Sudan University of Science and Technology

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Performance Evaluation of Femtocell Using Cognitive Interference Management in LTE Networks

A Research Submitted in Partial fulfillment for the Requirements of the Degree of B.Sc. (Honors) in Electronics Engineering (Communications)

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DECLARATION

قال تعالى:

﴿ اللَّهُ نُورُ السَّمَاوَاتِ وَالْأَرْضِ مَثَلُ نُورِهِ كَمِشْكَاةٍ فِيهَا مِصْبَاحٌ الْمِصْبَاحُ فِي زُجَاجَةٍ الزُّجَاجَةُ كَأَنَّهَا كَوْكَبٌ دُرِّيٌّ يُوقَدُ مِنْ شَجَرَةٍ مُبَارَكَةٍ زَيْتُونَةٍ لَا شَرْقِيَّةٍ وَلَا غَرْبِيَّةٍ يَكَادُ زَيْتُهَا يُضِيءُ وَلَوْ لَمْ تَمْسَسْهُ نَارٌ نُورٌ عَلَى نُورٍ يَهْدِي اللَّهُ لِنُورِهِ مَنْ يَشَاءُ وَيَضْرِبُ اللَّهُ الْأَمْثَالَ لِلنَّاسِ وَاللَّهُ بِكُلِّ شَيْءٍ عَلِيمٌ ﴾

صدق الله العظيم

[سورة النور:35]

DEDICATION

This project is lovingly dedicated to our respective parents and teachers who have been our constant source of inspiration.

They have given us the drive and discipline to tackle any task with enthusiasm and determination, without their support this project would not have been made possible.

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Firstly, everything happens with the grace of God, so we thank the almighty God for providing us an opportunity, strength and ambience to successfully accomplish this project.

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We are extremely graceful to the celebrated authors whose research works have been freely consultant and referred in our project.

Finally, we would like to thanks all people who support our project, foremost have been our families who encouraged us to work hard and to continuous this work and colleagues for their kindness and support.

ABSTRACT

In 4G system there are many services can be offered to the users, and effective resource management will lead to give them a proper quality of services they require. In heterogeneous networks the deployment of femtocells may introduce extra interference to macrocell base stations. An effective interference management mechanism is required to optimize the system performance. This research is focusing on both co/cross-tier Interference in heterogeneous networks and finds a way through Cognitive Interference management to increase the quality of received signal. A resource allocation scheme is proposed to resolve the two-tier downlink interference problem, and effectively manage the resources between macro/femtocell's users according to the received signal-to-interference-plus-noise ratio (SINR). The improvement in the system achieved is shown in the simulation using the Matlab programming language. The results are achieved in parameters that improved the system and enhanced the performance compared to the system without Spectrum Splitting-based Cognitive Interference Management, including SINR improvement by 7 dB, Throughput is raised by 7.5%; thus, leads to increase the Spectral efficiency, diminish the delay time by 8.2% ,reduction of outage probability.

المستخلص

في نظام الجيل الرابع للإتصالات هنالك العديد من الخدمات التي يمكن تقديمها للمستخدمين، الإدارة الفعالة للموارد المتوفرة تقود إلى إعطاء هؤلاء المستخدمين الخدمات المطلوبة بجودة تتناسب مع حوجتهم، قد يحدث تداخل بين الإشارات داخل نطاق الشبكات المتباينة، لذلك لابد من وجود الية فعالة للحد من هذا التداخل فبالتالي تحقيق أداء أفضل للنظام. هذا البحث يركز على مشكلة التداخل بين المكونات المتماثلة والغير متماثلة للمحطات الرئيسية في الشبكات المتباينة حيث يتم تخصيص الموارد للمستخدمين عن طريق آلية إدارة التداخل الإدراكية إعتمادا على نسبة الإشارة المستقبلة إلى إشارتي التداخل والضجيج مجتمعتين.تم تطبيق الآلية عن طريق المحاكاة بإستخدام برنامج الماتلاب مما أدى إلى تحسين أداء النظام وذلك بزيادة نسبة الإشارة المستقبلة إلى إشارتي التداخل والضجيج بمقدار 7 ديسبل،كذلك إرتفع خرج النظام بمقدار7.5%؛ مما أدى إلى زيادة الكفاءة الطيفية بنفس القدر، وأيضا تم تقليل زمن تأخير الإرسال بمقدار8.2%،بالإضافة إلى نقصان إحتمالية إنقطاع الخدمة. كل النتائج السابقة مقارنة مع تطبيق النظام دون إستخدام آلية التداخل الإدراكية.

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LIST OF SYMBOLS

σ Log-normal shadowing.

Pr Received power.

Pt Transmitted power.

Gt Transmitted gain.

Gr Received gain.

PL Path loss.

L Wall loss.

H Frequency selective fading.

Y Received signal.

G Channel gain.

P Transmit power.

η Thermal noise.

I Received co-channel interference.

Ca Capacity of UE.

T Throughput.

α Constant of BER.

Ks Number of subcarriers per RB.

Ss Symbol rate per subcarrier.

ε_s Symbol efficiency.

DR Data rate.

BW Bandwidth.

C Code rate.

m Modulation rate.

SE Spectral Efficiency.

N Packet size .

D Delay.

OP Outage Probability.

SINR Signal to Interference plus Noise Ratio.

LIST OF ABBREVIATIONS

1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
3GPP	Third Generation Partnership Project
A-GPS	Assisted Global Position System
BS	Base Station
BSC	Base Station controller
BTS	Base Transceiver Station
BPSK	Binary Phase Shift Keying
CA	Carrier Aggregation
CID	Cell Identifier
CIM	Cognitive Interference Management
CP	Cyclic Prefix
DL	Downlink
E-CIF	Enhanced Cell Identifier
eICIC	Enhanced inter-cell interference coordination
eNB	Evolved Node B

FBS	Femto Base Station
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplexing
FDMA	Frequency Division Multiple Access
FUE	Femto User Equipment
GPS	Global Position System
GSM	Global System for Mobile Communication
HetNet	Heterogeneous Network
IMT	International mobile telecommunication system
ISI	Inter-symbol Interference
ITU	International telecommunication union
LTE	Long Term Evolution
Matlab	Matrix laboratory
MBMS	Multimedia Broadcast Multicast Services
MBS	Macro Base Station
MIMO	Multi-Input Multi-Output
MS	Mobile Station
MUE	Macro User Equipment
OFDM	Orthogonal frequency Division Multiplexing

OFDMA Orthogonal frequency Division Multiple Access

OTDOA Observed Time Difference of Arrival

PAPR peak-to-average power ratio

QAM Quadrature Amplitude Modulation

QOS Quality of Service

RB Resource Block

RF Radio Frequency

RN Relay Node

SC-FDMA Single Carrier Frequency Division Multiple Access

SS-CIM Spectrum Splitting-based Cognitive Interference Management

SINR Signal to Interference and noise ratio

TDM Time Division Multiplexing

TDMA Time Division Multiple Access

TDD Time Division Duplex

UL Uplink

UE User Equipment

CHAPTER ONE
INTRODUCTION

1.1 Preface

Every day, there is a growing demand for higher data rate services and the conventional macrocell network is unable to provide better services to data-rate hungry users. To handle tremendous traffic burden, the recent heterogeneous network has emerged with an answer in the form of low power femtocell networks which bring the BS (base station) closer to the users [1].

In such development, interference is a critical issue since the femtocells reuse the same spectrum which is already allocated to the macrocells. Therefore, the femtocells have potential of introducing interference into the main macrocell network as network users can install femtocell access points in any place without coordinating with the wireless network provider. Two-tier networks are wireless systems comprising of macro-cellular network(s) being underlain by smaller coverage femtocells. Interference in two-tier networks includes cross-layer interference, which occurs between a femtocell and a macrocell, and co-layer interference, which occurs among network elements that belong to the same network layer. To mitigate the interference impact in two tier networks, interference management can be performed [2].

1.2 Problem Statement

The femtocell is deployed over the existing macro network, and it uses same spectrum with the macrocell which cause interference problem, the femtocell is often turned on and off, and installed at unknown location, because it is managed by a personal customer, not by a network operator.

1.3 Proposed Solution

We propose a cognitive resource allocation scheme for interference management on the downlink that handles both co-layer and cross-layer interference scenarios. The resource-blocks in the macrocell (in frequency and time domain) are allocated to the users according to the received signal-to-interference-plus-noise-ratio (SINR). Then the rest of resource blocks are allocated to the femtocell.

1.4 Aim and Objectives

The main aim of this project is to enhance performance of femtocell using cognitive interference management, which increases the amount of resources.

The objectives of this project are:

- To develop a mathematical model for performance metrics.
- To simulate the performance metrics using Matlab.
- To evaluate the performance of the system considering:
  - SINR.
  - Throughput.
  - Spectral efficiency.
  - Transmission Delay.
  - Outage Probability.

1.5 Methodology

Studying the basic idea of the cognitive interference management scheme via dynamic resource block (RB) allocation for both macro and femto-cell tiers depending on the signal to interference plus noise ratio (SINR) level, and completing the mathematical models that cover and reflect the improvements happened to the system with and without the cognitive interference management scheme with figures using Matlab.

1.6 Thesis Outlines

Chapter One: It is an introduction of the research and it covers the Problem Statement, proposed Solution and Aim and Objectives.

Chapter Two: It is a literature review and it gives a Background of the LTE, LTE Advanced, OFDM and general background involved in the research, also discussed the related works in the last decade.

Chapter Three: Discussed the basic idea of the methodology, represents the procedures of the cognitive interference management scheme, and considering the mathematical models which represents the performance of the system.

Chapter Four: It covers the results obtained and discussion of the results.

Chapter Five: Consists of a brief conclusion of the research, and the recommendations for the future researchers.

CHAPTER TWO
LITREURE REVIEW

2.1 Background

Mobile Communication technologies are often divided into generations, with 1G being the analog mobile radio system, 2G the first digital mobile systems, and 3G the first mobile systems handling broadband data. The long term evolution LTE is often called 4G [3].

This continuing race of increasing sequence numbers of mobile system generations is in fact just a matter of labels .what important is the actual system capabilities and how they have evolved [3].

2.1.1 General Features of LTE

LTE represents a radical new step forward for the wireless industry, targeting order-of-magnitude increases in bit rates with respect to its predecessors by means of wider bandwidth and improved spectral efficiency. Beyond the improvement in bit rates, LTE aims to provide a highly efficient, low-latency, packet-optimized radio access technology offering enhanced spectrum flexibility [4].

The LTE design presents radical differences at every layer. Like many other communication technologies the physical layer uses OFDM waveforms in order to avoid the inter symbol interference that typically arises in high bandwidth systems. One differentiating aspect of the LTE standard is MIMO [4].

2.1.1.1 Inter-symbol Interference

ISI stands for Inter-symbol Interference, is an interference usually generated when transmitting in a multipath fading channel. In this kind of channel, multiple copies of transmitted signal are received at different time intervals, which causes interference, in a multipath fading channel, the received signal can be delayed copy of the original signal coming through receive antenna, creates interference thus changing of amplitude and phase[5].

2.1.1.2 Orthogonal Frequency Division Multiplexing

OFDM stands for Orthogonal Frequency Division Multiplexing, is considered as one of the most promising wireless techniques for future generation cellular systems. It is a special case of multi-carrier transmission [6]. Large numbers of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels shown in Figure 2.1 [6].

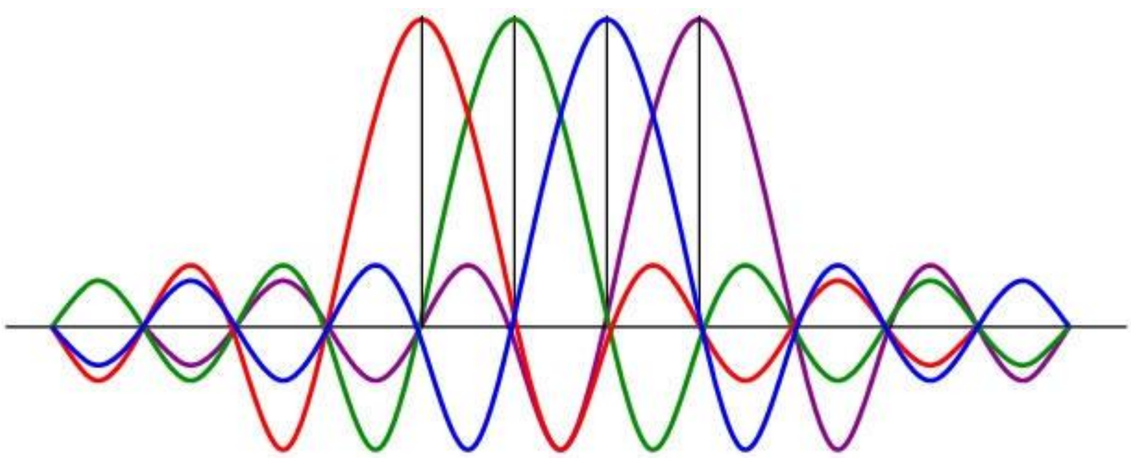

Figure 2.1: Orthogonal Sub-Carriers in OFDM

The multiplexing deals with allocation/accommodation of users in given bandwidth, which deals with allocation of available resources. In FDM we need guard band between adjacent frequency bands so extra overhead and lower throughput. OFDM supports multiple users via TDMA basis. Shown in Figure 2.2 [6].

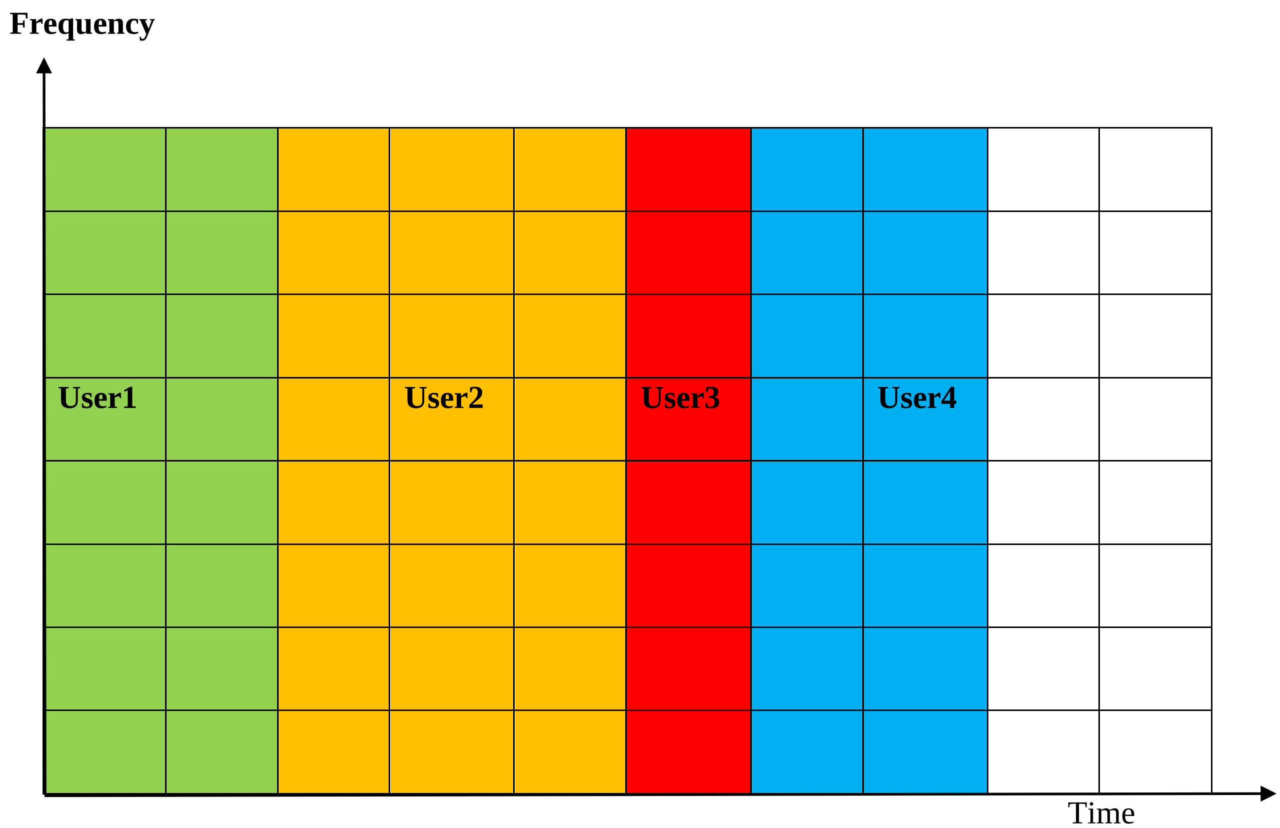

Figure 2.2: OFDM Resources Allocation

OFDM is combination of modulation and multiplexing. Normal modulation is single carrier modulation technique in which the incoming information is modulated over a single carrier [6]. Also OFDM is a multicarrier modulation technique which employs several carriers within the allocated bandwidth to convey the information from source to destination. Each carrier may employ one of the several available digital modulation techniques [6].

OFDM is robust against frequency selective fading and narrowband interference; different frequency components of the signal experience different fading [6].

It is very difficult to handle frequency selective fading at the receiver in which case the design of the receiver is hugely complex. Instead of trying mitigate frequency selective fading as whole (which occurs when huge bandwidth is allocated for the data transmission over frequency selective fading channel). OFDM mitigates the problem by converting the entire frequency selective fading channels [6].

OFDMA supports either on TDMA or FDMA basis or both at the same time. Also supports simultaneous low data rate transmission from several users [6]. Further improvement to OFDMA over OFDM robustness to fading and interference since it can assign subset of subcarriers per user by avoiding assigning bad channel or subcarrier power shown in Figure 2.3 [6].

2.1.1.3 Frame Structure in LTE

The LTE frame structure is as shown in Figure 2.3 below. The frame duration is 10 ms and each frame is divided into sub-frames of 1ms each. The sub-frames are further divided into two slots of 0.5 ms durations. Depending on the cyclic prefix configuration, each slot has seven and six OFDM symbols, in the normal and extended cyclic prefix respectively. In the frequency domain, resources are grouped in units of 12 subcarriers from each OFDM symbol, separated by 15 kHz and therefore occupying a total of 180 kHz. One resource block is defined as twelve subcarriers for duration of one slot. The resource block is the main unit to schedule transmissions over the air interface [7].

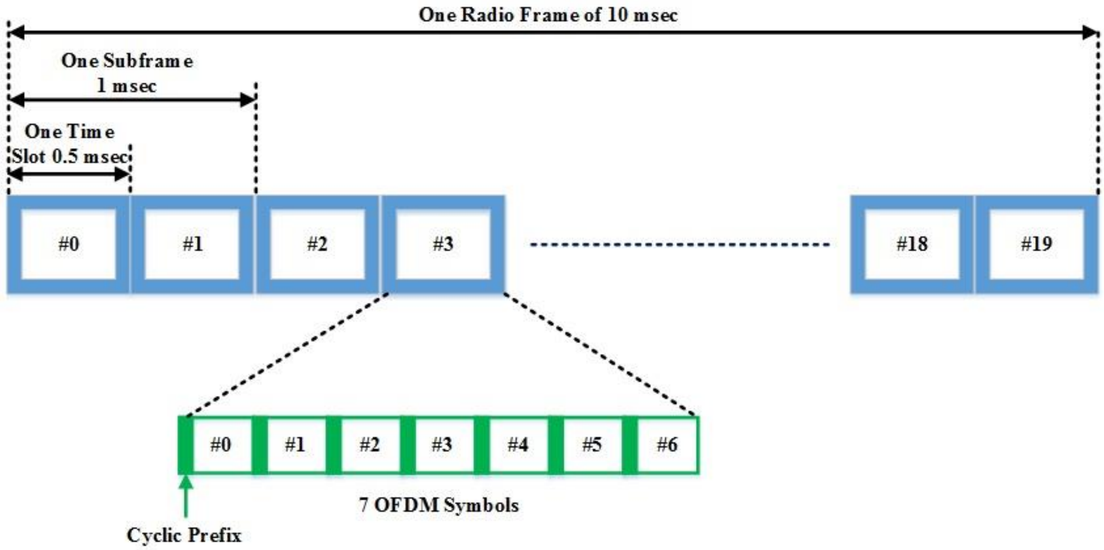

Figure 2.3: LTE Frame Structure

2.1.1.4 Single Carrier FDMA

In cellular applications, a big advantage of OFDMA is its robustness in the presence of multipath signal propagation. The immunity to multipath derives from the fact that an OFDMA system transmits information on M orthogonal frequency carriers, each operating at M times the bit rate of the information signal. On the other hand, the OFDMA waveform exhibits very pronounced envelope fluctuations resulting in a high peak-to-average power ratio (PAPR). Signals with a high PAPR require highly linear power amplifiers to avoid excessive inter modulation distortion. To achieve this linearity, the amplifiers have to operate with a large back off from their peak power. The result is low power efficiency (measured by the ratio of transmitted power to dc power dissipated). This places a significant burden on portable wireless terminals. Another problem with OFDMA in cellular uplink transmissions derives from the inevitable offset in frequency references among the different terminals that transmit simultaneously. Frequency offset destroys the orthogonality of the transmissions, thus introducing multiple access interference. To overcome these disadvantages, 3GPP (The 3rd Generation Partnership Project) is investigating a modified form of OFDMA for uplink transmissions in the long-term evolution (LTE) of cellular systems.

The modified version of OFDMA, referred to as single carrier FDMA (SC-FDMA). As in OFDMA, the transmitters in an SC-FDMA system use different orthogonal frequencies (subcarriers) to transmit information symbols. However, they transmit the subcarriers sequentially, rather than in parallel. Relative to OFDMA, this arrangement reduces considerably the envelope fluctuations in the transmitted waveform. Therefore, SC-FDMA signals have inherently lower PAPR than OFDMA signals However, in cellular systems with severe multipath propagation [8].

2.1.1.5 Multi Input Multi Output

MIMO is used to increase the overall bit rate through transmission of two (or more) different data streams on two (or more) different antennas - using the same resources in both frequency and time, separated only through use of different reference signals to be received by two or more antennas [9].

2.1.2 Releases of LTE

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 works on LTE was to define a set of performance and capability targets for LTE. This included targets on peak data rate, user/system throughput, spectral efficiency and control/user latency plane [10]. Once the targets were set, 3GPP studies on the feasibility of different technical solution considered for LTE were followed by development of the detailed specification.

2.1.2.1 Release 8 – LTE

The first release of LTE specification, Release 8, was completed in the spring of 2008 and commercial network operation began in late 2009 [10]. Release 8 when LTE was introduced for the very first time. All the releases following only enhanced the technology. The following is the main achievements [11]:

- High peak data rates: Up to 300 Mbps in downlink and 75 Mbps in uplink when using 4x4 MIMO and 20 MHz bandwidth [11].
- High spectral efficiency [11].
- Flexible bandwidths: 1.4,3,5,10,15 and 20 MHz [11].
- Short round-trip time: 5ms latency for IP packets in ideal radio conditions.
- Simplified architecture [11].
- OFDMA in downlink and SC-FDMA in uplink [11].
- Multiple Antenna schemes [11].
- Operation in paired (FDD), and un-paired (TDD).

2.1.2.2 Release 9 – Enhancement to LTE

The initial enhancements were included to LTE in Release 9. These were in fact the improvements which were left behind from Release 8 or perhaps provided some minor improvements. These improvements are listed below with brief description [11].

- **Femtocell:** Femtocell is basically a small cell used in offices or homes. 3G Femtocells are deployed around world, and in order for LTE users to take advantage of femtocell [11].
- **MIMO Beam forming**: Beam forming is used to increase cell edge throughput by directing beam towards specific UE (user equipment) by position estimation at eNB (evolved nodeB refer to BS). In Release 8, LTE supported single layer beam forming based on user-specific Reference Symbols. In Release 9, single layer beam forming has been extended to multilayer beam forming [11].
- **MBMS:** With Multimedia Broadcast Multicast Services (MBMS), operators have capability to broadcast services over LTE network. The idea is not novel to the LTE and has been used in legacy networks as well but for LTE, the MBMS channel has evolved from data rate and capacity perspective. The MBMS was already defined at physical layer in Release 8 but with Release 9, higher layer and network layer aspects were completed [11].
- **LTE positioning:** Three position methods are specified in LTE Release 9 i.e. Assisted GPS (A-GPS), Observed Time difference of arrival (OTDOA) and Enhanced Cell ID (E-CID). The goal is to improve

the accuracy of user locations in case of emergency scenarios where the user itself is unable to disclose his whereabouts [11].

2.1.2.3 Release 10 – LTE Advanced

The LTE-Advanced specifications in Release 10 includes significant features and improvements to fulfill ITU IMT-Advanced requirements, which sets higher speeds than what UE can achieve from 3GPP Release 8 specifications. Some key requirements lay down by IMT-Advanced are as below [11]:

- 1 Gbps DL / 500 Mbps UL throughputs.
- High spectral efficiency.
- Worldwide roaming Following are some significant improvements in release 10:

- **Enhanced uplink multiple access:** Release 10 introduces clustered SC-FDMA in uplink. Release 8 SC-FDMA only allowed carriers along contiguous block of spectrum, but LTE-Advanced in release 10 allows frequency selective scheduling in uplink [10].
- **MIMO enhancements:** LTE-Advanced allows up to 8x8 MIMO in downlink and on the UE side it allows 4X4 in uplink direction [10].
- **Relay Nodes:** In order to decrease coverage loop holes, Relay nodes are one of the features proposed in release 10. The relay nodes or low power eNBs extending the coverage of main eNB in low coverage environment. The relay nodes are connected to Donor eNB (DeNB) through U_n interface [11].
- **Enhanced inter-cell interference coordination (eICIC):** eICIC introduced in 3GPP Release 10 to deal with interference issues in

HetNet. eICIC mitigates interference on traffic and control channels. eICIC uses power, frequency and also time domain to mitigate intra-frequency interference in HetNets (heterogeneous networks) [11].

- **Support for HetNets :** The combination of large macro cells with small cells results in HetNets. Release 10 intended to layout the detail specification for HetNets [11].
- **Carrier Aggregation (CA):** To achieve these very high data rates; it is necessary to increase the transmission bandwidths over those that can be supported by a single carrier or channel. The method being proposed is termed carrier aggregation, it is possible to utilize more than one carrier and in this way increase the overall transmission bandwidth [11]. These channels or carriers may be in contiguous elements of the spectrum, or they may be in different bands.

2.1.3 Femtocell

Femtocells are single mode, power efficient, backward compatible, low cost and easy to install devices. They can increase the capacity of macrocell as they use the same spectrum as that of macrocell. As the radius of Femtocell is much smaller as compared to that of macrocell, that is why it can provide high data rates in any environment such as home or office. Moreover, femtocells can also be a cost effective solution for enterprises because of their self-organizing networks characteristics [12].

2.1.4 Femtocell's access modes

In general, femtocells can operate in three access modes:

- **Closed access:** Only subscriber with permission can access the femtocell (for example the members of a family). This model is referred as CSG (Closed Subscriber Group) by the 3GPP [13].
- **Open access:** All subscribers of operator have authority to make use of femtocell. This mode is frequently used in public places, such as airports and shopping malls. Femtocell operated in open access mode can also be used to benefit UE with its services. Open access mode is usually used to improve indoor coverage [13].
- **Hybrid access:** A limited amount of the femtocell resources are shared to all UEs, while most resources are used to operate in a CSG manner. In a small business or enterprise environment, the hybrid access mode of femtocell may be used [13].

2.1.5 Interference Management

Generally, interference management techniques can be classified into:

- **Interference cancellation**: Demodulating desired information and then using it along with channel estimates to cancel interference out from the received signal being defined, e.g. SIC, PIC, and MUD. Most of these methods require information of the characteristics of the interfering signal and antenna arrays at the receiver system. Therefore, these methods are less suitable for user equipment's UEs; but more suitable for BSs so they are generally used for uplink interference management [2].

- **Interference randomization**: Mitigating interference by dynamically and periodically allocating different times or frequencies to users, e.g. time and frequency hopping. These approaches need high synchronization between a BS and a UE as well as not considering channel gain. They will be more complicated when femtocells are deployed densely [2].
- **Interference avoidance**: Managing radio resources in such a manner to avoid the impact of interference, e.g. frequency reuse/ spectrum splitting, power control, and spectrum arrangement. However, these schemes are based on centralistic controlled process, less efficient in spectrum utilization, FBSs (femto-BSs) load will increase when the number of MUEs (macro-UEs) is high and spectrum occupation fluctuates, and also the MBS (macro-BS) needs information of its underlying FBSs [2].
- **Distributed interference management**: Each BS has ability to control its radio resources. This approach needs information exchange and coordination between two network tiers. Therefore, this method will increase systems' overhead as the number of femtocells rises up [2].

2.2 Related Works

Z. Bharucha, A. Saul, G. Auer, and H. Haas (2010) focused on mitigating downlink femtocell-to- macrocell interference through dynamic resource partitioning, in the way that HeNBs (Home eNBs) are denied access to downlink resources that are assigned to MUEs in their vicinity.

So, interference to the most vulnerable MUEs is effectively controlled at the expense of a modest degradation in femtocell capacity [20].

S. Rangam (2010) presented that with sub-band partitioning in the macrocell network, femtocells would have improved opportunities for communication with minimal interference to the macrocell network. And the short-range femtocell links adaptively allocate their power across the sub-bands based on a load-spillage power control method [21].

H. Claussen (2007) studied the feasibility of coexistence of femto/macrocells in the same frequency bands. Key requirements for co-channel operation of femtocells such as auto-configuration and public access are discussed. A method for power control pilot and data that ensures a constant femtocell radius in the downlink and a low pre-definable uplink performance impact to the macrocell is proposed [22].

V. Chandrasekhar and J. G. Andrews (2008) proposed a decentralized algorithm for spectrum allocation between macrocell and femtocell layer [23].

CEWiT (R1-104106) presented an overview of the techniques and solutions proposed by various companies in the ongoing 3GPP discussions to handle interference scenarios in hetnets [24].

S. Kaimaletu, R. Krishnan, S. Kalyani, N. Akhtar, and B. Ramamurthi(2011) proposed a cognitive interference management scheme in which interfering RBs (resource-blocks) are blocked to handle downlink interference by implementing cognitive process to some extent in heterogeneous femto/macrocell networks. Along with the increasing number of BSs and UEs, the system’s complexity and overhead will increase. And this method did not consider the quality of each RB [25].

CHAPTER THREE
SPECTRUM SPILLITING BASED-COGNITIVE INTERFERENCE MANAGEMENT

Interference in two-tier networks includes cross-layer interference, which occurs between a femtocell and a macrocell, and co-layer interference, which occurs among network elements that belong to the same network layer [2].

After investigation and research to solve co-channel interference problem in the downlink, choosing spectrum splitting-based cognitive interference management to be under studying to simplify, speed up information exchange among base-stations and reduce system's complexity and overhead.

3.1 Spectrum Splitting-based Cognitive Interference Management

We propose SS-CIM via dynamic RB allocation for both macro and femtocell tiers. In this method, the macrocell allocates RBs based on the SINR level of the RSRP (reference-signal-received-power) of its served UEs. By blocking some RBs with SINR lower than a threshold, the MBS allocates good RBs for MUEs. Then scheduler distributes the RBs to each user in different times. Whilst, based on the control channel information from the MBS, FBSs allocate RBs that are not occupied by the macrocell to serve its users.

3.1.1 SINR Level Identification and Spectrum Splitting

In this step, the MBS identifies each RSRP being received from all MUEs and marks RBs with SINR lower than threshold as '1', as shown in Table 3.1, the MBS counts the number of users with low SINR (weak users) in each RB. After that, it orders the number of weak users of each

RB. Then it chooses a threshold ϕ, a parameter which can be set by the algorithm. When the RB has a number of weak users above ϕ, it will be blocked. Subsequently, the MBS determines RBs to be blocked by prioritizing RBs with high number of weak users. All processes above will result in a RB allocation map as shown in Table 3.2. Flag '1' represents a RB being allocated to the macrocell. Figure 3.1 summarizes all process above.

Table 3.1: Weak Resource Block Matrix

	RB_1	RB_2	RB_3	…	RB_n
UE_1	1	0	1	…	0
UE_2	0	1	1	…	0
UE_3	1	0	1	…	1

3.1.2 Control-Channel Information Sensing

In this step, all femtocells simultaneously sense the PDCCH (Physical Downlink Control Channel) from the MBS. PDCCH from the MBS holds information of RB allocation for all MUEs in one sub-frame. FBSs use this information to observe RBs being occupied by the MBS, and find out unoccupied ones to allocate to their served users. Based on this, each FBS generates its RB allocation map shown in Table 3.2.

Table 3.2: Resource Block Allocation Map

RB index	Allocation flag
1	0
2	1
3	0
…	…
N_{RB}	1

Step 0: ρ = ones(N_{RB},1);

Step 1: find($\gamma_{ik} < \gamma_{th}$);

Step 2: if $\gamma_{ik} < \gamma_{th}$ then $\psi_{ik} = 1$, else $\psi_{ik} = 0$;

Step 3: $\Psi = \sum_{K} \psi ik$;

Step 4: $\theta = \{\Psi_i\}\ i \in \{1,...,n\},\ \Psi_i \in \{\Psi\},\ \Psi_i \neq 0,$

$\Psi i \neq \Psi_j$ for $i \neq j$;

Step 5: θ_{sorted} = sort(θ,'descend');

Step 6: $\phi = \frac{n}{Nwu}$,

$n = \{a < N_{wu} : a \in N\}$;

Step 7: $\lambda = \lfloor \phi \times n(\theta) \rfloor$;

Step 8: for k = 1 to λ

find($m|\Psi_m = \theta_{sorted,k}$), $m \in \{\emptyset, 1, ..., N_{RB}\}$;

$\rho_m = 0$;

Step 9: end

Figure 3.1: Pseudocode of RB allocation in the macrocell

3.1.3 Frame-based Transmission and Scheduling

Based on Table 3.2, the scheduler in each BS (both macro and femtocells) will allocate RBs to its served UEs for downlink transmission. By using a multicarrier PF (proportional fair) scheduler [10], the distribution of RBs among users in frequency and time domain can be maintained proportionally.

3.2 Adaptive Modulation and Coding AMC

In cellular communication system the quality of a signal received by user equipment UE depends on number of factors the distance between the desired and interfering BSs, path loss exponent, shadowing, short term Rayleigh fading and noise [19].

In order to improve the system capacity, peak data rate, and coverage reliability. These systems must be able to adapt and adjust the transmission parameters based on link quality; the signal transmitted to any particular user is modified to account for the signal quality variation through a process commonly referred method for link adaptation or AMC [19].

AMC raises the overall system capacity in which provides the flexibility to match the modulation coding scheme to the average channel conditions or received signal quality for each user [19].

The implementation of AMC offers several challenges, first AMC is sensitive to measurement and delay in order to select the appropriate modulation, the schedule must aware of the channel quality. Also delay in reporting channel measurement also reduces the reliability of channel quality estimate [19].

The basic idea of link adaptation is to adapt the link efficiently in the actual channel conditions by varying certain transmission parameters. Transmission power, symbol rate, constellation size and coding scheme can be dynamically adapted in response to the time–varying channel. With selection of these transmission parameters, the system makes the most out of a time varying channel, instead of fixing the parameters for worst-case channel. The tradeoff involves minimizing the error probability for robustness and maximizing the instantaneous throughput for bandwidth efficiency [19].

Adaptive modulation and coding (AMC) is one of the adaptive techniques to counteract fading and enhance the performance of wireless system. It selects an optimal combination of modulation and coding scheme (MCS) to maximize bandwidth efficiency. The decision is based on the channel state information (CSI) each MCS is associated with a coding rate and constellation size, which has given bit rate. A quality of service (QoS) constraint on delivery delay is usually imposed [19].

Communication channel quality can have a significant impact on the performance of wireless communication system. Channel with high quality can transfer data at higher rate and lower latency than channel with low quality. Channel quality should therefore be factor that needs to be considered when scheduling message transmissions in communication system [19].

One commonly used technique to compute Channel Quality Indicator (CQI) is to determine a value of metric channel and then use the value to compute the CQI. The CQI for channel can then be used variety of operations involving the channel, such as scheduling transmissions on the channel. In communications system that has plurality of channels, a single CQI can be used for multiple channels as long as they are sufficiently close in frequency to each other. By using single CQI it is not necessary to compute CQI for each channel and hence computation and processing time can be saved [19].

Table 3.3: Adaptive Modulation and Coding

CQI Index	Min SINR[dB]	Modulation	Code Rate	Efficiency [bits/sym]
0	-	None	-	0
1	-6	QPSK	0.076	0.1523
2	-5	QPSK	0.12	0.2344
3	-3	QPSK	0.19	0.3770
4	-1	QPSK	0.3	0.6061
5	1	QPSK	0.44	0.8770
6	3	16QAM	0.59	1.1758
7	5	16QAM	0.37	1.4766
8	8	16QAM	0.48	1.9141
9	9	16QAM	0.6	2.4063
10	11	16QAM	0.45	2.7305
11	12	64QAM	0.55	3.3223
12	14	64QAM	0.65	3.9023
13	16	64QAM	0.75	4.5234
14	18	64QAM	0.85	5.1152
15	20	64QAM	0.93	5.5547

3.3 Channel Model of SS-CIM

Assume there are total N macrocells in the network and each macrocell is served by an eNB. A number of femtocells 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 indoor and served by femtocell. HeNB is referred as FUE (femtocell user equipment). Assume the network is deployed in urban area, then the path loss model which described in [14] by 3GPP in LTE-advanced standard can be used to model the signal degradation. Let the network operates in 2GHz, then the PL (path loss) between macrocell and MUE can be calculated as:

$$\mathbf{PL_{outdoor}(dB)= 15.3+37.6\ log_{10}(d) + \sigma^2} \tag{3.1}$$

In Eq (3.1), d is the distance (meter) between MUE m and macrocell 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 [14]. Similarly, the path loss for FUE f and femtocell F:

$$\mathbf{PL_{indoor}(dB)= 38.64+20\ log_{10}(d) + L_{wall}} \tag{3.2}$$

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 RB-m can be expressed as:

$$\mathbf{G}_{m,u} = \mathbf{10}^{-(PL_{m,u} + \psi_{\sigma})/10} |\mathbf{H}_{m,u}|^2 \tag{3.3}$$

Where *PL* is the path-loss; ψ_σ is log-normal shadowing with zero mean and standard deviation in σ dB [11]; $|H\ m,u|^2$ is frequency selective fading with Rayleigh distribution. A wall penetration loss is 13 dB, Thermal noise density is -120 dBm/RB [2].

Universal (i.e., full) frequency reuse and FDD is considered, such that each cell utilises the entire system bandwidth B_{sys}. 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_{vu} on RB_m is given by [15]:

$$\mathbf{Y}_{m,u} = \mathbf{P}_{m,u}\, \mathbf{G}_{m,[u,vu]} + \mathbf{I}_{m,u} + \boldsymbol{\eta} \tag{3.4}$$

Where $G_{(m,[u,vu])}$ signifies the channel gain (including fading and shadowing effects) between the MS_u and its serving BS_{vu}, observed on RB_m [15]. Furthermore, $P_{m,u}$ denotes the transmit power allocated to MS_u on RB_m, Su_m the desired received power, $\eta=\eta_0 B_{RB}$ the thermal noise, η_0 is the noise spectral density, and $I_{m,u}$ is the co-channel interference received on RB_m from MSs in neighboring cells [15], defined by:

$$\mathbf{I}_{m,u} = \sum_{i \in I_m}^{n} \mathbf{P}_{m,i}\, \mathbf{G}_{m,[u,vi]} \tag{3.5}$$

Where I_m represents the set of co-channel interferers (i.e., set of MSs in neighboring cells that are also assigned RB_m [15]. Hence, the SINR observed at the MS_u on RB_m is calculated by:

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

- **Received Power**

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

$$P_r = P_t + G_t + G_r - PL \quad (3.7)$$

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 Performance Metrics

3.4.1 Channel Gain

The value of L_{wall} is up to the distance between UE and BS (both= macrocell and femtocell). The value, L_{wall} equals 7,10 and 15 (dB) if d is within (0-10m) or (10m -20m) or (20m-30m), respectively [14]. So, the channel gain (g) for *i*-th UE can be calculated as:

$$\mathbf{G = 10^{[-PL/10]}} \quad (3.8)$$

3.4.2 SINR of MUE

In LTE standard, resource block (RB) is minimum unit for data resource allocation [14], the downlink signal to interference plus noise ratio (*SINR*) value on RB_a of a MUE_m:

$$SINR_{m,M,a} = \frac{P_{M,a}\, G_{m,M,a}}{N_0\Delta f + \Sigma\beta_{m',a}\, P_{M',a}\; G_{m,M',a} + \Sigma\beta_{f,a}\; P_{F,a}\; G_{m,F,a}} \qquad (3.9)$$

3.4.3 SINR of FUE

In Eq. (3.9), $P_{M,a}$ and $P_{M',a}$ are transmit powers of serving macrocell and neighboring macrocell set *M'* on resource block a. $P_{F,a}$ is the set transmit power of femtocells which interfere to MUE_m. *G* is channel gain which can be computed by (3.8). *M'* and *F* are sets of neighboring macrocells and femtocells, respectively. $\beta_{M',a}$ and $\beta_{F,a}$ are binary values which denote the resource block a is assigned for eNBs *M'* and HeNBs *F* [14]. $\beta_{m(f),a}$= 1 if resource block a is assigned for eNB *M'*(or HeNB *F*), otherwise $\beta_{m(f),a}$ = 0. Similarly, *SINR* of FUEs *f* is calculated:

$$SINR_{f,F,a} = \frac{P_{F,a}\, G_{m,F,a}}{N_0\Delta f + \Sigma\beta_{f',a}\, P_{F',a}\; G_{f,F',a} + \Sigma\beta_{m,a}\; P_{M,a}\; G_{f,M,a}} \qquad (3.10)$$

3.4.4 Capacity

The capacity (*Ca*) of MUE m (or FUE *f*) on resource block a can be given by (3.11) [14]:

$$\mathbf{C}a_{\,m(f),a} = \Delta f * \log_2(1+\alpha SINR_{\,m(f),a}) \qquad (3.11)$$

It should be mentioned that (3.12)-(3.14) are given for the downlink [14].

3.4.5 Throughput

The user throughput T_u is calculated as the data transmitted on the RBs assigned to MS_u

$$T_u = \sum_{m}^{n_{RB,a}} K_s\, S_s\, \mathcal{E}_s(SINR_{m,a}) \qquad (3.12)$$

In Eq. (3.11), α is a constant of Bit Error Rate (BER), and can be defined [α=-1.5/ln(5BER)] with the setting BER is 10^{-6} [14]. Thus, the total throughput for each macrocell serving and femtocell serving can be calculated by:

$$T_{m(f),a} = \sum_{m(f)=1}^{N_{m(f)}} \sum_{a=1}^{N_a} \beta_{m(f),a}\, C_{am(f),a} \qquad (3.13)$$

Where $n_{RB,a}$ is the total number of RBs allocated to MS_u, Ks the number of subcarriers per RB, S_s the symbol rate per subcarrier, and $\mathcal{E}_s$ the symbol efficiency (i.e., modulation and coding order), dependent on the achieved *SINR*, given in Table (3.3). Finally, the system throughput is the sum rate of all *MS*s in the network [15].

$$T_{sys} = \sum_{u} T_u \qquad (3.14)$$

3.4.6 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 [16].

$$\mathbf{DR = 2 \times BW \times C \times log\ (m)} \quad (3.15)$$

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

3.4.7 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 [17].

$$\mathbf{SE = \frac{DR}{BW}} \quad (3.16)$$

Where *DR* represents data rate, *BW* is the bandwidth.

3.4.8 Transmission delay

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

$$\mathbf{D} = \frac{\mathbf{N}}{\mathbf{2 \times BW \times C \times \log(m)}} \tag{3.17}$$

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

3.5.9 Outage Probability

The outage probabilities of, $OP_{eNB,n}$ and $OP_{HeNB,n}$ for both macro and home UEs in the nth eNB are[18]:

$$OP_{eNB,n} \cong \frac{Y_{MUE.n}^{OP}}{J} \ , \ OP_{HeNB,n} \cong \frac{Y_{HUE.n}^{OP}}{L} \tag{3.18}$$

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

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Simulation Parameters

The parameters used in the simulation using Matlab are shown in Table 4.1.

Table 4.1: System Simulation Parameters

Symbol Parameter (Unit)	Value
N_F FFT size	512
Δf sub-carrier spacing (kHz)	15
N_{slot} number of slots per sub-frame	2
N_{RB} number of resource blocks per sub-frame	50
N_{scRB} number of sub-carriers per RB	12

4.2 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.

4.2.1 Signal to Interference plus Noise Ratio

In Figure 4.1, SS-CIM method results in SINR improvement of an average around 7 dB over not to use it, where green line determines using SS-CIM and the red line without using the SS-CIM. This improvement caused by exclusive RB allocation for femtocells that reduces strong interference from the macrocell, especially at cell-edge area.

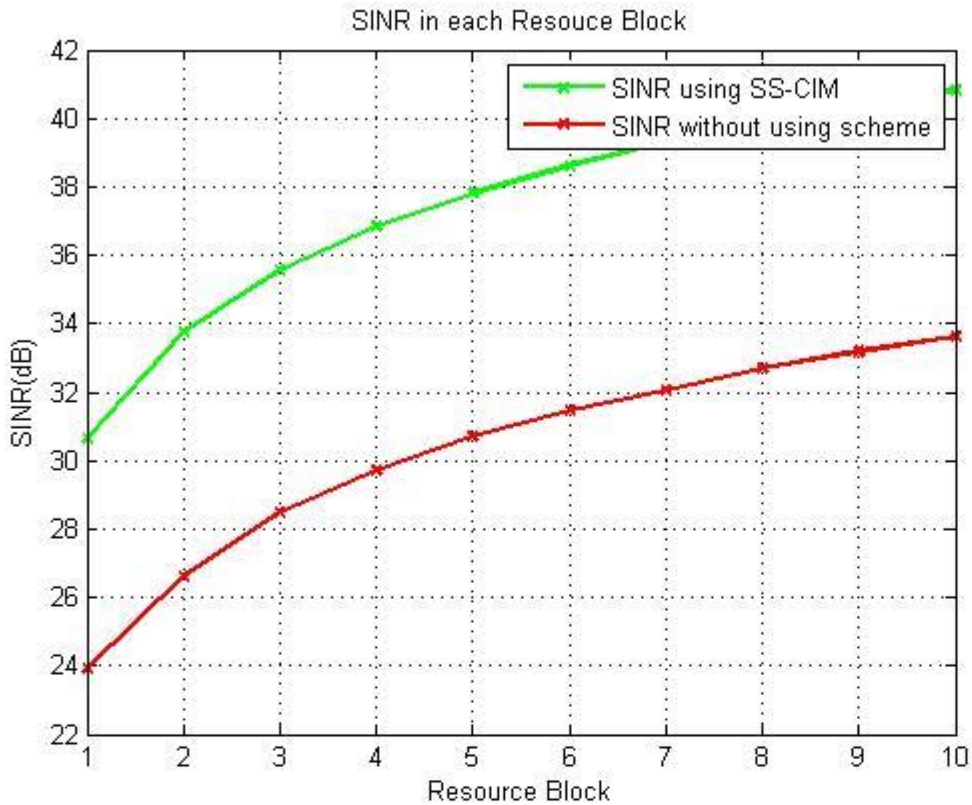

Figure 4.1: Compare SINR when using SS-CIM and without SS-CIM

4.2.2 Throughput

The throughput shown in Figure 4.2, in which green line determine the SS-CIM and the red line determine without using SS-CIM scheme, increased by 7.5% than without SS-CIM due to the increasing in the SINR and adding the adaptive modulation and coding AMC which change the modulation type and coding depending on the channel .

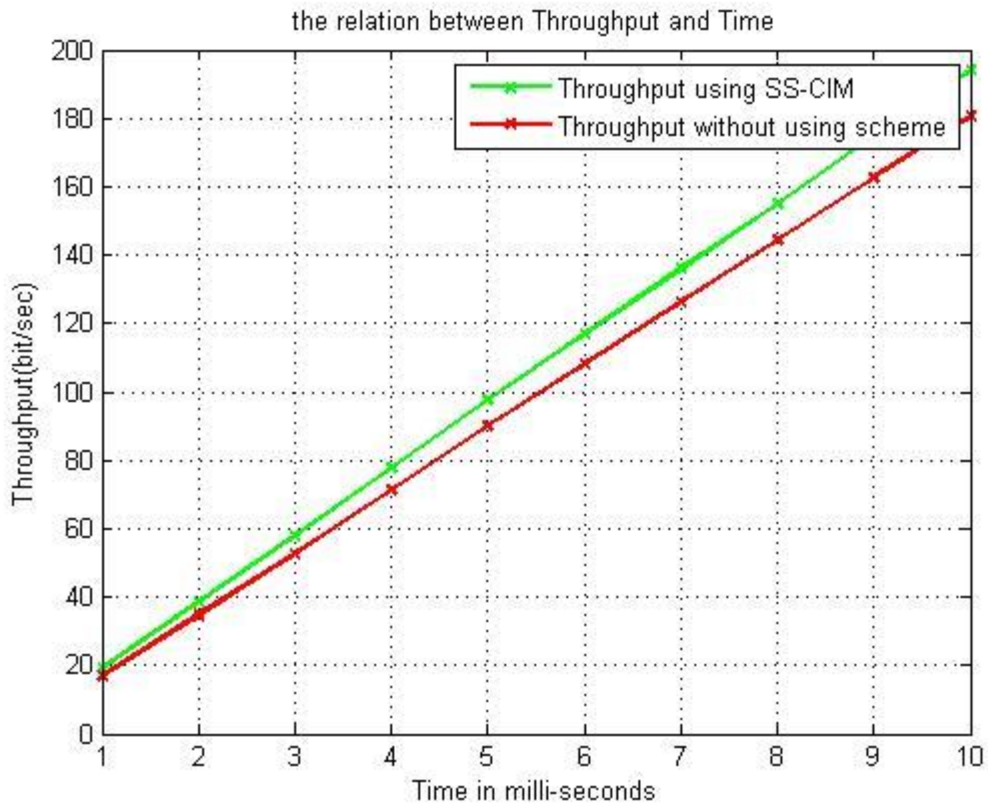

Figure 4.2: Comparison of Throughput in SS-CIM scheme and without SS-CIM

4.2.3 Spectral Efficiency

Corresponding to the increasing in the throughput by SS-CIM scheme lead to increase the Spectral efficiency as compared to not using SS-CIM by 7.5%. Shown in Figure 4.3. The green line indicates to spectral efficiency when using SS-CIM and the red line to not using SS-CIM.

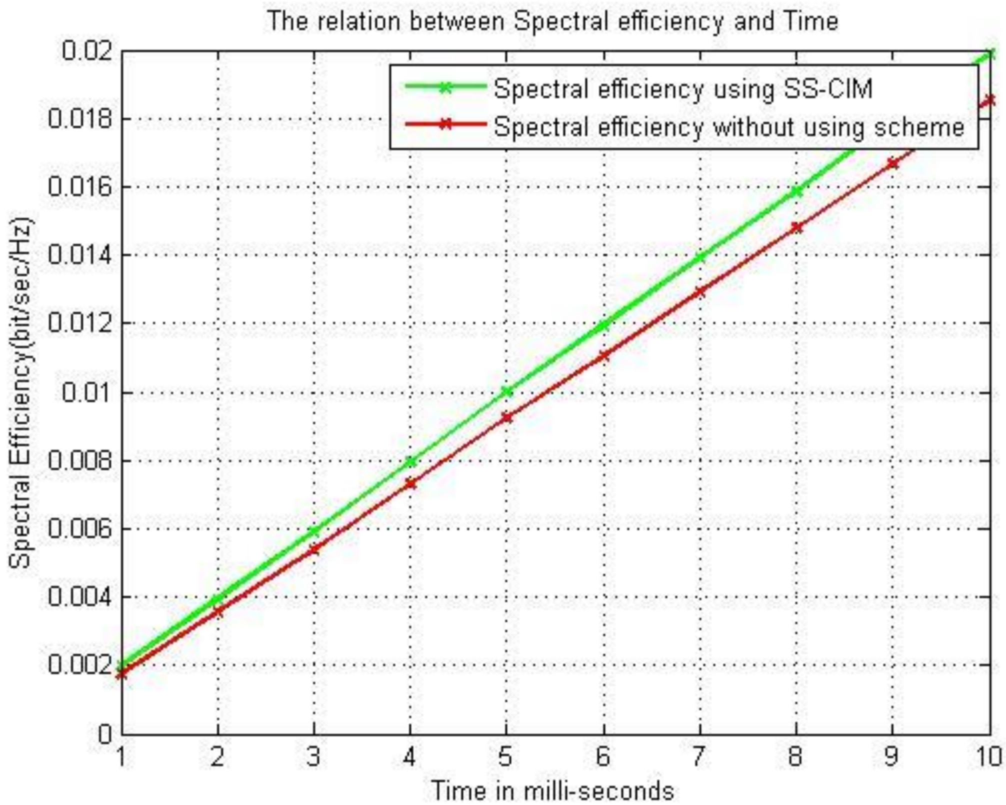

Figure 4.3: Compare Spectral efficiency between using SS-CIM and without

4.2.4 Transmission Delay

The delay time when using SS-CIM scheme is less than without scheme by 8.2% seen in a Figure 4.4, where the green line represents SS-CIM and the red line represents without SS-CIM. This reduction in transmission delay is caused by the increasing of the data rate.

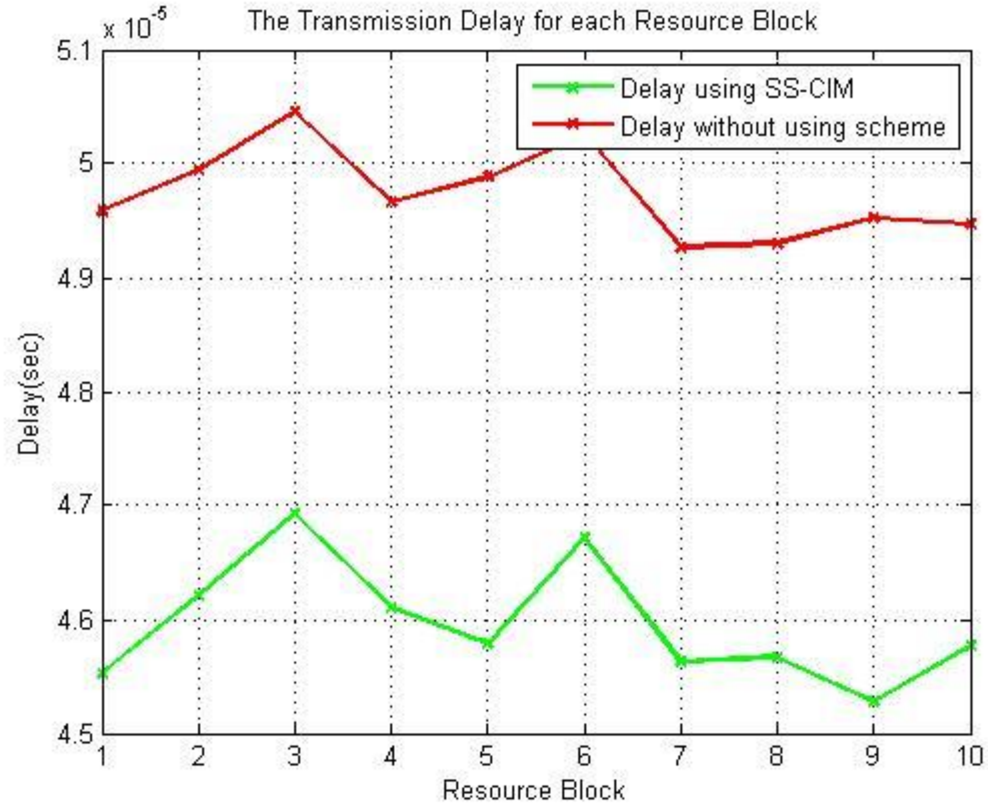

Figure 4.4: compare delay using SS-CIM and without SS-CIM

4.2.5 Outage probability

The decrease in outage probability is achieved by increasing of the SINR As shown in Figure 4.5. This decrement in Outage probability is a result of increasing the overall SINR.

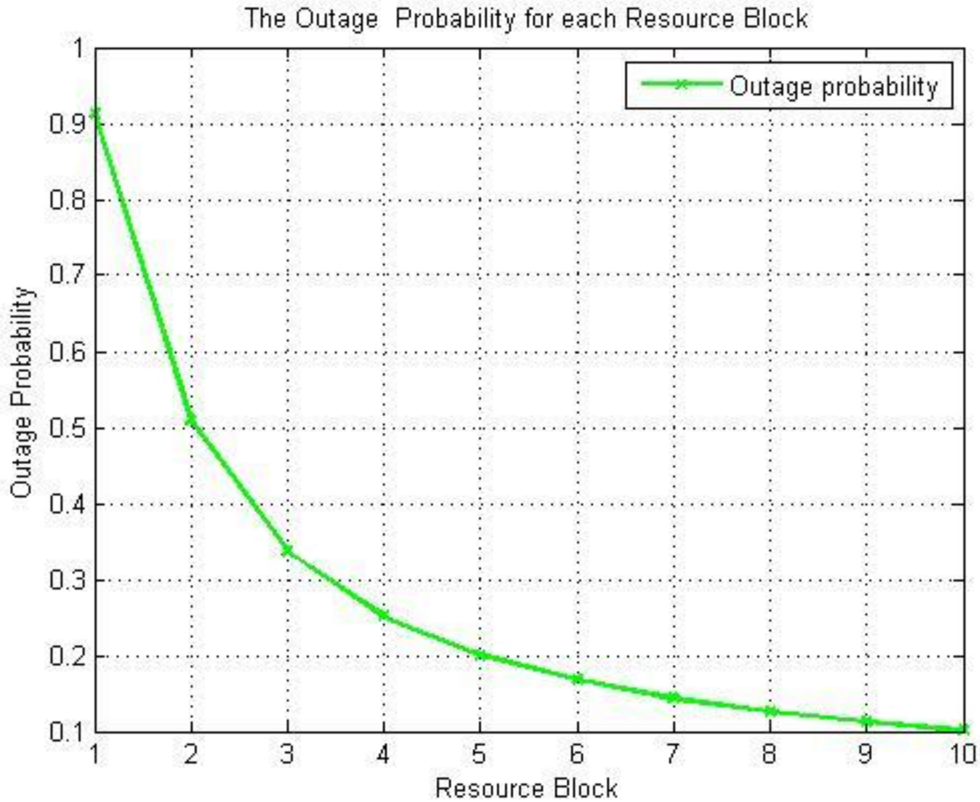

Figure 4.5: compare outage probability using SS-CIM and without SS-CIM

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research investigated chooses of the Spectrum splitting-based cognitive interference management scheme via dynamic resource block (RB) allocation for both macro and femto-cell tiers depending on the signal to interference plus noise ratio (SINR) level, to enhance the system by managing interference. It represents this enhancement by mathematical model and simulation using Matlab.

The results achieved in several parameters that affect the performance of the system due to use the SS-CIM scheme mainly compared without using it. From the results can be noticed that SINR increased by around 7 dB, Throughput is enhanced about 7.5% and, Spectral Efficiency around 7.5%, transmission delay is reduced by 8.2% and outage probability decreased with time.

5.2 Recommendations

Recommending continuing the researches of the system improvement:

- Investigate about other femtocell access modes which include closed and hybrid modes.
- Evaluating uplink scenarios as same as downlink scenario using Spectrum Splitting based Cognitive Interference Management.

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Appendix

Matlab code

```
clear,clc,close all

%==simulation_parameter==================================================
===================

intf_min = 1 ; % The minimum value of intf
intf_max = 25 ; % The maximum value of intf
noise = 2 ; % noise value

sig_min = 40 ; % minimum signal gain
sig_max = 80 ; % maximum signal gain

sinr_thr_64QAM_1 = 24.4 ; % use 64-QAM with code rate 3/4
dr64_1 = 8 ; % the data rate in each RE
cr64_1 = dr64_1  * 3/4 ; % the useful data in each RE
sinr_thr_64QAM_2 = 22.6 ; % use 64-QAM with code rate 2/3
dr64_2 = 8 ; % the data rate in each RE
cr64_2 = dr64_2  * 2/3 ; % the useful data in each RE
sinr_thr_16QAM_1 = 18.1 ; % use 16-QAM with code rate 3/4
dr16_1 = 4; % the data rate in each RE
cr16_1 = dr16_1  * 3/4 ; % the useful data in each RE
sinr_thr_16QAM_2 = 16.3 ; % use 16-QAM with code rate 1/2
dr16_2 = 4 ; % the data rate in each RE
cr16_2 = dr16_2 * 1/2 ; % the useful data in each RE
sinr_thr_QPSK_1 = 11.1 ; % use 64-QPSK with code rate 3/4
drq_1 = 2 ; % the data rate in each RE
crq_1 = drq_1  * 3/4 ; % the useful data in each RE
sinr_thr_QPSK_2 = 9.3 ; % use 64-QPSK with code rate 3/4
drq_2 = 2 ; % the data rate in each RE
crq_2 = drq_2 * 3/4 ; % the useful data in each RE

RE_num = 12 * 6 ; % number of REs
p_size = 50 * ones(1,10) ; % packet size ?????Hypothesized, should be
changed?????

num_frm = 10 ; % the number of radio frames
sub_frm = 10 ; % the number of sub frames
res_frm = 50 ; % resource blocks per sub frame
BW = 10*10^6; %system Bandwidth

%=======================================================================
===================

rad_dr = zeros(1,num_frm) ; % data rate values in each radio frame
```

```
rad_dr_n = zeros(1,num_frm) ; % data rate values in each radio frame in
normal case

for numi = 1 : num_frm % initializing the value for each radio frame

blk = zeros(1,res_frm) ; % to represent the state of the resource
blocks 0 is "normal" , 1 is "blocked"

intf_val = zeros(1,res_frm) ; % intf values
intf_val_n = zeros(1,res_frm) ; % intf values in normal case
sig_val = zeros(1,res_frm) ; % signal values
sig_val_n = zeros(1,res_frm) ; % signal values in normal case
sinr_val = zeros(1,res_frm) ; % sinr values
sinr_val_n = zeros(1,res_frm) ;% sinr normal case values
REs = zeros(1,res_frm) ; % REs values matrix
REs_n = zeros(1,res_frm) ; % REs normal case values
sinr_tot = zeros(1,sub_frm) ; % total sinr from the radio frame start
to the current sub frame
thr_tot = zeros(1,sub_frm) ; % total amount of data from the radio
frame start to the current sub frame
sinr_tot_n = zeros(1,sub_frm) ; % normal case sinr
thr_tot_n = zeros(1,sub_frm) ; % normal case thr
dr = zeros(1,res_frm) ; % data rate values in each resource block
dr_n = zeros(1,res_frm) ; % data rate values in each resource blocks in
normal case
sub_dr = zeros(1,sub_frm) ; % data rate values in each sub frame
sub_dr_n = zeros(1,sub_frm) ; % data rate values in each sub frame in
normal case
blk_o = zeros(1,sub_frm) ; % used to calculate the total number of
blocked RBs in radio frame
sinr_o = zeros(1,sub_frm) ; % to calculate the total of sinr in RBs
than was blocked
SE = zeros(1,sub_frm); %spectral Efficiency value in each RB
SE_n = zeros(1,sub_frm); %spectral Efficiency value in each RB in
normal case

for ii = 1 : sub_frm
%     disp(['====Sub frame: ((' num2str(ii) '))============'])
    for iii = 1 : res_frm
        intf_rng = rand(1) ; % used to calculate intf range

        if blk(iii) == 1 % if blocked the intf value and the intf value
in the norm case will not be equal
            intf_val(iii) = intf_min ; % when blocked intf will be at
its minimum
            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 to accure
            elseif intf_rng >= 0.2
                intf_val_n(iii) = intf_min + (intf_max-
intf_min)/4*rand(1) ; % 20% propability to accure
            else
                intf_val_n(iii) = intf_max - (intf_max-
intf_min)/4*rand(1) ; % 20% propability to accure
            end
```

```
        elseif intf_rng >= 0.4 % if blocked the intf value and the intf
value in the norm case 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 to accure
            intf_val_n(iii) = intf_val(iii) ;
        elseif intf_rng >= 0.2
            intf_val(iii) = intf_min + (intf_max-intf_min)/4*rand(1) ;
% 20% propability to accure
            intf_val_n(iii) = intf_val(iii) ;
        else
            intf_val(iii) = intf_max - (intf_max-intf_min)/4*rand(1) ;
% 20% propability to accure
            intf_val_n(iii) = intf_val(iii) ;
        end

        sig_rng = rand(1) ; % used to calculate signal range

        if blk(iii) == 1 % if blocked the signal value and the signal
value in the norm case will not be equal
            sig_val(iii) = sig_max - ((sig_max-sig_min)/3)*rand(1) ; %
when blocked sig will be close to its maximum
            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 to accure
            elseif intf_rng >= 0.2
                sig_val_n(iii) = sig_min + (sig_max-sig_min)/4*rand(1)
; % 20% propability to accure
            else
                sig_val_n(iii) = sig_max - (sig_max-sig_min)/4*rand(1)
; % 20% propability to accure
            end
        elseif  sig_rng >= 0.4 % if blocked the signal value and the
signal value in the norm case 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 to accure
            sig_val_n(iii) = sig_val(iii) ;
        elseif intf_rng >= 0.2
            sig_val(iii) = sig_min + (sig_max-sig_min)/4*rand(1) ; %
20% propability to accure
            sig_val_n(iii) = sig_val(iii) ;
        else
            sig_val(iii) = sig_max - (sig_max-sig_min)/4*rand(1) ; %
20% propability to accure
            sig_val_n(iii) = sig_val(iii) ;
        end

        sinr_val(iii) = sig_val(iii) / (intf_val(iii)+noise) ;
%calculate the signal to intf and noise value
        if blk(iii) == 1
            sinr_o(ii) = sinr_o(ii) + sinr_val(iii) ;
        end
        sinr_val_n(iii) = sig_val_n(iii) / (intf_val_n(iii)+noise) ; %
using sinr value without modification

        % calculating the nubmer of bits sended in each resource block:
        % the number of REs in each resorse block is 12 * 6
```

```
        % using the value of sinr we can determine the mod and the code
        % rate to calculate the %%%DATA%%% size in the REs as following
        if sinr_val(iii) >= sinr_thr_64QAM_1 ;
            REs(iii) = RE_num * cr64_1 ; % useful data in 64QAM REs_row
* REs_col * code rate
    dr(iii) = RE_num * dr64_1 ; % data rate in 64QAM REs_row * REs_col
* data rate
        elseif sinr_val(iii) >= sinr_thr_64QAM_2 ;
            REs(iii) = RE_num * cr64_2 ;
    dr(iii) = RE_num * dr64_2 ;
        elseif sinr_val(iii) >= sinr_thr_16QAM_1 ;
            REs(iii) = RE_num * cr16_1 ; % useful data in 16QAM *
REs_row * REs_col * code rate
    dr(iii) = RE_num * dr16_1 ;
        elseif sinr_val(iii) >= sinr_thr_16QAM_2 ;
            REs(iii) = RE_num * cr16_2 ;
    dr(iii) = RE_num * dr16_2 ;
        elseif sinr_val(iii) >= sinr_thr_QPSK_1 ;
            REs(iii) = RE_num * crq_1 ; % useful data in QPSK * REs_row
* REs_col * code rate
    dr(iii) = RE_num * drq_1 ;
        elseif sinr_val(iii) >= sinr_thr_QPSK_2 ;
            REs(iii) = RE_num * crq_2 ;
    dr(iii) = RE_num * drq_2 ;
        else
            blk(iii) = 1 ; % reaching this limit is not acceptable this
resource block
                           % will be blocked and re-allocated
            sig = sig_max - ((sig_max-sig_min)/3)*rand(1) ;
            sinr_val(iii) = sig / (intf_min + noise) ; % signal is at
its maximum , intf is at its minimum
    sinr_o(ii) = sinr_o(ii) + sinr_val(iii) ;
            REs(iii) = RE_num * cr64_1 ;
    dr(iii) = RE_num * dr64_1 ;
        end

        if sinr_val_n(iii) >= sinr_thr_64QAM_1 ;
            REs_n(iii) = RE_num * cr64_1 ; % bits in 64QAM REs_row *
REs_col * code rate
    dr_n(iii) = RE_num * dr64_1 ; % data rate in 64QAM REs_row *
REs_col * data rate
        elseif sinr_val(iii) >= sinr_thr_64QAM_2 ;
            REs_n(iii) = RE_num * cr64_2 ;
    dr_n(iii) = RE_num * dr64_2 ;
        elseif sinr_val(iii) >= sinr_thr_16QAM_1 ;
            REs_n(iii) = RE_num * cr16_1 ; % bits in 16QAM * REs_row *
REs_col * code rate
    dr_n(iii) = RE_num * dr16_1 ;
        elseif sinr_val(iii) >= sinr_thr_16QAM_2 ;
            REs_n(iii) = RE_num * cr16_2 ;
    dr_n(iii) = RE_num * dr16_2 ;
        elseif sinr_val(iii) >= sinr_thr_QPSK_1 ;
            REs_n(iii) = RE_num * crq_1 ; % bits in QPSK * REs_row *
REs_col * code rate
    dr_n(iii) = RE_num * drq_1 ;
        else
            REs_n(iii) = RE_num * crq_2 ;
```

```
    dr_n(iii) = RE_num * drq_2 ;
        end

%          disp(['==Resource block: ((' num2str(iii) '))=====']) 
%          disp(['sig ' num2str(sig_val(iii)) ' , '
num2str(sig_val_n(iii))])
%          disp(['intf ' num2str(intf_val(iii)) ' , '
num2str(intf_val_n(iii)) ])
%          disp(['sinr ' num2str(sinr_val(iii)) ' , '
num2str(sinr_val_n(iii))])
%          disp(['REs ' num2str(REs(iii)) ' , ' num2str(REs_n(iii))])
%          disp(['dr ' num2str(dr(iii)) ' , ' num2str(dr_n(iii))])
%          disp(['Block : ' num2str(blk(iii))])
%          disp(' ')
    end

    blk_o(ii) = sum(blk) ;

    % calculate the total amount of sinr & data
    if ii == 1
    sub_dr(ii) = sum (dr) ;
    sub_dr_n(ii) = sum (dr_n) ;
        sinr_tot(ii) = sum(sinr_val) ;
        thr_tot(ii) = sum(REs) ;
        sinr_tot_n(ii) = sum(sinr_val_n) ;
        thr_tot_n(ii) = sum(REs_n) ;
        SE(ii) = thr_tot(ii)/BW;
        SE_n(ii) =thr_tot_n(ii)/BW;
    else
    sub_dr(ii) = sub_dr(ii-1) + sum (dr) ;
    sub_dr_n(ii) = sub_dr_n(ii-1) + sum (dr_n) ;
    sinr_tot(ii) = sinr_tot(ii-1) + sum(sinr_val) ; % calculate the
total sinr from the radio frame beginning
    sinr_tot_n(ii) = sinr_tot_n(ii-1) + sum(sinr_val_n) ; % claculate
for normal case
    thr_tot(ii) = thr_tot(ii-1) + sum(REs) ; % total amount of useful
data
    thr_tot_n(ii) = thr_tot_n(ii-1) + sum(REs_n) ;
    SE(ii) =  thr_tot(ii)/BW;
    SE_n(ii) =thr_tot_n(ii)/BW;
    end

%     disp([thr_tot(ii),thr_tot_n(ii)])

end

if 1 % in our research the rad_dr will be calculated independently for
each radio frame ,
     % can also use the condition [if numi == 1] if wanted the rad_dr
be accumulated
rad_dr(numi) = sum(thr_tot) ;
rad_dr_n(numi) = sum(thr_tot_n) ;
else
rad_dr(numi) = rad_dr(numi-1) + sum(thr_tot) ;
rad_dr_n(numi) = rad_dr_n(numi-1) + sum(thr_tot_n) ;
end
```

```
% disp([rad_dr(numi),rad_dr_n(numi)])

end
% blk_o,sinr_o,sinr_tot
% to calculate the outage probability:
outage_prob = (blk_o .* sinr_o) ./ (res_frm * sinr_tot) ;

% to calculate the sinr values in db:
sinr_tot_db = 10 * log10(sinr_tot)
sinr_tot_db_n = 10 * log10(sinr_tot_n)
% to calculate the throughput values in Kilo:
thr_tot_k = thr_tot / 1024 ;
thr_tot_n_k = thr_tot_n / 1024 ;
% to calculate delay:
de = p_size ./ rad_dr ;
de_n = p_size ./ rad_dr_n ;

% thr_tot_k
% thr_tot_n_k
% thr_tot_k - thr_tot_n_k

%
########################################################################
##################################
% you should notice that the plots are generated from the data gathered
in the last radio frame simulation (from “only a single” radio frame)
%
########################################################################
##################################

% disp(['outage probability = ' num2str(outage_prob)])
plot(1:sub_frm,sinr_tot_db,'g-x','linewidth',2),hold
on,xlabel('Resource Block'),ylabel('SINR(dB)')
plot(1:sub_frm,sinr_tot_db_n,'r-x','linewidth',2),grid,legend('SINR
using SS-CIM','SINR without using scheme'),title('SINR in each Resouce
Block'),hold off
figure
plot(1:sub_frm,thr_tot_k,'g-x','linewidth',2),hold on,xlabel('Time in
milli-seconds'),ylabel('Throughput(bit/sec)')
plot(1:sub_frm,thr_tot_n_k,'r-x','linewidth',2),grid,legend('Throughput
using SS-CIM','Throughput without using scheme'),title('the relation
between Throughput and Time'),hold off
figure
plot(1:num_frm, de,'g-x','linewidth',2),hold on,xlabel('Resource
Block'),ylabel('Delay(sec)')
plot(1:num_frm, de_n ,'r-x','linewidth',2),grid,legend('Delay using SS-
CIM','Delay without using scheme'),title('The Transmission Delay for
each Resource Block'),hold off
figure
plot(1:sub_frm,outage_prob,'g-x','linewidth',2),grid,xlabel('Resource
Block'),ylabel('Outage Probability'),legend('Outage
probability'),title('The Outage  Orobability for each Resource Block'),
hold off
figure
```

```
plot(1:sub_frm,SE,'g-x','linewidth',2),hold on,xlabel('Time in milli-
seconds'),ylabel('Spectral Efficiency(bit/sec/Hz)')
plot(1:sub_frm,SE_n,'r-x','linewidth',2),grid,legend('Spectral
efficiency using SS-CIM','Spectral efficiency without using
scheme'),title('The relation between Spectral efficiency and Time')
```