done by a UE based on Maximum RSRP (Max. RSRP) among several surrounding cells. As a result of different power characteristics in heterogeneous networks, this results in less offloaded users from Macro to the low-power cell, which leads to load imbalance in HetNets.

CRE is one of the recent solutions to solve the problem of UL interference. In this concept, the low-power cell RSRP is positively biased by a CSO, as shown in Figure 2-7 to increase their DL coverage , and to overcome the situation of fewer users offloaded from Macro cell towards the low-power cell [22]. The bias value refers to a threshold that triggers handover between two cells. A positive bias means that UE will be handed over to the low-power cell when the difference in signal strength from the Macro cell and low-power cell drops below a bias value.

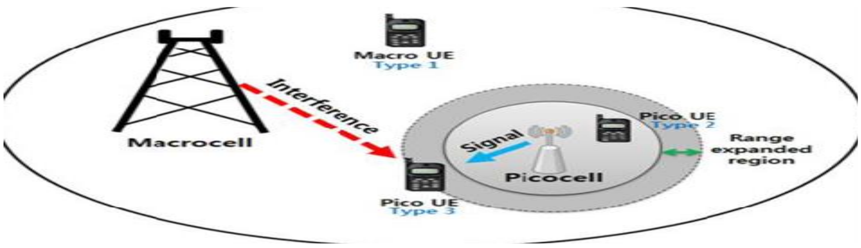

Figure 2.7: Cell Range Expansion[22]

Maximum gain can be achieved by adjusting handover boundaries between the Macro cell and low-power cells. Neighboring Cell List (NCL) is periodically broadcast by the serving cell to facilitate users in monitoring air interface; this list includes neighboring cells and their pilot signals. UE performs channel measurements and reports the results to its serving cell periodically, which in turn decides whether to start HO procedures via exchanging HO-related command message with the target cell. If the serving cell receives a measurement report (MR) from a UE about Pico cell, it will add a bias to the Downlink Received Signal Strength (DL RSS) pilot signal coming from that Pico cell (Pico RSRP). DL RSSs are usually averaged and filtered by UEs in both frequency and time domains to cope with signal fluctuation caused by channel fading . It has been shown in [23] that, using optimal biasing achieves 35-40% better gain, compared to heterogeneous networks without biasing. A bias value (0~20 dB) [24] indicates the threshold to trigger handover between two cells. A positive bias value is applied to the low-power cell where UE is handed over to the low-power cell when the difference in signal strength between Macro / low-power cell in CE region drops less than this bias value. "CRE may be useful for the Macro cell to reduce the number of handovers". Employing a positive bias is necessary to improve load balance in HetNet [25]. However, fixed bias value could not adapt the change in user distribution over time, so it is important to dynamically adjust the RE region according to the system performance feedback, to achieve the optimum load balancing and better cell-edge user throughput while maintaining the overall cell performance.

2.4 Interference Management in LTE

Two main types of interference management have been highlighted in most mobile systems: Interference cancellation and interference mitigation. The first type of interference management is implemented on the received signals by subtracting the interfering signals to allow only the required signals from being decoded successfully. Despite the fact of achieving high capacity, the implementation of interference cancellation in mobile systems may result in high process complexity to estimate the interfering signals. As a result, interference mitigation has gained more attention to prevent the interference before its occurrence. This mitigation can always be achieved by frequency planning, power control, and antenna planning. Mobile networks operators have several spectrum bands, which should be carefully utilized to achieve higher capacity while maintaining the lowest levels of interference [26].

2.5 Inter-Cell Interference Mitigation in Heterogeneous Deployment

HetNets face several challenges that affect the performance of such networks (e.g. load balance, Inter-cell Interference, cell selection, mobility robustness, etc.), so many solutions have been introduced through the successive releases of LTE to overcome the aforementioned challenges. Several spectrum assignments have been adopted in heterogeneous networks for efficient spectrum utilization. One of these assignments is the fully-dedicated spectrum, where a different set of spectrum bands are assigned for the Macro cells and low-power cell. In this approach, the cross-tier interference is totally avoided. However, the limited spectrum share for each tier results in low spectrum efficiency which has a negative impact on the network performance. Therefore, shared spectrum (co-channel deployment) can offer higher spectrum utilization but with the cost of high interference possibilities that necessitate a well-planned inter-cell interference coordination in such implementations. The next subsections will discuss some of the most efficient techniques to mitigate the ICI problem based on literature [27].

a) Power-Domain Inter-Cell Interference Coordination (PD-ICIC)

UEs measure the DL Received Signal Strength (RSS) of the pilot signals continuously of the surround cells to choose the serving cell. Noting that, the pilot signal is usually transmitted at a fixed power and it implies the Physical Cell Identities (PCIs). Moreover, the NCL, which contains the list of neighbor cells and the pilot signals are broadcast by the serving cell periodically. Thus, UE performs the channel measurements and report them back to its serving cell, which is significant for making a handover decision. In this scheme a cooperative algorithm is required to make a decision for the maximum power that every Macro cell can apply on each RB used by cell-edge UEs to provide the necessary SINR for these UEs. UE calculates the maximum tolerable ICI, target SINR, and the noise power, to measure the maximum power and the RB index that can be used by the neighbor cell. In this way, Macro cells should allocate RB powers according to the power constraints derived from previous steps to mitigate the potential interference toward the cell-edge UEs of the neighbor cells. Such scheme requires a scheduling priority as there is independent power allocation for the available RBs. One of the main challenges in this scheme is how to maintain the required throughput of all attached UEs when using different power allocation on some RBs [27].

b) Coordinated Multipoint (CoMP)

It is a technique developed by 3GPP for LTE-Advanced (Release 11 and onward) to send and receive data to/ from several points to ensure the optimum performance regarding cell-edge and system throughputs . The primary difference between the standard MIMO and CoMP is that the transmitters in the latter are not physically co-located.

The idea behind this technique is to enable dynamic coordination of transmission and reception over several base stations, to turn the Inter-Cell Interference into a useful signal, especially at cell borders where the problem of ICI increases. Several types of CoMP have been introduced, which are defined for the downlink as follows:

Joint Transmission (JT): This is a type of spatial multiplexing when more than one point cooperate so that UE data is transmitted simultaneously from several points.

Dynamic Point Selection (DPS): In this case, all points share the UE data, while only one point is chosen to transmit this data according to the coordination of all surrounding points.

Other types of coordinated scheduling and beamforming are also defined where UE data is only available and transmitted from a single point, but all points coordinate their scheduling decisions and resource allocation inside the cooperating set [27].

c) **Frequency Domain-based Inter-Cell Interference Coordination (FD-ICIC)**

According to 3GPP standards in [28], CA is considered a prominent method of performing frequency-domain ICIC. Interference in DL control channels can be mitigated by partitioning the component carriers (CCs) in the cell layers into two different sets: Primary Component Carrier (PCC) for data and control, while the Secondary Component Carrier (SCC) is mainly for data (or also for control if power control applied) . Figure 2-8 illustrates such a CA-based ICIC scheme. Carrier aggregation is used by both Macro cell and low-power cell layers where both layers enable data communication over f1 and f2. The Macro cell includes the control information only on f1 while low-power cell includes the control information only on f2 .

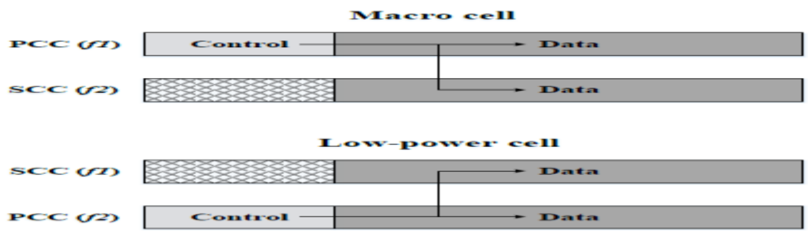

Figure 2.8: Frame configuration for CA-based ICIC scheme[27]

By using this simple mechanism, the control signaling for the different layers is separated. In such a case, the Macro cell adopts the carrier f1 as the PCC while applying power control schemes on carrier f2 to minimize interference on low-power tier. Similarly, low-power cell utilizes f2 as the primary carrier and applies power control schemes on f1.

Most researchers focus on Control Channel (CCH) interference, while few papers concentrate on both data and control signaling interference where the interference is mitigated by reducing the transmit power of some CCs of the macro cell which leads to less network capacity.

The above scheme, however, has the constraint that the different layers need to be time synchronized [29].

d) Time Domain-based Inter-Cell Interference Coordination (TD-ICIC)

The time domain-based ICIC schemes basically rely on reducing the transmission activity on certain subframes by each of the cell layers to minimize interference to the victim layers . These subframes are indicated as Almost Blank Subframes (ABS). This solution is suggested by 3GPP LTE-A (Release 10) to solve the problem of low DL signal quality in cell expanded region and to reduce the PDCCH outage which causes link failure. Moreover, it can overcome the case of larger cell expanded region that causes more interference in DL [30]. Figure 2-9 illustrates this solution, where the Macro cell will be muted or transmit data with a minimum power through some “protected” subframes (ABS), to avoid the high cross-tier interference by enabling CE region UEs from using these protected sub-frames achieving better spectrum efficiency. Noting that in these ABSs, only common reference signals (critical control channels, broadcast, paging information) are transmitted by the Macro cell to maintain the mobility robustness in HetNets . Noting that such scheme requires that both networks layers (macro/ low-power cell layers) should exchange ABS subframe information to achieve the required performance.

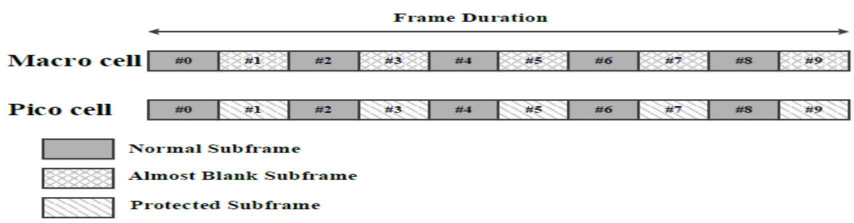

Figure 2.9: (ABS) for range expansion in HetNet [31]

According to [32], ABS technique can improve both cell-edge and cell throughputs as a result of using these protected subframes by some Pico users as well, where Macro cell keeps silent through these subframes.

The simulation results of [33] show that both average and the cell-edge throughputs of the low-power cells (e.g. Pico cell) can be dramatically enhanced when employing ABS technique as a result of reducing DL interference for Pico users when Pico cell uses protected sub-frames for data transmission. In HetNets scenario with CRE and ABS interference coordination, it is noted that data rates of offloaded user highly depend on the amount of ABSs rather than the bias value (especially from a user perspective), as a result of limited scheduling opportunities of offloaded users within ABSs. Even though employing CRE, UE may suffer from significant interference from Macro cell using the same carrier frequency (intra-frequency).

2.6 Related Works

In [34] the authors focus on the heterogeneous cellular scenarios with macrocells, femtocells or picocells users may suffer from significant co channel cross-tier interference. The author proposed ABSF technique to be used to reduce the cross tire interference, thus vulnerable users get a chance to be scheduled in ABSFs with reduced cross-tier interference. Then the authors analyze downlink scenarios using stochastic geometry and formulate a condition for the required number of ABSFs based on base station placement statistics and user throughput requirement. ABSFs improves the performance of the system considerably. The fraction of victim users in outage decreases from over 95% to 30% or even 10%, depending on the scheduling algorithm.

In [35] the authors proposed Multi-tone ABS to enhance ABS, which is referred to single-tone since only two choices can be applied on each subframe. The aim of the author is to increases the spectrum utilization of MBSs, and also save much power compared to the original ABS scenarios. The author found that the proposed Multi-tone ABS reaches the following achievement: The spectrum is a precious resource, and we increase the spectrum utilization, improve the performance of MBSs without harming the performance of PBSs. The capacity and the latency of MBSs are improved and the power consumption of Multi-tone ABS is less than the original ABS scenario.

The authors of [36] provides a novel optimization formulation to achieve optimal small cell CSOs and macro cell ABS or RP-ABS patterns. The performance of the outlined optimization framework is evaluated by state-of-the-art LTE system level simulations. Simulation results indicate an average network capacity gain of 19.4% from optimizing ABS-eICIC parameters, and a 22.8% gain from optimizing RP-ABS-eICIC parameters. Similarly, a 42.2% average gain in user data rates is achieved from optimizing ABS-eICIC parameters, and a 45.9% gain from optimizing RP-ABS-eICIC parameters.

Existing algorithms for ABS provisioning usually share resources proportionally among HetNet nodes in a long-term perspective (e.g., based on traffic forecast). In [37] the author argue instead that this mechanism can be exploited to save power in the HetNet. in fact, during ABSs, the macro consumes less power, since it only transmits pilot signals. Dually, the micros may inhibit data transmission themselves in some subframes, and optimally decide when to do this based on knowledge of the ABS period. This allows us to de- fine a power saving framework that works in the short term, modifying the ABS pattern at the fastest possible pace, serving the HetNet traffic at reduced power cost. Our framework is designed using only standard signaling. Simulations show that the algorithm consumes less power than its competitors, especially at low loads, and improves the UE QoS.

In [38] the number of ABSFs is derived based on the QoS of each macro user MUE, and then based on the required muted rate for each MUE a dynamically optimal blank rate can be set for each HeNB. Since each

HeNB has unique characteristics, each HeNB has to decide its own muted rate.

In [39] the authors proposed a distributed algorithm for jointly optimizing almost blank subframe (ABS) and cell selection bias (CSB) patterns in Long Term Evolution-Advanced (LTE-A) heterogeneous networks (HetNets). The author formulate the optimization problem as an exact potential game, where a Nash equilibrium point is guaranteed to be achieved within finite number of plays. Through simulations, the author demonstrate the fast convergence of the algorithm, an increase in average user rate, and a tremendous improvement on the service fairness of the users.

In [40] the author develop a novel EE-eICIC algorithm to determine the amount of ABSs and user equipment (UE) that should associate with picocells or macrocells from energy efficiency perspective. Due to the no smooth and mixed combinatorial features of this formulation, the author focus on a suboptimal algorithm design. Using generalized fractional programming and the convex programming theory, the author propose an iterative and relaxed-rounding algorithm to solve the problem. Numerical results illustrate that the proposed EE-eICIC algorithm achieves superior performance in comparison with state-of-the-art methods in terms of energy efficiency of both system and user.

In [41] the author perform local RE bias adaptation at service layer, local ABS ratio adaptation at BS layer, and coordination among local solutions for a global solution at a network layer. To provide the service scalability, the author encapsulate the service details into the local RE bias adaptation sub problem, which is isolated from the other parts of the algorithm, and the author also introduce some implementation examples of the sub problem for different services.

Chapter Three

Mathematical Model and Simulation

3.1 Overview

a) Almost Blank Subframes (ABS) based eICIC

An ABS is defined as minimum transmission of subframes, where zero data signal will be transmitted from the macro cell but only transmit the most critical information required for the system to provide support to legacy LTE (Release 8/9) UEs. Therefore, through ABS, the signals that are primarily sent are common reference signals (CRS) and other required system information. As a result, through subframes where the macro-cell transmits ABS, the low power small cells are able to schedule UEs from a larger geographical area that else would experience too high interference from the macro layer [42].

b) Reduced Power Almost Blank Subframes (RP-ABS) based eICIC

The reduced power almost blank subframes (RP-ABS) the macro cell doesn't totally blank the power on eICIC subframes, as it could use these subframes with reduced power to serve cell center users in the macro cell. Therefore, it's efficiently utilized the entire subframe, but of course requires intelligent scheduling and coordination between the macro cell and the coordinated small cells. The amount of power reduction could be static or dynamic. With static RP-ABS, the splitting of eICIC subframes to non-eICIC subframes is usually fixed and the amount of power reduction could be equal to the range expansion preference and also is fixed for all eICIC subframes. Whereas in dynamic RP-ABS, the small cell scheduler must communicate with the macro cell scheduler to exchange the amount of eICIC resource blocks and the equivalent required power reduction on each eICIC resource block. Thus, the capacity gain from using reduced power subframes over almost blank subframes depends on the ratio of eICIC subframes to non-eICIC subframes within a radio frame and the intelligence of the scheduling and coordination. The macro cell scheduler usually allocates the RP-ABS resource blocks to cell centers, where the quality of RP-ABS resource blocks are ranked in terms of fading and power reduction then allocated to cell center to achieve the preferred quality of experience determined by the scheduling objective [42].

3.2 Mathematical Model

Assume the network is deployed in urban area, then the path loss model which described by 3GPP in LTE-advanced standard can be used to model the signal degradation. Let the network operates in 2GHz.
Pl (path loss) between macro cell and MUE can be calculated as[43]:

$$Pl_{outdoor}(dB) = 15.3 + 37.6\log_{10}(d) + \sigma^2 \quad (3.1)$$

Where d is the distance (meter) between MUE m and macro cell M. σ^2 is a factor which represents the outdoor log-normal shadowing (in dB) which is characterized by the Gaussian distribution with zero mean and standard deviation. Similarly, the path loss for PUE_p and Pico cell P[43]:

$$Pl_{outdoor}(dB) = 38.64 + 20\,log_{10}(d) + L_{wall} \quad (3.2)$$

The model represents the combination of all channel characteristics and functions as a filter of transmitted signal. Hence, the channel gain of user u on RP-m can be expressed as[43]:

$$\mathrm{G_{m,u}} = \frac{10^{-(\mathrm{Pl_{m,u}}+\varphi^{\sigma})}}{10^{|\mathrm{H_{m,u}}|}} \quad (3.3)$$

Where Pl is the path-loss; $\varphi^{\sigma}$is log-normal shadowing with zero mean and standard deviation in σ dB ; $|H_{m,u}|^2$ is frequency selective fading with Rayleigh distribution. A wall penetration loss is 13 dB, Thermal noise density is -120 dBm/RB . Universal (i.e., full) frequency reuse and FDD is considered, such that each cell utilises the entire system bandwidth Bsys. The set of RBs M, where $|M| = M$, is distributed by each BS to its associated MSs. Throughout this work, u defines an MS, and vu the BS with which this MS is associated. The received signal observed by MS_u from BS_{sv} on RB_m is given by :

$$Y_{m,u} = P_{m,u} G_{m,[u,uv]} + I_{m,u} + \eta \qquad (3.4)$$

Where $G_{m,[u,uv]}$ signifies the channel gain (including fading and shadowing effects) between the MS_u and its serving BS_{VU}, observed on RBm. Furthermore, $P_{m,u}$ denotes the transmit power allocated to MSu on RBm, Sum the desired received power, $\eta = \eta_0 BRB$ the thermal noise, $\eta_0$is the noise spectral density, and $I_{m,u}$ is the co-channel interference received on RB_m from MS_s in neighboring cells , defined by:

$$I_{m,u} = \sum_{I_m}^{n} P_{m,i} G_{m,[u,vi]} \qquad (3.5)$$

Where I_m represents the set of co-channel interferers (i.e., set of MSs in neighboring cells that are also assigned RB_m . Hence, the SINR observed at the MS_u on RB_m is calculated by[44]:

$$SINR_{m,u} = \frac{S_{m,u}}{I_{m,u} + n} = \frac{P_{m,u} G_{m,[u,vu]}}{\sum_{i \in lm}^{n} P_{m,i} G_{m,[u,vi]} + n} \qquad (3.6)$$

3.3 Received Power

The amount of power that is actually received by receiver can be calculated by[45]:

$$P_r = P_t + G_t + G_r - Pl \tag{3.7}$$

Where P_r represents received power, P_t is the transmitted power, G_t is the transmitted gain, $G_r$is the received gain, and Pl is the Path loss.

3.4 Channel Gain

The value of L_{wall} is up to the distance between UE and BS (both= macrocell and Picocell). The value, L_{wall} equals 7,10 and 15 (dB) if d is within (0-10m) or (10m -20m) or (20m-30m), respectively. So, the channel gain (g) for i-th UE can be calculated as:

$$G = 10^{[-Pl/10]} \tag{3.8}$$

3.5 SINR of MUE

In LTE standard, resource block (RB) is minimum unit for data resource allocation , the downlink signal to interference plus noise ratio (SINR) value on RB_a of a MUE_m[44]:

$$SINR_{m,M,a} = \frac{P_{M,a}G_{m,M,a}}{N_0\Delta f + \sum \beta_{m,a}P_{m,M,a}G_{m,M,a} + \sum \beta_{f,a}P_{F,a}G_{m,F,a}} \tag{3.9}$$

3.6 Capacity

The capacity (Ca) of MUE m (or *PUE f*) on resource block a can be given by (3.11) :

$$Ca_{m(f),a} = \Delta f * \log_2\left(1 + \propto SINR_{m(f),a}\right) \tag{3.10}$$

Where Ca:capacity , Δf difference in bandwidth in different microcells , SINR: signal to noise interference ratio

3.7 Throughput

Network throughput is the rate of successful message delivery over a communication channel. Throughput is usually measured in bits per second, and sometimes in data packet per second. Throughput is the accumulated data rate, and the data rate will obviously increase due to the increasing in the bandwidth utilization; accordingly the throughput will increase.

$$Th = \sum datarate \, / \, sec \qquad (3.11)$$

Where Th = Throughput

3.8 Data Rate

Data transfer rate is the average number of units of data, such as bits, characters, blocks, or frames, transferred per unit time from a source and accepted as valid by a sink.

$$DR = 2 \times BW \times c \times \log(m) \qquad (3.12)$$

Where DR represents data rate, BW is the bandwidth, c is the code rate, and m is the modulation rate .

3.9 Spectral Efficiency

It refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol, and sometimes by the media access control .

$$SE = \frac{DR}{BW} \qquad (3.13)$$

Where DR represents data rate, BW is the bandwidth.

3.10 Transmission delay

It increases when the data rate is decrease as point in equation.

$$D = \frac{N}{2 \times BW \times C \times \log(m)} \quad (3.14)$$

Where *N* is the packet size, *BW* is the bandwidth, *C* is the code rate, and *m* is the modulation rate.

3.11 Outage Probability

The outage probabilities of, $OP_{eNB,n}$ and $OP_{PeNB,n}$ for both macro and pico UEs in the nth eNB are[46] :

$$OP_{eNB,n} \cong \frac{Y_{MUE.n}^{OP}}{J}, OP_{PeNB,n} \cong \frac{Y_{PUE.n}^{OP}}{L} \quad (3.15)$$

Where $Y_{MUE.n}^{OP}$, $Y_{PUE.n}^{OP}$ are the number of SINR ←6dB and also considering bit error rate < 10^{-6} for MUE and PUE

3.12 Simulation Scenario

The simulation cover a scenario of standard 3GPP and ITU standards for configuring the a Macro cell that have coverage of several Micro cells and Pico cells, the scenario covers the antenna used, antenna height, modulations techniques, transmission power, number of resource block that depends on the bandwidth of the system.

Assume there are total N microcells in the network and each microcell is served by an eNB. A number of Pico cells are randomly distributed in entire network. The UE which is located outdoor and served by macrocell eNB is referred as MUE while user equipment which is located outdoor and served by Pico cell. HeNB is referred as PUE (Pico cell user equipment).

The scenario has a parameters settings including the minimum value of inferences to the maximum value of inferences, and the noise value which effect the signal, also the minimum signal gain with the maximum signal gain was set in the simulation.

For the modulation technique the QAM was chosen with a different code rate and modulation order, packet size and the number of users is included. And mainly the number of subframes and frames initially used the number of radio frames and the bandwidth for the simulation is a range from 5MHz to 20MHz.

The system starts with setting the number of micro cells in the simulation then setting the number of Pico cells in the simulation based on the ITU standards, the standards of ITU give an exact interference distance that may occur in the scenario, then according to the standards of LTE-A the SINR has a unique value which is the optimal for the network, thus a comparison between the SINR in a specific simulation time is compared to the target to initialize a communication between the Micro cell and Pico Cell through x2 interface to start using the ABS and Reduced Power ABS.

Chapter Four

Results and Discussion

4.1 Introduction

The main results that give support to the concepts explained along this thesis are presented and analyzed. This results is conducted by simulated a simple LTE-advanced link using MATLAB to study the Almost Blank Subframe and Reduced Power Almost blank Subframe schemes and their performance in term of SINR, throughput, spectrum efficiency, transmission delay time, and outage probability.

4.2 Simulation Parameters

List of parameters were used to simulate the network performance for ABS and RP-ABS (shown in table 4-1) Some of the parameters are algorithm constants , we have used the fixed values throughout all simulations.

Table 4.1 The general simulation parameters used.

Parameter	Value
Minimum value of inferences	1
maximum value of inferences	25
Noise value	2
minimum signal gain	40
maximum signal gain	80
use 64-QAM with code rate 3/4	24.4
the data rate in each RE	8
the useful data in each RE	dr64_1* 3/4
use 64-QAM with code rate 2/3	22.6
the data rate in each RE	8
the useful data in each RE	dr64_2 * 2/3
use 16-QAM with code rate 3/4	18.1
the data rate in each RE	4
the useful data in each RE	dr16_1 * 3/4
use 16-QAM with code rate 1/2	16.3
the data rate in each RE	4

the useful data in each RE	dr16_2 * 1/2
use 64-QPSK with code rate 3/4	11.1
the data rate in each RE	2
the useful data in each RE	drq_1* 3/4
use 64-QPSK with code rate 3/4	9.3
the data rate in each RE	2
the useful data in each RE	drq_2 * 3/4
number of REs	12 * 6
packet size	50 * ones(1,10)
the number of radio frames	10
the number of sub frames	10
resource blocks per sub frame	50
system Bandwidth	10*10^6

4.3 Simulation Results

After finishing the mathematical model, and using Matlab to simulate the development on the performance metrics, the chosen metrics are: Signal to Interference plus noise ratio, Throughput, Spectral efficiency, Transmission delay, and Outage probability.

The results was obtained from a different configuration to the inputs, such as varying the power of the transmitted subframe and showing the results, variation on the number of Subframes and the effect on throughput results, testing the outage probability for both systems RP-ABS and ABS. moreover the Subframes delay time comparison which is a relation between the number of Subframes and the delay time in seconds or ms. The simulation covers some of the quality of service parameters.

The aim of the results is to obtain an analysis and discussion related to the results in order to evaluate the performance of the enhanced intercell interference method in time domain, nevertheless two method was compared the almost blank subframe and the reduced power blank subframe.

4.4 Signal to Interference Noise Ratio

Figures (4.1a) and (4.1b) Show the increasing in the Signal to interference and noise ratio in dB due to the increasing Received Power in dB, the x axes represent the Received power and the y axes represent the Signal to interference noise ratio and the black line indicates to SINR RP-ABS and the red line for ABS for each figure. The configuration of pico power was 10dB for figure (4.1a) and 5 dB for figure (4.1b). To calculate the optimization taken the average using four points.

In Figure (4.1a) RP-ABS method results in SINR improvement of an average around 11.25% over ABS method. For the 10dB pico power configuration the average difference is about 1.5 dB the enhancement on the SINR was obtained from increasing the receive power and the pico power was 10dB for the two methods, the increasing of RP-ABS over ABS is due to the low power on transmission which is synchronized between the Macrocell and Pico Cell in RP-ABS.

Figure (4.1a): Comparison of SINR for RP-ABS and ABS (pico power 10dB)

In Figure (4.1b) RP-ABS method results in SINR improvement of an average around 16% over ABS method. For the 5dB pico power configuration the average difference is about 2dB the enhancement on the SINR was obtained from increasing the power and decrease the pico power from 10dB to 5dB for the two methods. the increasing of RP-ABS over ABS is due to the low power on transmission which is synchronized between the Macrocell and Pico Cell in RP-ABS.

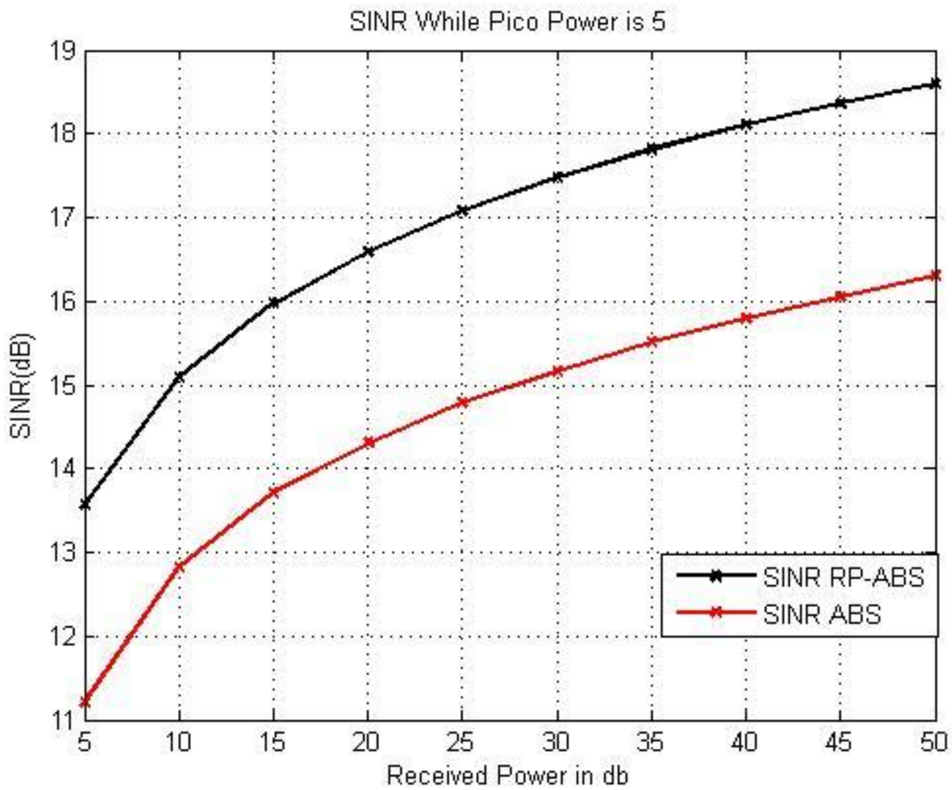

Figure (4.1b): Comparison of SINR for RP-ABS and ABS (pico power 5dB)

For the 5dB pico power SINR enhancement about 6.5% over the 10dB pico power because it is represent the interference when it is low the SINR is high.

4.5 Throughput

Figures (4.2a) and (4.2b) Show the increasing in the throughput of the system due to the increasing in number of Users, the x axes represent the number of received and the y axes represent the throughput and the black line indicate to RP-ABS and the red line for ABS for each figure. when configuring the bandwidth was 10MHz in figure (4.2a) and 20MHz for figure (4.2b). To calculate the optimization taken the average using four points.

In Figure (4.2a) RP-ABS method results in throughput improvement of an average around 3.2% over ABS method. For the 10MHz bandwidth configuration the average difference is about 2 bits per sec the enhancement on the throughput was due to the variation on number of bits that transmitted from RB-ABS and ABS.

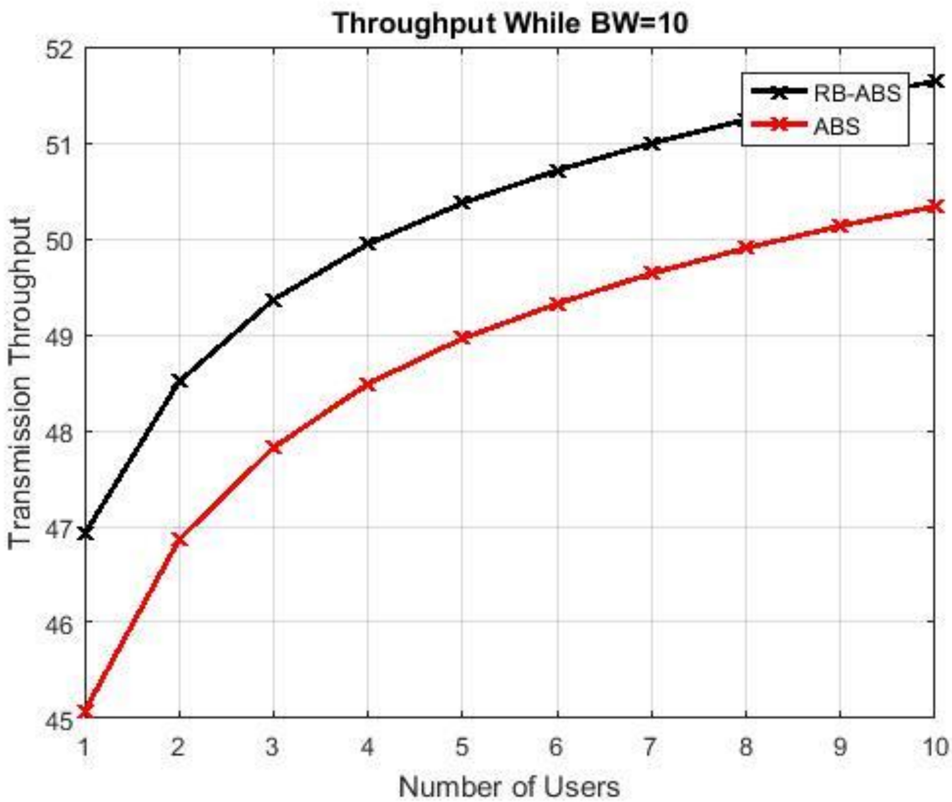

Figure (4.2a): Comparison of Throughput for RP-ABS and ABS (BW=10MHz)

In Figure (4.2b) RP-ABS method results in throughput improvement of an average around 3.3% over ABS method. For the 20MHz bandwidth configuration the average difference is about 4 bits per sec the enhancement on the throughput was due to the variation on number of bits that transmitted from RB-ABS and ABS. the increasing of RP-ABS over ABS is due to the increase in bandwidth.

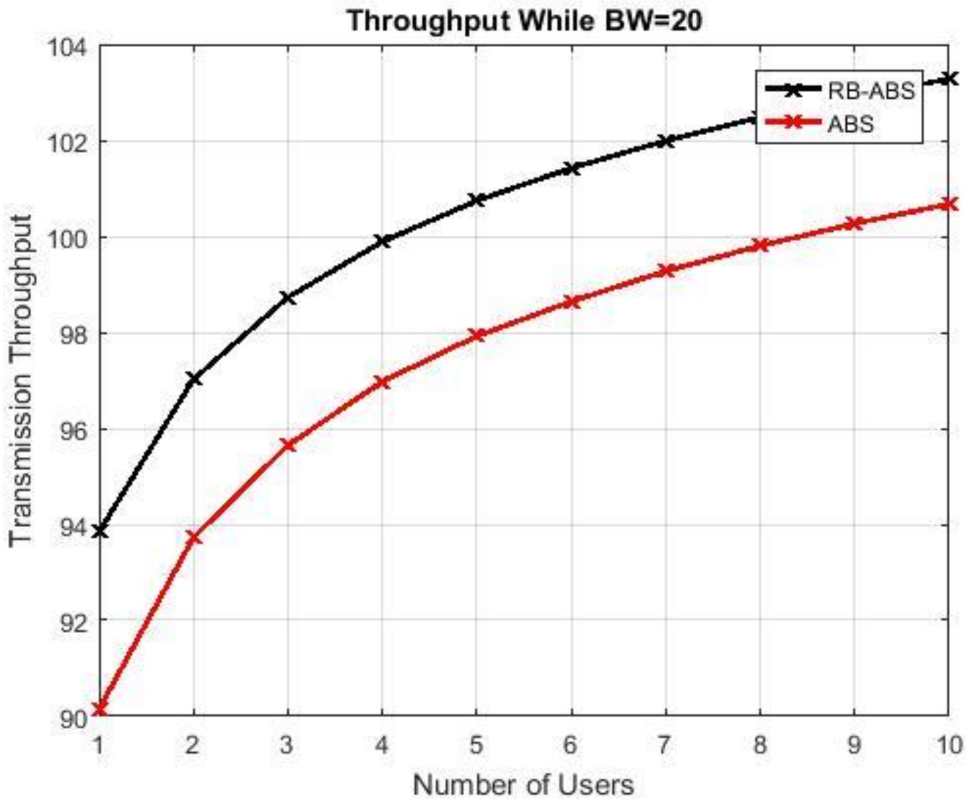

Figure 4.2b: Comparison of Throughput for RP-ABS and ABS (BW=20MHz)

For the 20MHz bandwidth the throughput enhancement about 95% over the 10MHz bandwidth, because the increased in bandwidth can handle the packet in less delay time.

4.6 Spectral Efficiency

Figures (4.3a) and (4.3b) Show the increasing in spectral efficiency of the system due to the increasing number of users share the resources, the Corresponding to the increasing in the throughput by RP-ABS scheme lead to increase the Spectral efficiency , the x axes represent the number of users and the y axes represent the spectral efficiency and the black line indicates to spectral efficiency RP-ABS and the red line for ABS for each figure. The configuration of bandwidth was 10MHz for figure (4.3a) and

5MHz for figure (4.3b). To calculate the optimization taken the average using four points.

In Figure (4.3a) RP-ABS method results in spectral efficiency improvement of an average around 30.5% over ABS method when using 10 MHz bandwidth. For the 10 MHz bandwidth configuration the average difference is about 0.8 bit/sec/Hz the enhancement on the spectral efficiency , the increasing of RP-ABS over ABS is due to the low power on transmission which is synchronized between the Macrocell and Pico Cell in RP-ABS.

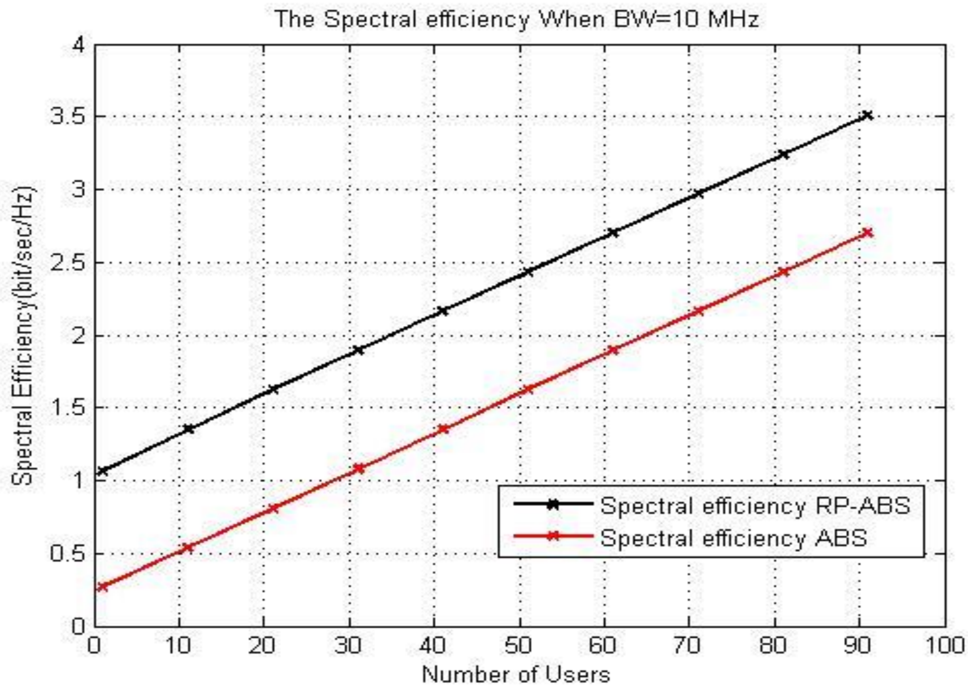

Figure (4.3a): Comparison of Spectral efficiency for RP-ABS and ABS (BW=10MHz)

In Figure (4.3b) RP-ABS method results in spectral efficiency improvement of an average around 35.25% over ABS method when using 5 MHz bandwidth. For the 5 MHz bandwidth configuration the average difference is about 1.5 bit/sec/Hz the enhancement on the spectral efficiency was obtained from decrease the Bandwidth from 10MHz to 5MHz for the two methods. The increasing of RP-ABS over ABS is due to the low power on transmission which is synchronized between the Macrocell and Pico Cell in RP-ABS.

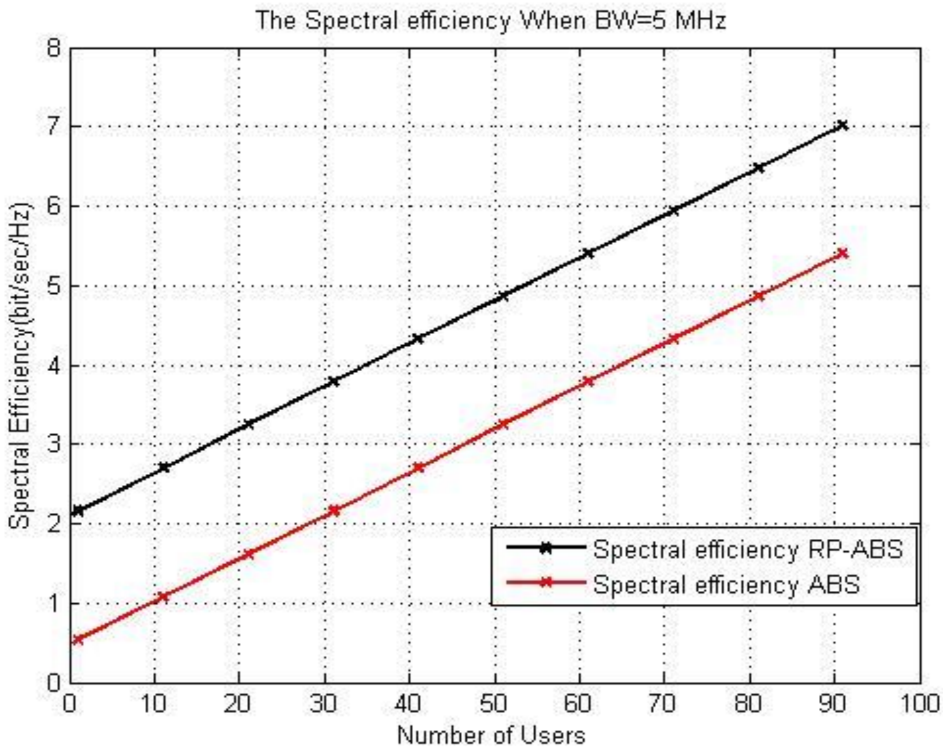

Figure (4.3b): Comparison of Spectral efficiency for RP-ABS and ABS (BW=5MHZ)

For the 5 MHz bandwidth the Spectral efficiency enhancement about 90% over the 10 MHz bandwidth.

4.7 Transmission Delay

Figures (4.4a) and (4.4b) represent the transmission delay of the system vs. number of Subframes, the x axes represent the number of Subframes and the y axes represent the transmission delay and the black line indicates to transmission delay RP-ABS and the red line for ABS for each figure. The configuration of packet size was 512 for figure (4.4a) and 1024 for figure (4.4b). To calculate the optimization taken the average using four points.

In Figure (4.4a) The transmission delay when using RP-ABS scheme is less than ABS scheme by 10.3% when using the packet size to

512. This reduction in transmission delay is caused by the increasing of the data rate.

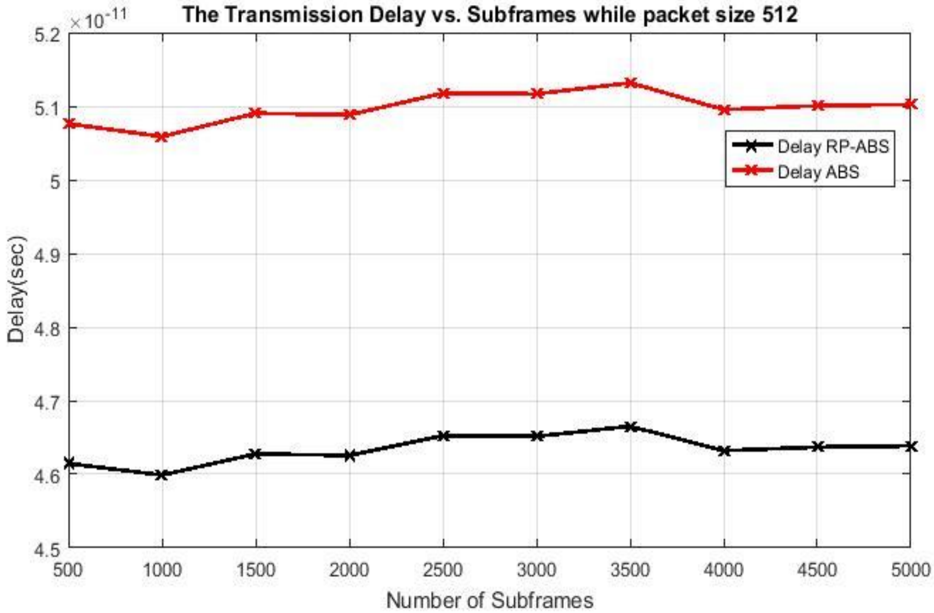

Figure (4.4a): Comparison of delay for RP-ABS and ABS (packet size 512)

In Figure (4.4b) The transmission delay when using RP-ABS scheme is less than ABS scheme by 10.13% when using the packet size to 1024. This reduction in transmission delay is caused by the increasing of the data rate.

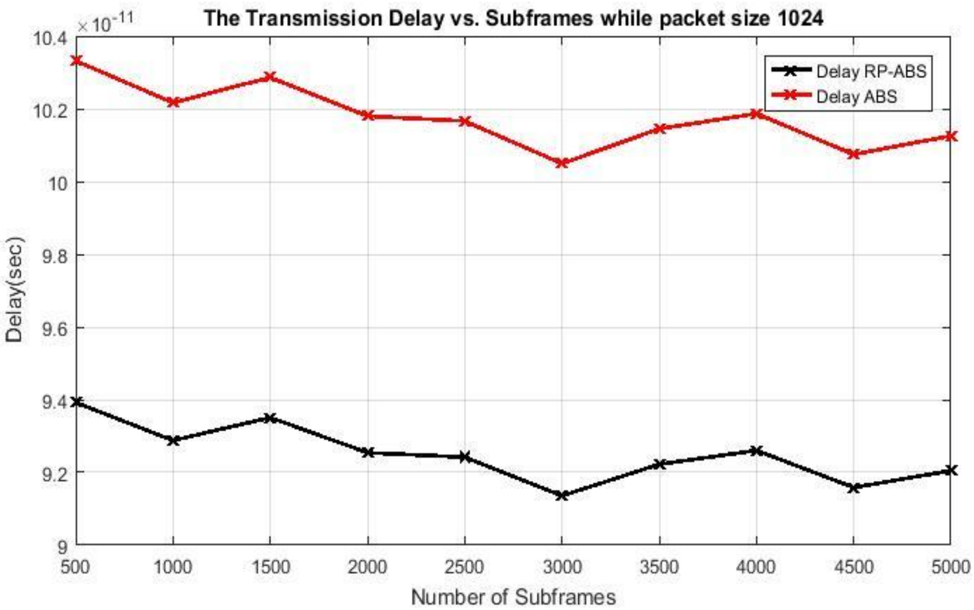

Figure (4.4b): Comparison of delay for RP-ABS and ABS (packet size 1024)

For the 512 packet size the transmission delay enhancement about 95 % over the 1024 packet size because the increase in packet size execute the increasing of the transmission data rate.

4.8 Outage probability

Figures (4.5a) and (4.5b) Shows the decreasing in the Outage probability of the system due to the increasing SINR, the x axes represent the SINR and the y axes represent the Outage probability and the black line indicates to Outage probability RP-ABS and the red line for ABS for each figure. The configuration of bandwidth was 5MHz for figure (4.5a) and 10MHz for figure (4.5b). To calculate the optimization taken the average using four points.

In Figure (4.5a) ABS method results in outage probability improvement of an average around 90% over RP-ABS method when using 5 MHz bandwidth. For the 5 MHz bandwidth configuration the average difference is about 0.35 the enhancement on the outage probability.

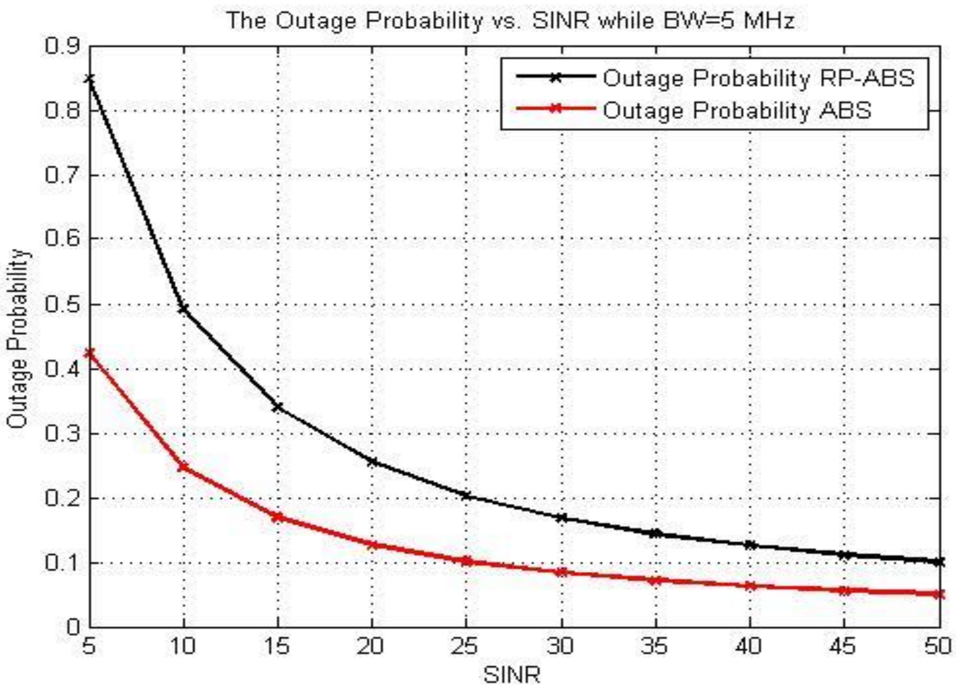

Figure (4.5a): Comparison of outage probability for RP-ABS and ABS (BW=5MHz)

In Figure (4.5b) ABS method results in outage probability improvement of an average around 95% over RP-ABS method when using 10 MHz bandwidth. For the 10 MHz bandwidth configuration the average difference is about 0.4 the enhancement on the outage probability.

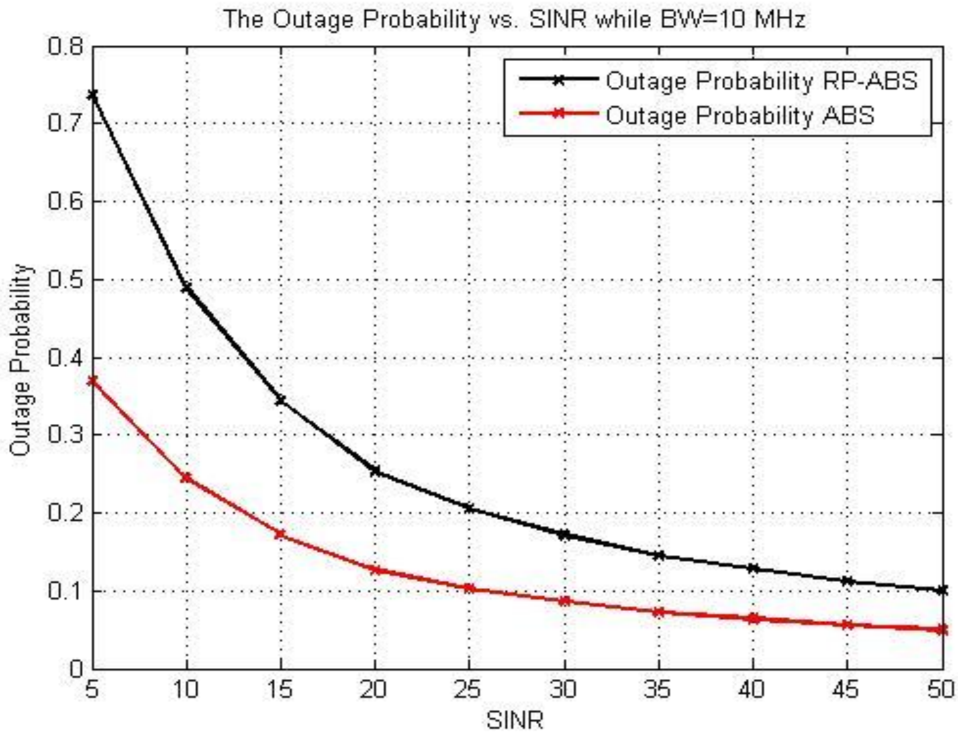

Figure (4.5b): Comparison of outage probability for RP-ABS and ABS (BW=10MHz)

For the 10MHz bandwidth the outage probability enhancement about 15% over the 5 MHz bandwidth.

Chapter Five

Conclusion and Recommendations

5.1 Conclusion

The inter cell interference is one of the challenges facing the long term evolution 4th generation, so many developers intend to solve the problem using variety of methods such as frequency domain solving method, time domain solving method and the power control method.

In this project the time domain method in eICIC was used to solve the problem of ICI by applying one of the scheduling algorithms that is the almost blank subframes and reduce power almost blank subframes. The ABS and RP-ABS technique enhance interference between macro cell and pico cell. The simulation result showed by compared of SINR , Throughput ,Transmission Delay ,Spectrum Efficiency ,Outage Probability for ABS and RP-ABS ,the network performance and the user experiences will enhance the reduction of the RP-ABS is efficient than the ABS about 11.25% , 3.2% , 30.5% , 10.3% , 90% on average in SINR, Throughput, Spectrum efficiency, Transmission Delay and Outage probability respectively.

5.2 Recommendations

To get the most benefits from the interference management in the LTE-A there are some recommendations should be taken under consideration in future research activities. To the best network performance Its better to choose the optimal bias value that minimizes the number of outage user equipment's for each base station individual and comparison of data rate and capacity for ABS & RP-ABS.

As known the interference management in the LTE-A has more than one scenario, in this thesis the comparison eICIC time domain (ABS&RP-ABS) was conducted, and it’s recommended to use different scenarios such as frequency domain in eICIC and all scenario for F-eICIC.

References

[1] H. ElShaer, Interference Management In LTE-Advanced Heterogeneous Networks Using Almost Blank Subframes, Sweden ,p.76 , 2012.

[2] A. Merwaday, S. Mukherjee, and I. G¨uven, "Capacity Analysis of LTE-Advanced HetNets with Reduced Power," *Electrical and Computer Engineering Faculty*, pp. 1-34, 30 Mar 2014.

[3] 3GPP TS 36.300, "Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN) ; Overall description; Stage 2," *3GPP tech. spec. ,* ver. 10.8.0, 2012

[4] D. Lopez, I. Guvenc, G. Roche and M. Kountouris, "Enhanced Intercell Interference Coordination Challenges in Heterogeneous Networks," *IEEE Wireless Commun.,* vol. 18, no. 3, pp. 22-30, 2011.

[5] E. Dahlman, S. Parkvall, and J. Sköld, 4G LTE/LTE Advanced for Mobile Broadband, First ed., Elsevier Ltd , 2011.

[6] S.Sesia, M.Baker and I.Toufik, LTE The UMTS Long Term Evolution: From Theory to Practice, 2nd ed., JohnWiley & Sons Ltd, 2011.

[7] 3GPP TS 36.211, “Physical channels and modulation (Release 14).” 3rd Generation Partnership Project-TSG-RAN, 2017.

[8] C. Johnson, *Long Term Evolution in Bullets*, 2nd ed., Northampton , England, 2012.

[9] D. Lopez, I. Guvenc, G. Roche and M. Kountouris, “Enhanced intercell interference coordination challenges in heterogeneous networks,” *IEEE Wirel. Commun.*, vol. 18, no. 3, pp. 22–30, 2011.

[10] S. Brueck, “Heterogeneous networks in LTE-Advanced,” *IEEE Int. Symp. Wirel. Commun. Syst.*, pp. 171–175, 2011.

[11] H. Otsuka, Y. Ichimura and K. Kikuchi, “Considerations of Small Cell Strategy in Mobile Communication Systems,” *IEEE Euro. Micro. Conf.* , pp. 1259–1262, 2013.

[12] 3GPP TR 36.932, “Scenarios and requirements for small cell enhancements for E-UTRA and E-UTRAN (Release 14).” 3rd Generation Partnership Project-TSG-RAN, 2017.

[13] Y. Damnjanovic, W. Aleksandar and J. Montojo, “A Survey on 3GPP Heterogeneous Networks,” *IEEE Wirel. Comm.*, pp. 10–21, 2011.

[14] 3GPP TR 36.842, “Study on Small Cell enhancements for E-UTRA and E-UTRAN.” 3rd Generation Partnership Project-TSG-RAN, 2013.

[15] 3GPP RP-121415, “New Carrier Type for LTE.” 3rd Generation Partnership Project-TSG-RAN, 2012.

[16] S. Hamouda, “A New Spectrum Sharing Trade in Heterogeneous Networks,” *IEEE Vehic. Tech. Conf.* , 2013.

[17] 3GPP RP-130391, “LTE Carrier Aggregation between TDD and FDD.” 3rd Generation Partnership Project-TSG-RAN, 2013.

[18] M. Shirakabe, A. Morimoto and N. Miki, “Performance evaluation of inter-cell interference coordination and cell range expansion in heterogeneous networks for LTE-Advanced downlink,” *Proc. Int. Symp. Wirel. Commun. Syst.*, pp. 844–848, 2011.

[19] E. Badanese, "A brief introduction to heterogeneous networks (hetnets) and its challenges", *IET Int. Conf. Commu. Tech. App.* ,2011.

[20] B. A. Salihu, Z. Suleiman, and M. U. M. Bakura, “Advances in inter-cell interference coordination for realization of robust Heterogeneous Networks in lte-a systems,” *Int. J. Eng. Sci. Invent.*, vol. 2, no. 2, pp. 40–48, 2013.

[21] 3GPP TS 22.220, “Service requirements for Home Node B (HNB) and Home eNode B (HeNB) (Release 14).” 3rd Generation Partnership Project-TSG, p. 25, 2017.

[22] S. Moon, S. Park and I. Hwang, “Cell range expansion and time partitioning for enhanced inter-cell interference coordination in heterogeneous network”, *Hawaii Int. Conf. Syst. Sci.*, pp. 5109–5113, 2014.

[23] X. Lin, R. Ratasuk and A. Ghosh, “Carrier aggregation in heterogeneous cellular networks,” *IEEE Int. Conf. Commun.*, pp. 5199–5203, 2013.

[24]H. Jiang, H. Wang, and L. Yang, “Carrier aggregation based interference coordination for LTE-A macro-pico HetNet,” *IEEE Veh. Technol. Conf.*, 2013.

[25]A. Ghosh, N. Mangalvedhe, and T. D. Novlan, “Heterogeneous cellular networks: From theory to practice,” *IEEE Commun. Mag.*, vol. 50, no. 6, pp. 54–64, 2012.

[26] F. Afroz, K. Sadrasogaran and H. Alkim, "Interference Management in LTE downlink Networks", *Int. J. Wirel. Mob. Net.* ,Vol. 7,No. 1, 2015

[27]A. Daeinabi, “Intercell Interference Mitigation in Long Term Evolution (LTE) and LTE-Advanced,” University of Technology, Sydney, 2015.

[28]3GPP TR36.874, “Technical Specification Group Radio Access Network; Coordinated multi-point operation for LTE with non-ideal backhaul (Release 12).” 3rd Generation Partnership Project-RAN ,2014

[29] 3GPP R3-111419, “A plan for LTE Rel-11 Carrier Based Interference Management.” 3rd Generation Partnership Project-TSG-RAN WG3, Barcelona, Spain, 2011.

[30] K. Okino, T. Nakayama, and Y. Kusano, “Pico cell range expansion with interference mitigation toward LTE-advanced heterogeneous networks,” *IEEE Int. Conf. Commun.*, pp. 3–7, 2011.

[31] I. F. Akyildiz, R. Balakrishnan, and E. Chavarria, “LTE-Advanced and the evolution to Beyond 4G (B4G) systems,” *Phys. Commun.*, vol. 10, pp. 31–60, 2014.

[32] A. Daeinabi, K. Sandrasegaran and X. Zhu, “Performance evaluation of cell selection techniques for picocells in LTE-advanced networks,” *IEEE Int. Conf. Electr. Eng. Comput. Telecommun. Inf. Technol.*, pp. 1–6, 2013.

[33] J. Oh and Y. Han, “Cell selection for range expansion with almost blank subframe in heterogeneous networks,” *IEEE Int. Symp. Pers. Indoor Mob. Radio Commun.*, pp. 653–657, 2012.

[34] M. Cierny, H. Wang and C. Wijting "On Number of Almost Blank Subframes in Heterogeneous Cellular Networks" *IEEE Tran. Wirel. Commu.* , Vol. 12, No. 10, 2013

[35] Z. Chen, T. Lin and D. Din "Multi-Tone Almost Blank Subframes for Enhanced Inter-Cell Interference Coordination in LTE HetNets" *IEEE Int. Conf. on Comp. Net. and Commu.*, 2015

[36] F. Alfarhan, R. Lerbour, and Y. Helloco "An Optimization Framework for LTE eICIC and Reduced Power eICIC" *IEEE glo. Commu. Conf.* , 2015

[37] A. Virdis, G. Stea, and M. Caretti "A distributed power-saving framework for LTE Het-Nets exploiting Almost Blank Subframes" IEEE, vol.1 , Issue:3 ,2017

[38] W. Lou , Y. T. Hou and Y. Hou "Cooperative Interference Mitigation Algorithm in Heterogeneous Networks" *IEEE Tran. Wirel. Commu.* ,vol: 15 , Issue: 8, 2015

[39] S. Deb, P. Monogioudis and P. Seymour "Algorithms for Enhanced Inter Cell Interference Coordination (eICIC) in LTE HetNets" *IEEE/ACM Trans. Net.* ,Vol. 22 , Issue: 1 , 2014

[40] J. Zheng, L. Geo and J. Ren "EE-eICIC: Energy-Efficient Optimization of Joint User Association and ABS for eICIC in Heterogeneous Cellular Networks" ,*Wirel. Commu. Mob. Comp.* , pp. 11, 2017

[41] H. Zhou, X. Wang and S. Yamada "EICIC Configuration Algorithm with Service Scalability in Heterogeneous Cellular Networks" *IEEE/ACM Trans. Net.* ,Vol. 25, Issue: 1, 2017

[42] M. Shipon "An Overview on Interference Management in 3GPP LTE Advanced Heterogeneous Networks" *Int. Jou. Fut. Gen. Commu. Net.* ,Vol. 8, No. 1, pp.55-68, 2015

[43] P. B. Chhetri and S. K. Ghimire " Inter-Cell Interference Mitigation in LTE-Advanced Heterogeneous Mobile Networks", Proc. IOE Grad. Conf. , pp.85-92 , 2016

[44] X. Chu, D. Lopez and F. Gunnarsson, "Heterogeneous Cellular Networks: Theory, Simulation and Deployment", 1st ed., Cambidge University press, 2013

[45] 3GPP TR 36.942, "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) System Scenarios." 3rd Genereation Partnership Project-TSG-RAN, 2017.

[46] B. V. Sagar, S. Ramesh and T. G. Krishna, "path loss and outturn analysis of LTE-A femtocells under co-channel interference using dynamic schemes" *IEEE Int. Conf. SCOPES* , 2016

Appendix

```
clear all
clc
closf all
%==simulation-parameter=======================
intf-min = 1 ;              % The min value of intf
intf-max = 25 ;             % The max value of intf
noi = 2 ;                   % noise value
sig-min = 40 ;              % min SG
sig-max = 80 ;              % max SG
sn-th-64Q-1 = 24.4 ;   % usef 64-Q with cr 3/4
d64-1 = 8 ;                 % the dr in each RL
c64-1 = d64-1  * 3/4 ;    % the usef data in each RL
sn-th-64Q-2 = 22.6 ;   % usef 64-Q with cr 2/3
d64-2 = 8 ;                 % the dr in each RL
c64-2 = d64-2  * 2/3 ;    % the usef data in each RL
sn-th-16Q-1 = 18.1 ;   % usef 16-Q with cr 3/4
d16-1 = 4;                  % the dr in each RL
c16-1 = d16-1  * 3/4 ;    % the usef data in each RL
sn-th-16Q-2 = 16.3 ;   % usef 16-Q with cr 1/2
d16-2 = 4 ;                 % the dr in each RL
c16-2 = d16-2 * 1/2 ;     % the usef data in each RL
sn-th-QP-1 = 11.1 ;    % usef 64-QP with cr 3/4
dq-1 = 2 ;                  % the dr in each RL
cq-1 = dq-1  * 3/4 ;      % the usef data in each RL
sn-th-QP-2 = 9.3 ;     % usef 64-QP with cr 3/4
dq-2 = 2 ;                  % the dr in each RL
cq-2 = dq-2 * 3/4 ;       % the usef data in each RL
```

```
RL-n = 12 * 6 ;          % no of RLs
p-sz = 1024  ;  % packet size Hypothesized, should be changed
n-f = 10 ;             % the no of radio frames
sb-f = 10 ;             % the no of sb frames
rls-f = 50 ;             % resource blocks per sb frame
BW = 10;                   % system Bandwidth
ra-d = zeros(1,n-f) ;     % dr values in each radio frame
ra-d-n = zeros(1,n-f) ;   % dr values in each radio frame in normal casf
for ni = 1 : n-f         % initializing the value for each radio frame
blk = zeros(1,rls-f) ;        % the state of the resource blocks 0 is "normal"
, 1 is "blocked"
intf-val = zeros(1,rls-f) ;   % intf values
intf-val-n = zeros(1,rls-f) ; % intf values in normal casf
sig-val = zeros(1,rls-f) ;    % s values
sig-val-n = zeros(1,rls-f) ;  % s values in normal casf
sn-val = zeros(1,rls-f) ;   % sn values
sn-val-n = zeros(1,rls-f) ; % sn normal casf values
RLs = zeros(1,rls-f) ;       % RLs values matrix
RLs-n = zeros(1,rls-f) ;      % RLs normal casf values
sn-to = zeros(1,sb-f) ;   % total sn from the radio frame start to the sb frame
th-to = zeros(1,sb-f) ;    % total amount of data from the radio frame start
to the currlnt sb frame
sn-to-n = zeros(1,sb-f) ; % normal casf sn
th-to-n = zeros(1,sb-f) ;  % normal casf th
d = zeros(1,rls-f) ;         % dr values in each resource block
d-n = zeros(1,rls-f) ;        % dr values in each resource blocks in  normal
casf
sb-d = zeros(1,sb-f) ;     % dr values in each sb frame
sb-d-n = zeros(1,sb-f) ;   % dr values in each sb frame in normal casf
```

blk- = zeros(1,sb-f) ; % usef d to calculate the total no of blocked RBs in radio frame

sn- = zeros(1,sb-f) ; % to calculate the total of sn in RBs than was blocked

SF = zeros(1,sb-f); % spectral Efficiency value in each RB

SF-n = zeros(1,sb-f); % spectral Efficiency value in each RB in normal casf

for ii = 1 : sb-f

disp(['====Sb frame: ((' n2str(ii) '))============'])

for iii = 1 : rls-f

intf-rng = rand(1) ; % usef d to calculate intf range

if blk(iii) == 1 % if blocked the intf value and the intf value in the norm casf will not be equal

intf-val(iii) = intf-min ; % when blocked intf will be at its min

if intf-rng >= 0.4

intf-val-n(iii) = intf-min+(intf-max-intf-min)/4 + (intf-max-intf-min)/2*rand(1) ;

% 60% propability

elsfif intf-rng >= 0.2

intf-val-n(iii) = intf-min + (intf-max-intf-min)/4*rand(1) ;

% 20% propability

elsf

intf-val-n(iii) = intf-max -(intf-max-intf-min)/4*rand(1) ;

% 20% propability

end

elsfif intf-rng >= 0.4

% if blocked the intf value and the intf value in the norm casf will be equal to each other

```
intf-val(iii) = intf-min+(intf-max-intf-min)/4 + (intf-max-intf-min)/2*rand(1) ;
% 60% propability
intf-val-n(iii) = intf-val(iii) ;
elsfif intf-rng >= 0.2
intf-val(iii) = intf-min + (intf-max-intf-min)/4*rand(1) ;
% 20% propability
intf-val-n(iii) = intf-val(iii) ;
elsf
intf-val(iii) = intf-max -(intf-max-intf-min)/4*rand(1) ;
% 20% propability
intf-val-n(iii) = intf-val(iii) ;
end
sig-rng = rand(1) ;
% usefd to calculate s range
if blk(iii) == 1
% if blocked the s value and the s value in the norm casf will not be equal
sig-val(iii) = sig-max -((sig-max-sig-min)/3)*rand(1) ;
% when blocked sig will be closf to its max
if sig-rng >= 0.4
sig-val-n(iii) = sig-min+(sig-max - sig-min)/4 + (sig-max - sig-min)/2*rand(1) ;
% 60% propability
elsfif intf-rng >= 0.2
sig-val-n(iii) = sig-min + (sig-max-sig-min)/4*rand(1) ;
% 20% propability
elsf
sig-val-n(iii) = sig-max -(sig-max-sig-min)/4*rand(1) ;
% 20% propability
```

```
end
elsfif sig-rng >= 0.4
% if blocked the s value and the  s value in the norm casf will be equal to
each other
sig-val(iii) = sig-min+(sig-max-sig-min)/4 + (sig-max-sig-min)/2*rand(1)
;
% 60% propability
sig-val-n(iii) = sig-val(iii) ;
elsfif intf-rng >= 0.2
sig-val(iii) = sig-min + (sig-max -sig-min)/4*rand(1) ;
% 20% propability
sig-val-n(iii) = sig-val(iii) ;
elsf
sig-val(iii) = sig-max  - (sig-max- sig-min)/4*rand(1) ;
% 20% propability
sig-val-n(iii) = sig-val(iii) ;
end
sn-val(iii) = sig-val(iii) / (intf-val(iii)+noisf) ;
%calculate the s to intf and noisf value
if blk(iii) == 1
sn-(ii) = sn-(ii) + sn-val(iii) ;
end
sn-val-n(iii) = sig-val-n(iii) / (intf-val-n(iii)+noisf) ;
%  using sn value without modification
% calculating the nubmer of bits in each resource block:
% the no of RLs in each resource block is 12 * 650
% using the value of sn we can determine the mod and the code
% rate to calculate the %%%DATA%%% size in the RLs as following
if sn-val(iii) >= sn-th-64Q-1 ;
```

```
RLs(iii) = RL-n * c64-1 ;
% usef data in 64Q RLs-row * RLs-col * cr
d(iii) = RL-n * d64-1 ;
% dr in 64Q RLs-row * RLs-col * dr
elsfif sn-val(iii) >= sn-th-64Q-2 ;
RLs(iii) = RL-n * c64-2 ;
d(iii) = RL-n * d64-2 ;
elsfif sn-val(iii) >= sn-th-16Q-1 ;
RLs(iii) = RL-n * c16-1 ;
% usef data in 16Q *  RLs-row * RLs-col * cr
d(iii) = RL-n * d16-1 ;
elsfif sn-val(iii) >= sn-th-16Q-2 ;
RLs(iii) = RL-n * c16-2 ;
d(iii) = RL-n * d16-2 ;
elsfif sn-val(iii) >= sn-th-QP-1 ;
RLs(iii) = RL-n * cq-1 ;
% usef data in QP * RLs-row  * RLs-col * cr
d(iii) = RL-n * dq-1 ;
elsfif sn-val(iii) >= sn-th-QP-2 ;
RLs(iii) = RL-n * cq-2 ;
d(iii) = RL-n * dq-2 ;
elsf
blk(iii) = 1 ;
% this limit is not acceptable this  resource block
% will be blocked and rl-allocated
sig = sig-max -((sig-max-sig-min)/3)*rand(1) ;
sn-val(iii) = sig / (intf-min + noisf) ;
% s is at its max , intf is at its min
sn-(ii) = sn-(ii) + sn-val(iii) ;
```

```
RLs(iii) = RL-n * c64-1 ;
d(iii) = RL-n * d64-1 ;
end
if sn-val-n(iii) >= sn-th-64Q-1 ;
RLs-n(iii) = RL-n * c64-1 ;
% bits in 64Q RLs-row * RLs-col * cr
d-n(iii) = RL-n * d64-1 ;
% dr in 64Q RLs-row * RLs-col * dr
elsfif sn-val(iii) >= sn-th-64Q-2 ;
RLs-n(iii) = RL-n * c64-2 ;
d-n(iii) = RL-n * d64-2 ;
elsfif sn-val(iii) >= sn-th-16Q-1 ;
RLs-n(iii) = RL-n * c16-1 ;
% bits in 16Q * RLs-row * RLs-col * cr
d-n(iii) = RL-n * d16-1 ;
elsfif sn-val(iii) >= sn-th-16Q-2 ;
RLs-n(iii) = RL-n * c16-2 ;
d-n(iii) = RL-n * d16-2 ;
elsfif sn-val(iii) >= sn-th-QP-1 ;
RLs-n(iii) = RL-n * cq-1 ;
% bits in QP * RLs-row * RLs-col * cr
d-n(iii) = RL-n * dq-1 ;
elsf
RLs-n(iii) = RL-n * cq-2 ;
d-n(iii) = RL-n * dq-2 ;
end
    disp(['==Resource block: ((' n2str(iii) '))=====']) 
    disp(['sig ' n2str(sig-val(iii)) ' , ' n2str(sig-val-n(iii))])
    disp(['intf ' n2str(intf-val(iii)) ' , ' n2str(intf-val-n(iii)) ])
```

```
        disp(['sn ' n2str(sn-val(iii)) ' , ' n2str(sn-val-n(iii))])
        disp(['RLs ' n2str(RLs(iii)) ' , ' n2str(RLs-n(iii))])
        disp(['d ' n2str(d(iii)) ' , ' n2str(d-n(iii))])
        disp(['Block : ' n2str(blk(iii))])
        disp(' ')
end
blk-(ii) = sum(blk) ;
% calculate the total amount of sn & data
if ii == 1
sb-d(ii) = sum (d) ;
sb-d-n(ii) = sum (d-n) ;
sn-to(ii) = sum(sn-val) ;
th-to(ii) = sum(RLs) ;
sn-to-n(ii) = sum(sn-val-n) ;
th-to-n(ii) = sum(RLs-n) ;
SF(ii) = th-to(ii)/BW;
SF-n(ii) =th-to-n(ii)/BW;
elsf
sb-d(ii) = sb-d(ii-1) + sum (d) ;
sb-d-n(ii) = sb-d-n(ii-1) + sum (d-n) ;
sn-to(ii) = sn-to(ii-1) + sum(sn-val) ;
% calculate the total sn from the radio frame beginning
sn-to-n(ii) = sn-to-n(ii-1) + sum(sn-val-n) ;
% calculate for normal case
th-to(ii) = th-to(ii-1) + sum(RLs) ;
% total amount of data
th-to-n(ii) =th-to-n(ii-1) + sum(RLs-n) ;
SF(ii) =  (th-to(ii)/BW)*100;
SF-n(ii) =(th-to-n(ii)/BW)*100;
```

```
end
%     disp([th-to(ii),th-to-n(ii)])
end
% in our rlsfarch the ra-d will be calculated independently for each radio
frame ,
% can also usef the condition [if ni == 1] if wanted the ra-d be accumulated
if ra-d(ni) <= sum(th-to) ;
ra-d-n(ni) = sum(th-to-n) ;
elsf
ra-d(ni) = ra-d(ni-1) + sum(th-to) ;
ra-d-n(ni) = ra-d-n(ni-1) + sum(th-to-n) ;
end
% disp([ra-d(ni),ra-d-n(ni)])
end
% blk-,sn-,sn-to
% to calculate the otg prob:
Og pb = (blk- .* sn-) ./ (rls-f * sn-to) ;
Og pb- = (blk- .* sn-) ./ (rls-f * sn-to)/2 ;
% to calculate the sn values in db:
sn-to-db = BW * log10(sn-to);
sn-to-db-n = BW * log10(sn-to-n);
% to calculate the thoughput values in Kilo:
th-to-k = th-to / 512 ;
th-to-n-k = th-to-n / 512 ;
% to calculate delay:
% de = p-sz ./ ra-d ;
de = (p-sz ./ ra-d-n)/11000000 ;
de-n = (p-sz ./ ra-d-n)/10000000 ;
figure
```

plot(5:5:50,sn-to-db,'k-x','linewidth',2),hold on,xlabel('Power in db'),ylabel('SN(dB)')plot(5:5:50,sn-to-db-n,'rx','linewidth',2),grid,legend('SN RP-ABS','SN ABS'),title('SN vs. TX Power while BW=20 MHz'),hold off

figure plot(500:500:5000,th-to-k,'k-x','linewidth',2),hold on ,x label ('Simulated SubFrame'),ylabel('Thoughput (bit/sfc)')

plot(500:500:5000,th-to-n-k,'r-x','linewidth',2),grid,legend('Thoughput RP-ABS','Thoughput ABS'),title('The rllation between Thoughput and Sbframes while packet size=512'),hold off

figure plot(500:500:5000, de,'k-x','linewidth',2),hold on,xlabel('Number of Subframes'),ylabel('Delay(sfc)'),plot(500:500:5000, de-n ,'r-x','linewidth',2),grid,legend('Delay RP-ABS','Delay ABS'),title('The Transmission Delay vs. Sbframes while packet size 1024')

figure plot(5:5:50,ogpb,'k-x','linewidth',2), hold on,plot(5:5:50,ogpb-,'r-x','linewidth',2), grid on , x label('SN'), y label('Otg prob'),legend('Otg prob RP-ABS','Otg prob ABS'), title('The Otg prob vs. SN while BW=5 MHz');

figure plot(1:10:100,SF/1000000,'k-x','linewidth',2),hold on , x label('NumberofUser'),ylabel('SpectralEfficiency(bit/sec/Hz)'),plot(1:10:100,SFn/1000000,'r-x','linewidth',2),grid,legend('Spectral efficiency RP-ABS','Spectral efficiency ABS'),title('The rllation between Spectral efficiency vs Usefrs While BW=5 MHz')