ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING
TELECOMMUNICATION ENGINEERING GRADUATE PROGRAM

Interference Mitigation Using eICIC in LTE-A Heterogeneous Network: The case of ethiotelecom

By

Beza Mengistu

Advisor: Dr. –Eng. Yihenew Wondie

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Electrical Engineering

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Declaration

I, the undersigned, declare that this thesis is my work, does not include any material that's been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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Abstract

The increase in smart device numbers and also high-capacity demanding services has led to growth in wireless cellular data traffic. This forces mobile operators to increase network capacity to meet subscriber demand. In order to increase network capacity, one solution can be dense network with macro cell, however this has high deployment cost as well as running cost. Therefore, Heterogeneous cellular networks (HetNets) can be a solution to serve this high demand on mobile data traffic and minimize cost.

HetNets consist of low power cells (micro / pico / femto cells) installed on the tier of well-planned macro base station (BSs). Due to random deployment of small BSs, the interference level in the network increases, especially in cell-edge areas, where two or more BSs compete for coverage and can transmit and receive from the same user equipment (UE) device. Interference is big challenge to capacity improvement and coverage enhancement, as well as for spectral efficiency and energy efficiency. To improve interference problem, operator need to deploy interference management techniques proposed in third Generation Partnership Project(3GPP), such as Inter Cell interference coordination eICIC, Further Inter Cell interference coordination (FeICIC), and Coordinated Multipoint (CoMP).

This thesis mainly focuses on downlink inter-cell interference in LTE- A macro-pico scenario and uses eICIC to mitigate intercell interference in Addis Ababa, Bole area. Due to small coverage area of pico cell, cell range expansion has been introduced to encourage UEs offloading from macro cell to pico cell and also Almost Blank Subframes (ABS) to mute macro cell and reserve resource for pico cell users. Computer simulations are carried out using matlab code after carrying out network simulation in winprop. According to the observation, Pico cell users are experiencing interference from high-power macro nodes. Cell edge users are experiencing high interference from macro cell and their throughput is low without eICIC. Moreover, the simulation results demonstrate HetNet deployment improves overall system throughput but interference is an issue to be solved. The simulation result shows 70% increase in cell edge user performance by using eICIC.

Keywords: *Heterogeneous network, eICIC, cell range expansion, almost blank subframes*

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List of Acronym

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
ABS	Almost Blank Subframe
BTS	Base Transceiver Station
CA	Carrier Aggregation
CDF	Cumulative Distribution Function
CRS	Common Reference signals
CRE	Cell Range expansion
CoMP	Coordinated Multi-Point transmission/reception
dB	Decibel
dBm	Decibel Milliwatt
DL	Downlink
DwPTS	Downlink Pilot Timeslot
eICIC	Enhanced Intercell Interference Coordinati
eNodeB	Enhanced NodeB
EPC	Evolved Packet Core
EUTRAN	Evolved Universal Terrestrial Radio
EPC	Evolved Packet Core
FDD	Frequency Division Duplex
ICIC	Inter Cell Interference Coordination
HSS	Home Subscriber Server
HetNets	Heterogenous network
IP	Internet Protocol
ITU	International Telecommunication Union
LPCs	Low Power Cells
LTE Long	Long Term Evolution
LTE-A	Long Term Evolution Advanced
MIMO	Multiple Input Multiple Output
MUE	Macro User Equipment
PUE	Pico User Equipment
PS	Packet-switched
OFDM	Orthogonal Frequency Multiplexing

OFDMA	Orthogonal Frequency Division Multiple Access
RB	Resource Block
RE	Resource Element
RRH	Remote Radio Head
RSRP	Reference Signal Received Power
SINR	Signal-to Interference plus Noise Ratio
TDD	Time Division Duplex
UL	Uplink
UMTS	Universal Mobile Telecommunications
UpPTS	Uplink Pilot Timeslot
UTRAN	UMTS Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access
3GPP	Third Generation Partnership Project

1. Introduction

1.1. Background

Continuous subscriber growth, increased use of smart phones and tablets, and services needing a high data rate generate ongoing and significant bandwidth needs for mobile networks and apps. The standard mobile networks 2G(second Generation)(GSM) and third Generation(3G) (Universal Mobile Telecommunications)(UMTS/WCDMA) are unable to meet consumers' demand for high-speed and high-quality mobile communication services. As a result, LTE (Long Term Evolution), is being employed for commercial services. LTE is a technology developed by 3GPP (Third Generation Partnership Project) that extends the GSM/UMTS mobile network standard approach. The LTE system utilizes the OFDMA (Orthogonal Frequency Division Multiple Access) modulation technique, which increases spectrum efficiency and reduces intra-cell interference.

LTE-Advanced (Release 10) is a performance enhancement to LTE (Release 8). It retains all of the features of Release 8/9 and introduces numerous new ones as advanced MIMO (Multiple Input Multiple Output) techniques, CA (Carrier Aggregation), HetNets (Heterogeneous Network) and COMP (Coordinated Multipoint) [1, 2].

Beyond LTE, network densification is essential to address continuous increase in data demand, but increasing the number of base stations may be expensive and needs more space. This resulted in the introduction of a new solution known as HetNets in 3GPP Release 10 LTE-Advanced [3, 4].

A traditional homogeneous cellular network is composed of a collection of high-power cells (Macro cell). HetNets, on the other hand, incorporate not only macro cell but also low-power cells such as pico eNodeB or femto eNodeB to fill in the region not covered by macro eNodeB [5].

The purpose of installing HetNets is to offload users from potentially crowded macro cells and toward LPCs (low power cells). The LPCs remove coverage holes in the macro-only network and capacity expansion in zones with very high traffic volumes [6]. LPCs improve outdoor/indoor coverage, increase spectrum reuse, and improve network throughput for cell-edge users. Additionally, it improves link quality and reduces power consumption by shortening the path between the transmitter and receiver.

Due to the transmission power disparity and use of the same frequency band by macro and small cell, HetNet faces two fundamental issues the first one is intercell interference and the second issue is load unbalance. CRE (Cell Range Expansion) is a technique for balancing network load between two eNBs (macro and low power cells) CRE is used to increase the coverage area of low-power cells and to offload traffic from macro cells to low-power cells by providing offset bias values to pico cell users (PUEs). By adding the CRE bias value, the user equipment (UE) is able to choose the small cell as the serving cell, hence increasing the small cell's coverage area. However, the increase of small cell coverage as a result of CRE suffer UE from DL(Downlink) severe interference from high power macro cells. These factors may result in a considerable reduction of performance for cell edge users. As a result, 3GPP Release 10 introduce enhanced inter-cell interference coordination (eICIC) [7].

eICIC is one of the approaches for reducing inter-cell interference and increasing network throughput by allowing macro and Pico eNBs to share radio resources for downlink transmissions by introducing ABS (almost black sub frames). Each macro in ABS remains silent for a period of time during which Pico can transmit [1].

1.2. Statement of the Problem

Ethio telecom's mobile subscriber continues to grow, while demand for higher data rates increases because of high-quality video streaming services and social networking etc. In order to satisfy these requirements, ethio telecom must expand its coverage, enhance its capacity, and optimize its use of scarce spectrum. On the ethio telecom side, continuous network expansion has been accomplished by using homogeneous network; nevertheless, densification of the network by the existing homogeneous network beyond this level can brings high development costs, inefficient energy usage, and high operational costs.

By deploying HetNet, we will be able to satisfy the increasing demand for data services while still providing an optimal customer experience. The interference problem that already exists in the company will increase with the installation of a small cell, requiring the use of an interference management technique. The company's current working interference management techniques are traditional methods which are based on homogenous deployments and are not compatible with

Hetnet; therefore, new and enhanced interference mitigation techniques, such as eICIC, should be implemented.

Motivated by the aforementioned problem, this thesis investigates the eICIC interference management technique, identifies its challenges and potential advantages to ethio telecom.

1.3. Objective

1.3.1. General Objective

The general objective of this thesis is to improve the performance of ethio telecom LTE- A network by using eICIC interference mitigation technique.

1.3.2. Specific Objectives

The specific objectives of this thesis are

- To analyze the impact of inter cell interference on network performance
- Compare the signal to interference and noise ratio (SINR) and throughput of LTE-A network for no eICIC and with eICIC.
- To see improvement on SINR and user throughput by using eICIC
- Performance evaluation of network of ethiotelecom before and after deploying eICIC
- To recommend heterogeneous network and eICIC method to implement in Addis Ababa LTE-A

1.4. Methodology

In the initial stage of the research, papers with the area of interference management technique were searched to understand interference management and also investigated if their solution is possible for the case of ethiotelecom. In the next step, the work target eICIC interference mitigation technique, investigation and analysis of the main constraining issues related to the cell user association, resource management and interference mitigation. In the third stage of the work, eICIC schemes that aims a better overall capacity improvement was developed. The proposed solution was designed under the consideration of the shortcoming that the ABS and CRE presents, related to the underutilization of the available resources from the macro-cell and the capacity degradation that pico users may experience. In order to overcome this constraint, eICIC will be used and simulation will be performed on winprop and matlab then Simulation results was compared by using the network performance matrix SINR and throughput to show the efficiency of the proposed solution.

The below figure shows the methodology followed in order to successfully achieve the goal of the thesis.

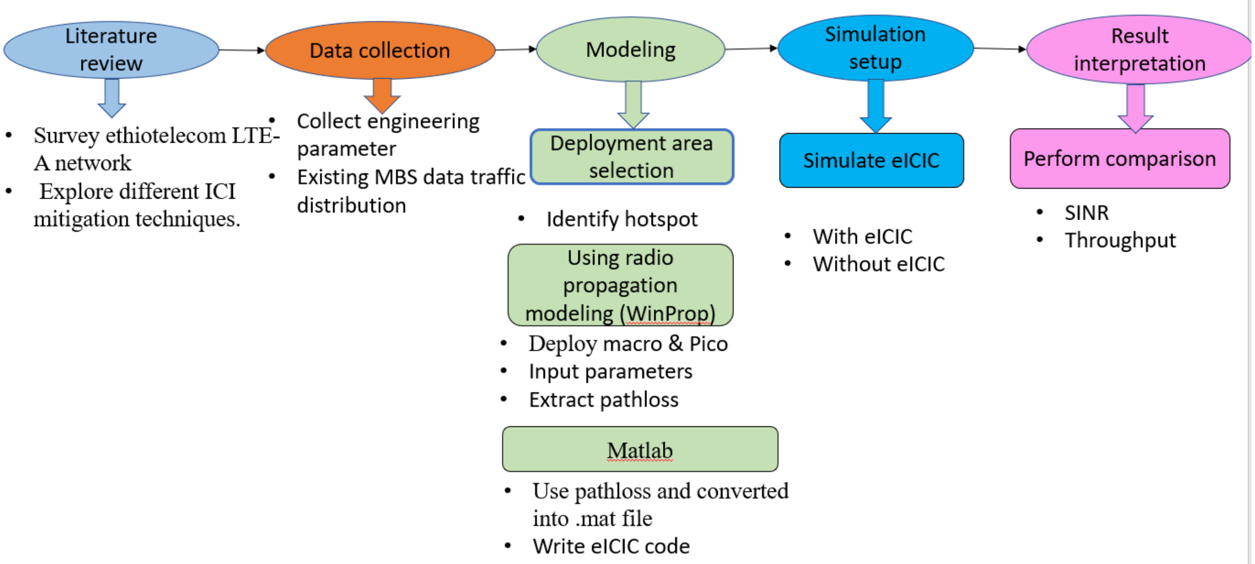


Figure 1.1 Methodology used for Intercell Interference Mitigation

1.5. Literature Review

Numerous researches have been conducted on the usage of Hetnets to enhance capacity and coverage, as well as on the impact of intercell interference on network performance degradation and the importance of mitigation techniques. So far, studies based on Hetnets deployment of macro and pico scenario, as well as eICIC, have focused on the use of PRE (Pico-cell Range Extension) and ABS pattern configuration to enhance network capacity while also achieving a higher level of user satisfaction and QoS (quality of service).

The following are selected and checked to support for the issue at in hand. The authors in [1] refers a Hetnet as mix of small and macro cells and a suitable solution for operators to fulfill the ever-increasing demands in capacity, throughput, and significantly reduce energy consumption in the network.

The authors in [3] ICI management techniques are investigated, comparing and contrasting their common features and differences, ranging from TDM-based enhanced inter-cell interference coordination (eICIC) to more sophisticated Organized Multi-Point (CoMP) techniques. Finally, in order to provide effective resource distribution and intercell interference reduction in LTE-Advanced HetNet, Carrier Aggregation (CA) is thoroughly investigated as an advanced and demanding process.

The authors in [8] emphasizes that the ABS technique proposed in 3GPP Release 10 represents a trade-off in eICIC. Due to the fact that the macro cell must close certain subframes to prevent interfering with the pico cell, it sacrifices performance in the meantime. The method by which users are offloaded from the macro cell to the pico cell has an impact on the eICIC performance. As a result, they emphasized on determining the optimal ratio between the closing subframe and the number of users offloaded from the macro cell to the pico cell in order to solve the system network utilization problem.

The authors in [9] obtained the user's SINR for macro cells in order to compute the CDF and then estimated the SINR threshold. The Adaptive control CRE Algorithm used determines a bias value based on the SINR threshold, enabling each user to have a different CRE bias value. The proposed method improves cell edge user throughput, while maintaining the average user throughput by choosing the optimal combination of two different CSOs.

The eICIC's performance in LTE- A macro-pico scenario is investigated using a combined with PRE in downlink. The overall system performance is assessed for a variety of different scenarios, including varying the number of pico cells, transmission power levels, and the number of UEs and their distribution throughout the network and packet scheduler. The simulation results indicate the recommended bias values for the PRE offset and the ABS muting ratio. With the help of both PRE and eICIC, the analysis demonstrates an increase in the percentage of UEs offloaded to pico-eNB. To summarize, the authors concludes that the optimal PRE offset and eICIC muting ratio are determined by a variety of parameters, including the number of pico-eNBs in the macro cell network [10].

HetNet for Enhanced Inter-Cell Interference Coordination was used to evaluate cell range expansion and time partitioning. The cell selection scheme is based on the SINR, and the cell expansion range can vary through the offset value. We can manage the interference between the macrocell and picocell, using ABS in the time domain. However, the impact of inter cell interference on user performance in the presence and absence of ABS is not well established. Additionally, the user performance in various ABS ratios was not well verified [11].

Authors in [12] examined the functionality and performance of eICICs in LTE HetNet Co-Channel deployments. The authors investigated user throughput in heterogeneous network with and without eICIC. The simulation results indicate that eICIC significantly enhances throughput. However, the mathematical contexts for estimating user performance were not described in detail. Additionally, the article did not analyze the overall system performance or the performance of specific cells with different CRE and ABS values. The improvement in performance seen when eICIC mechanisms are introduced to a simple HetNet is shown in [13]. On the other side, the authors [14] investigated HetNet performance analysis through the perspective of eICIC parameters. However, the system's overall performance was not evaluated with or without eICIC.

The author [15] proposes an adaptive algorithm for dynamically adjusting the Low Power Node (LPN) coverage area. Using this algorithm, the LPN coverage area is dynamically expanded in response to varying traffic situation in the network, thereby avoiding unnecessarily increased interference caused by range extension. [16] In terms of improving data rate, it is important to note that adaptive bias-based cell selection strategies are a more efficient option for traffic load balancing than static bias-based approaches. The use of adaptive cell selection is restricted in LTE-Advanced HetNets by emphasizing the importance of estimating cell load.

1.6. Scope and Limitations

1.6.1. Scope

This thesis focuses mainly on the deployment of small cells under the existing macro BS and the performance improvements that may be realized by strategically placing these cells to optimize network capacity. It is focused on the LTE-A network and covers a total area of 8.9 square kilometers in Addis Ababa.

1.6.2. Limitations

This thesis is only concerned with intercell interference in a downlink LTE-Advanced network consisting of a macro cell and a pico cell. The pico cell is considered to be placed in the macro cell coverage area as a hotspot. Hetnet and eICIC interference mitigation are used to enhance the network capacity and performance.

1.7. Contribution

To accommodate the growing traffic and the high-speed data rate demand, ethio telecom has to plan and expand the existing cellular network with the concept of HetNet with interference mitigation techniques.

As mentioned before, this thesis investigates the improvement in coverage and user data rate that can be achieved with the usage of eICIC in the Addis Ababa LTE network. The research incorporates the actual location of eNodeB into the simulation, as well as terrain and engineering data for Addis Ababa LTE network.

Therefore, from the output of this research ethio telecom will get an insight into Hetnet deployment approaches, to increase capacity and coverage for keeping the required QoS and data rate demand. In addition, cell edge user's SINR and throughput will be improved and also overall network performance. As a result, this study will be useful in the future when HetNet and interference mitigation are required for the present AA LTE-A network.

1.8. Thesis Organization

This thesis document organized in to six chapters. The first chapter concentrates on introduction of the thesis. It includes problem statements, thesis objectives, methodologies used, works related to this thesis, scope, limitation and its contributions. In Chapter two an overview of LTE-A network and Chapter three overview of inter cell interference mitigation and description of eICIC algorithm. In Chapter four, the system model and simulation assumption discussed. In Chapter five, the simulation results and discussions presented. In final Chapter, conclusions and future works are presented.

2. Overview of LTE-A and Heterogenous Network

2.1. Introduction

The enormous popularity of smartphones has necessitated the development of mobile broadband networks. UEs demand high data rates, high spectral efficiency, and minimal latency. With these ever-increasing demands, the capacity of 2G and 3G networks is approaching saturation point. Due to the need for radio network improvements, LTE was introduced by 3GPP as release-8 which is LTE first specification, and it has been approved with release-9 as its last version [17].

However, the improvements made in Release-8 and Release-9 are insufficient to fulfill all of the requirements associated with these potential demands. 3GPP has continued to work on LTE enhancements and has introduced evolved versions of LTE that are standardized as release 10 and beyond and are referred to as LTE-Advanced. These evolved versions of LTE are intended to improve user data rates and efficiency [18]. LTE-A is regarded as the next major evolutionary step toward the development of 5G telecommunications systems, as it complies with the International Telecommunication Union Radio communication sector (ITU-R) specifications for an International Mobile Telecommunication-Advanced (IMT-Advanced) system with a high capacity for services. 3GPP wants to ensure that sufficient improvements were made while advancing from release -8/9 to release 10 LTE-Advanced capabilities and finally meeting the 4G specification. LTE already delivers data rates close to the Shannon limit in terms of link performance. LTE-A should focus specifically on improving cell-edge user performance and average spectrum efficiency rather than on peak spectrum efficiency [19].

This chapter begins by introducing LTE-Advanced, explaining its architecture and most important characteristics, and then depicts the Heterogeneous Network concept.

Features of LTE 3GPP Release -8 to Release 12 [19]

Release -8 which is announced in 2008 has 100Mbit/s for downlink and 50Mbit/s for uplink and latency is below 10ms. It uses bandwidths of 1.4, 3 ,5, 10, 15 or 20MHz and OFDMA at downlink and SC-FDMA at uplink. Peak spectrum efficiency up to DL15 bps/Hz and UP 3.75 bps/Hz.

Release-9 -in this Release femtocells self-organizing network are introduced

LTE-A features are introduced to be compatible with release-8 which is using the same carrier [20]

Release-10 -Peak data rate up to 3Gbps DL and 1.5Gbps UL, Peak spectrum efficiency up to DL-30 bps/Hz and UL - 15 bps/Hz. MIMO 8×8 in DL and 4×4 in UL . introduction of Heterogeneous, carrier aggregation to allow the combination separate carriers to increase bandwidth utilization (up to five carriers to enable bandwidths up to 100MHz is possible) and also eICIC to mitigate inter cell interference.

Release-11- this release enhancements to Carrier Aggregation, MIMO, relay nodes and introduction of Coordinated multipoint transmission and reception to enable simultaneous communication with multiple cells.

Release-12 - introducing enhanced small cells for LTE, inter-site carrier aggregation, to mix and match the capabilities and backhaul of adjacent cells, new antenna techniques and advanced receivers to maximize the potential of large cells, interworking between LTE and WiFi or HSPDA.

2.2. LTE-A Architecture

The LTE/LTE-A architecture was developed to create a packet-switched (PS) network capable of supporting all sorts of services, including voice communication, with the minimum latency and an improved Quality of Service(QoS) [21]. The architecture of LTE/LTE–A consists two main parts. These are: LTE Evolved Universal Terrestrial Radio (EUTRAN) and LTE evolved packet core (EPC).

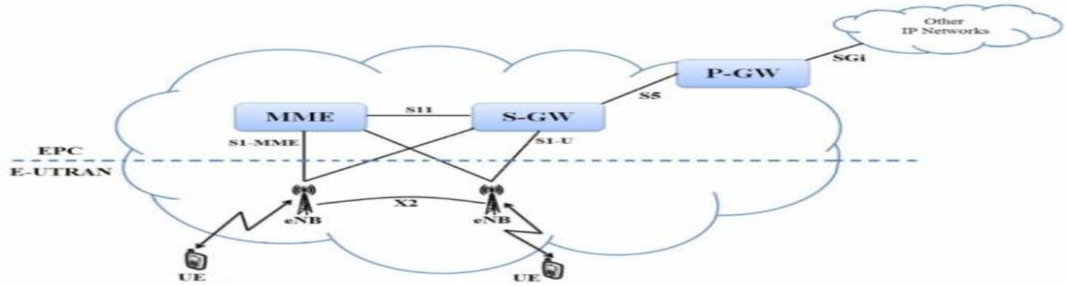


Figure 2.1 LTE/LTE-A architecture [24]

I. Evolved Packet Core (EPC)Overview

LTE packet core networks assumes a full Internet Protocol (IP) network architecture and are designed to support voice in the packet domain. It features support for multiple access networks, including 3GPP legacy such as GSM and UMTS, as well as other non-3GPP systems (for example WiMAX or cdma2000). It is comprised of main network components, such as a mobility management entity (MME), a serving gateway (S-GW), a PDN Gateway (P-GW), and a Home Subscriber Server (HSS).

- Mobility Management Entity (MME): This network element is in responsible for user mobility, intra-LTE handovers and security authentications, as well as the choice of PGW/SGW.
- Serving Gateway(S-GW): It ends the interface towards EUTRAN. At a given point of time, each UE is associated with a single Serving GW. SGW serves as a local mobility entity for handovers of inter eNBs.
- Packet Data Network Gateway(P-GW): is responsible for all IP packet-based operations, including deep packet inspection, UE IP address allocation, transport-level packet marking in both uplink and downlink, and accounting, etc
- Home Subscriber Server (HSS): The HSS provides a range of purposes, including mobility management, support for call and session establishment, user authentication, and access authorization

II. Evolved Universal Terrestrial Radio (EUTRAN) Overview

The E-UTRAN is comprised of base stations (referred to as evolved Node B in LTE) that are interconnected with each other via the X2 interface. The LTE evolved Node B (eNodeB) is the only node in the E-UTRAN and is responsible for all Layer one (1) and Layer two (2) radio related functionalities. The eNodeB operates as a bridge between the UE and the EPC, relaying data through the S1 interface between the radio interface and the EPC.

Other functionalities of the eNodeB are:

- Channel Coding and de-coding.

- Radio Resource Control: This relates to the allocation, modification, and release of resources required for transmission between the user terminal and the eNodeB over the radio interface.
- Radio Mobility Management: Refers to a measurement processing and handover decision.
- Radio Resource Management (RRM): administrates the usage of the radio resources.

S1 and X2 Interfaces

The different networking components of the LTE-A system are connected in order to exchange information. Various transmission medium may be utilized to achieve this information exchange, resulting in differences in latency and throughput capacities between them [38].

The main interfaces in LTE-A are X2 and S1. As seen from LTE/LTE- A architecture in Figure.2.1, eNBs are interconnected via X2 logical interface. X2 is a point-to-point logical interface, which provides transmission of information between neighboring eNBs to undertake the following tasks [20]:

- Handover management and coordination
- Load Management
- Network Optimizations
- Updating eNB configuration, activating cell

On the other hand, eNBs connected to MME via S1. The S1 interface enables connections between MME and eNBs in a many-to-many manner [23].

The main purpose of this interface is to allow the exchange of signaling information [37] making possible some of the features described above, especially those related to user mobility and RRM.

2.3. LTE-A Frame Structure

The smallest unit of the LTE radio frame is referred to as a slot, and it has a length of 0.5 msec. Each time slot comprises of a number of OFDM symbols including the cyclic prefix [38]. Two successive slots form a sub-frame with a duration of 1-msec. And 10 sub-frames form a 10-msec frame. LTE radio frame. In particular, a t the sub-frame level, link adaptation and channel-dependent scheduling for a time-varying channel happen. Thus, the sub-frame length is accordance with the minimum downlink TTI (Transmission Time Interval), which is 1-msec., as opposed one TTI of duration of 2-msec. for HSPA and 10-msec. for UMTS [38].

LTE-A supports either FDD or TDD modes, and two types of frame structure are standardized by 3GPP TS 36.211[22].

a) Frame structure type 1:

The type 1 frame structure is used in frequency division duplex (FDD), where the radio frame is divided into 10 equally-sized subframes with a time span of 1-msec, each subframe consisting of two time slots (0.5-msec). As a result, a radio frame (10-msec) contains twenty time slots. Each radio frame has 307200 Ts (the fundamental time unit), which corresponds to 30.72 MHz; hence, one Ts = 1/ (15000×2048) second. Figure 2.2 illustrates the radio frame structure type 1.

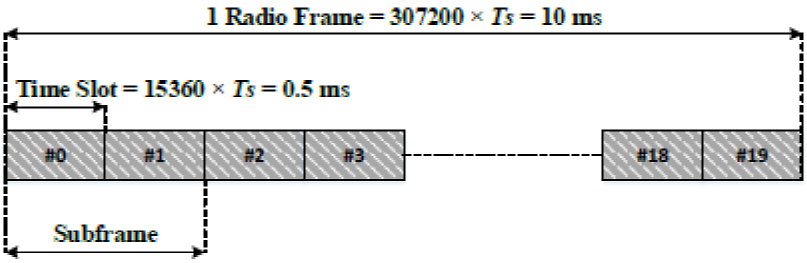


Figure 2.2 Radio Frame Structure (type1) [22]

b) Frame structure type 2:

The radio frame is divided into two equal half frames, each of which is divided into five equal 1-millisecond subframes. Two types of subframes are defined in this frame, as shown in Figure 2.3 special and nonspecial subframes. Downlink Pilot Timeslot (DwPTS), Guard Period (GP), and Uplink Pilot Timeslot (UpPTS) are the special subframes that exist in both halves of the radio subframe.

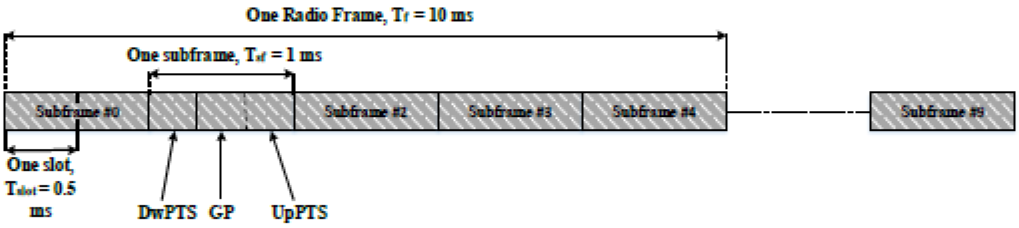


Figure 2.3 Radio Frame Structure (type 2) [22]

As previously stated, because of the extensive growth of mobile data demands, cellular operators must analyze the coverage and capacity issues in their existing networks in order to satisfy subscriber expectations. The motivation for enhancing LTE Release-10 was to support cost-effectively higher peak rates. LTE-Advanced technology is capable of handling ITU requirements for IMT advanced.

LTE-Advance proposes the use of advanced technologies such as Adaptive Modulation Coding, carrier aggregation, MIMO and heterogeneous networks to support exponential traffic growth while also enhancing the network's overall performance [23]. We will highlight the first three technologies and we will discuss heterogenous network in depth.

I. Adaptive Modulation Coding rate in LTE/LTE-A

In LTE/ LTE -A, Adaptive modulation and coding (AMC) is used [24]. AMC adjusts to the suitable combination of modulation and coding rate to the channel conditions in order to provide the user with the maximum possible data rates. The user's SNR is used to establish the selection. When the SNR is high, a method called higher-order modulation is used with a better spectral efficiency. In the case of low SNR, a low-spectral-efficiency lower-order modulation technique may be adapted [25]. Lower order modulation is more robust to noise and can recover from severe interference, but it has a lower bit rate of transmission. A higher order modulation scheme provides a higher data rate. However, it is susceptible to interference, noise, and estimate errors in the channel.

The UE measures and reports CQI to eNBs. The signal quality obtained from UE is not only dependent on the quality of the radio channel, the level of noise, and the level of interference, but also on the receiver's quality [26]. Quadrature phase shift keying (QPSK), 16-quadrature amplitude modulation (16QAM), and 64-quadrature amplitude modulation (64QAM) are supported in the DL direction of LTE/LTE-A, whereas 64QAM is supported in the UL direction.

II. Multiple Input Multiple Output (MIMO) Antenna

MIMO is a significant developing feature in LTE standards that uses multiple antennas at the transmitter and receiver ends to increase the capacity of the communication channel achieving the LTE standard's requirements in terms of peak data. It may improve the performance of mobile networks by improving data rates and the accuracy of the communication link. In LTE, it is standardized up to 4x4 for DL and 2x2 for UL, however in LTE-A, it is standardized up to 8x8 for DL and up to 4x4 for UL. The MIMO system used in the LTE/LTE-A standard can be classified as transmit diversity, receive diversity, beamforming, and spatial multiplexing. The same transmission bits are transmitted over multiple independent antennas in transmit diversity and beamforming. As a result, it does not lead to higher data rates, but rather makes the radio link more robust.

III. Carrier Aggregation

Carrier Aggregation (CA) is one of the features in LTE-Advanced to improve data rate. It allows user equipment receive signal from more than one component carrier.

CA can be used in both FDD and TDD. The aggregated carriers can be called component carrier. Each CC can have bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz and adding the maximum of five CC to find the maximum bandwidth of 100MHz.

In FDD aggregated carrier can be different in uplink and downlink. But the uplink CC is always equal or less than downlink CC and each CC can have different bandwidth. In case of TDD the number of CCs and also the bandwidths of each CC is the same for both DL and UL.

2.4. Heterogeneous Network

Traditionally, mobile broadband networks have been built as homogenous networks composed of macro cells. The positioning of the macro base stations is carefully designed to maximize coverage while minimizing interference between them. Each base station in these networks has a similar transmit power level, antenna pattern, backhaul connectivity, and receive noise limit. Additionally, all cells provide unlimited access to the network's UEs [5].A Heterogeneous Network (HetNet) is a collection of low-power nodes distributed within an existing macro cell network. LPNs (also called small cells) operate at substantially lower power levels. This deployment enables increased spectral efficiency per unit area by eliminating coverage gaps in the macro-only network and increasing capacity in zones with very high traffic volumes (often referred to as hotspots) [5]. As a result, Heterogeneous Networks are envisioned as the main enablers of LTE advanced performance improvement [27]. Figure 2.4 illustrates a possible HetNet deployment.

HetNet is one of the most effective methods of optimizing spectrum and network use. It involves the deployment of multiple radio access techniques within the same coverage area (Inter-RAT implementation), whereas in this thesis, the term "HetNet" refers to the heterogeneous deployment of LTE- A system in which regular high cells (Macro cells) are superimposed on low-power cells, forming a multi-tier network (as shown in Figure 2.4). This approach is used to increase network capacity and/or coverage in a variety of deployment circumstances. Additionally, these sorts of networks may improve throughput for both average and cell-edge users[27].

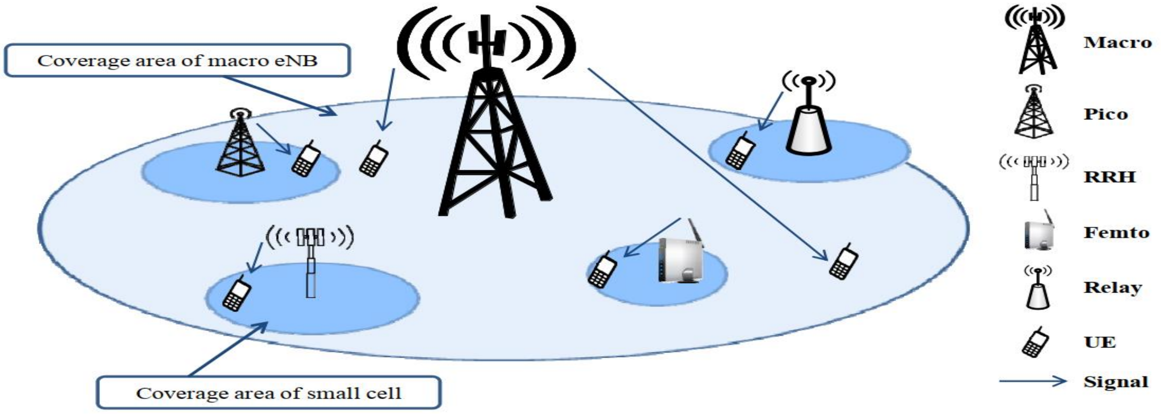


Figure 2.4 Heterogeneous Network Deployment using different low-power nodes [28]

A HetNet may be deployed using a variety of various sorts of small cells. Not only may small cells be operator deployed as macro cells, but also user deployed. Several of them may coexist in close proximity to one another [27]. summarizes the properties of macro and small cells. There is a full overview of the many kinds of small cells in [1, 5].

Types of nodes	Transmit power	Coverage	Placement	Access
Macrocell	46 dBm	Few Km	Outdoor	Open to all UEs
Microcell	30-37 dBm	<2Km	Outdoor	Open to all UEs
Picocell	23-30 dBm	<300m	Indoor and outdoor	Open to all UEs
Femtocell	<23 dBm	<50m	Indoor	Open or restricted (CSG)
Relay	30 dBm	300m	Outdoor	Open to all UEs
RRH	30 dBm	300m	Indoor and outdoor	Open to all UEs

Table 2.1 Description of the different small cell

Figure 2.5 shows hetnet deployment with their backhaul and unlike homogenous network cells in hetnet has different transmit power levels, antenna patterns, backhaul connectivity.

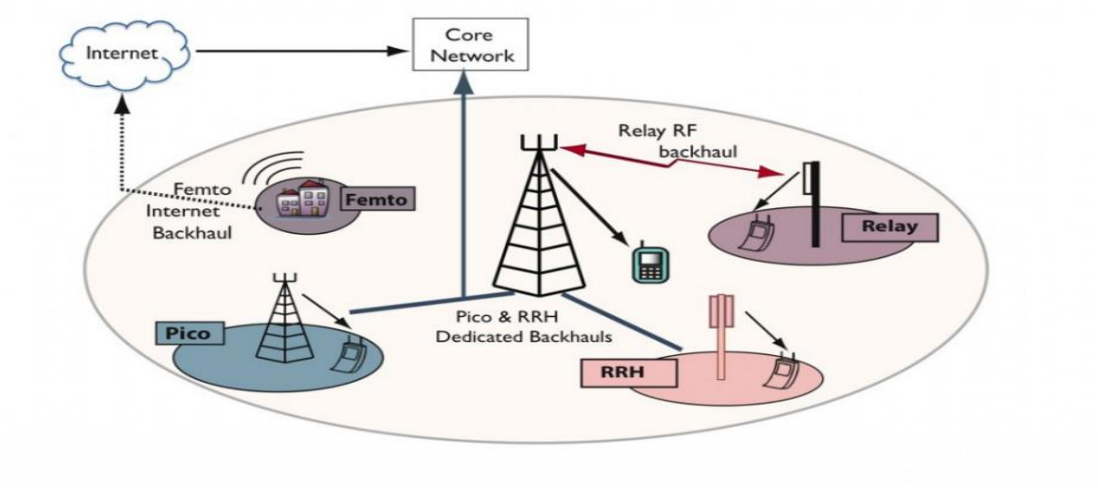


Figure 2.5 Small cell and there backhaul [29]

Macro cells and small cells communicate through the S1 or X2 interface. These interfaces add some amount of delay to the transmission. On the other hand, RRH nodes use a fiber fronthaul that has a near-zero latency, making it a suitable backhaul.

2.5. Heterogeneous Network Deployment of LTE-A

As mentioned in [1], there are two types of deployments that may be employed in a HetNet: cochannel deployment and dedicated carrier deployment. Co-channel is a communication protocol in which all nodes share the same carrier frequency and dedicated carrier, with separate carriers for the macro and low-power layers. Each one has technological difficulties as well as benefits. A basic overview is available in [1] and following sections explain the main design features of co-channel deployment.

2.5.1. Co-Channel Deployment

Macro and small cells share the same frequency carrier in a co-channel deployment. If available spectrum is limited, this may be the only alternative. Balance the load between the different levels is essential in a co-channel deployment. This is accomplished via the use of the Range expansion (RE). Because the carrier frequency is shared across the high-power and low-power layers when Range Extension is used, interference issues arise. To protect users in the RE region, it is necessary to have a robust control and management of inter-layer interference. The approach known as enhanced Inter-Cell Interference Coordination (eICIC) has been investigated for this purpose and has shown promising results [30]. The network's design must take into consideration two important features: UE cell selection and interference management. These features will be discussed in further depth in the subsections follows.

I. UE Cell Selection

The method for selecting a cell for an arriving UE is based on the received signal strength measurement by the UE. The highest signal cell is chosen as the serving cell. There are a variety of indicators of signal strength. Measurements are carried in LTE A are as follows: [31, 32].

- Reference Signal Received Power (RSRP), which calculates the average power of the resource components carrying cell-specific reference signals throughout the measurement frequency spectrum for each cell. This indicator indicates the amount of power received from each cell.
- Reference Signal Received Quality (RSRQ), which is determined by dividing RSRP by total received power, taking into account the resource's channel quality. This indication offers additional information that is beneficial in situations when RSRP is insufficiently dependable for performing cell selection or handover. Cell selection is often dependent on the RSRP level in co-channel systems. Due to the significant transmit power discrepancy between macro and small cells, macro cells cover a significantly larger area than small cells, which results in the

small cells serving a limited number of customers. To maximize the benefit of cell splitting, it is important for the network to balance load between the macro and pico layers[33]. The most commonly used technique is the Range Extension offset[5].

- Other studies have focused on SINR, such as in[34], where the authors recommend selecting the cell with the highest SINR and monitoring it during normal transmission subframes for macro cells and ABS subframes for pico cells. The load in each cell is neglected in this situation. Additionally, adopting throughput-based algorithms is an alternative. These algorithms aim to balance the load among the cells by identifying the one with the best throughput, taking both the load in each cell and the channel quality into consideration. As proposed in [34], the throughput of each cell may be estimated as a function of SINR and the number of users. When selecting the serving cell, this algorithm is highly dependent on the network's present condition.

In [35] compares SINR-based cell selection to RSRP and RSRQ-based cell selection techniques for LTE-A HetNet. RSRP-based cell selection is inefficient since it simply shows the received power from different cells and does not indicate the channel's quality for resource allocation. SINR is the optimum criteria for downlink to achieve high throughput in order to obtain precise channel quality for cell selection. UE calculates the SINR of each cell and selects the cell with the maximum SINR as the serving cell. Cell selection criteria based on SINR is given by:

Serving cell selected = argmax [SINR]

II. Range Extension

A positive bias factor is applied to the pico cell's RSRP or SINR level, hence expanding their coverage area. This offset is referred as Cell Range Extension bias (CRE) [5] .A typical deployment using CRE can be seen in Figure 2.6.

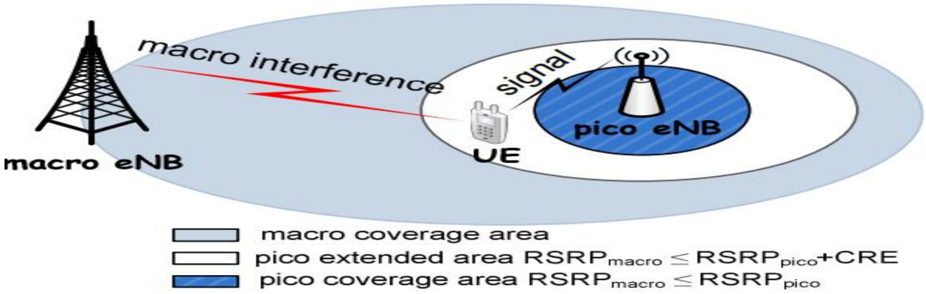


Figure 2.6 HetNet topology using RE in the pico layer [28]

Adding this Range Extension offset, the cell selection is calculated as follows:

$$\text{selected cell} = \text{argumax}[\text{RSRP macro}, \text{RSRP pico} + \text{CRE}]$$

The selected cell is either the cell with the strongest macro signal or the cell with the strongest pico signal plus range extension. This benefits pico cells by pushing more users to utilize them. The RE offset value is sent to users through the Radio Resource Control (RRC) protocol[28]. The users in the network can now be categorized into three types:

- Macro UEs, which are users who are connected with a macro cell.
- Center pico UEs, those users who are within the pico's coverage area and are connected to the pico.
- RE pico UEs, users who are connected to a pico cell but are located within the pico cell's extended coverage area.

Although the RE approach enables load distribution between macro and small cells, hence improving the network's overall performance, the RE offset must be carefully selected:

- Users within a pico cell's extended area may experience significant interference from the macro. Thus, interference management strategies are essential for these users in the RE region. Section 1.3 will discuss these strategies.
- It is not recommended to use large RE offsets without managing interference, since this might increase the occurrence of Radio Link Failures (RLFs) caused by the poor channel quality observed by users in the range extension area[23].

It is not straight forward to determine the optimal RE settings for different networks since they are dependent on numerous factors such as the network's load, the number of macro and pico cells, the position of base stations, and the inter-site distance etc. It is important to investigate each situation, which produces a scalability problem.

2.5.2. Dedicated Deployment

Inter-layer interference is not an issue in a dedicated carrier deployment since macro and low-power nodes are placed on different frequency carriers. The issue in this scenario is bandwidth fragmentation between the layers, which prevents the network from performing optimally. To overcome this and hence enhance performance, collaborative inter-site CA has been presented as the best approach so far. The concept is to enable certain user equipment (UEs) to connect simultaneously to a macro cell and a small cell, so using the larger transmission bandwidth provided by the two layers. In [36] will provide further information about this method. Figure 2.7 illustrates a UE connection in CA mode.

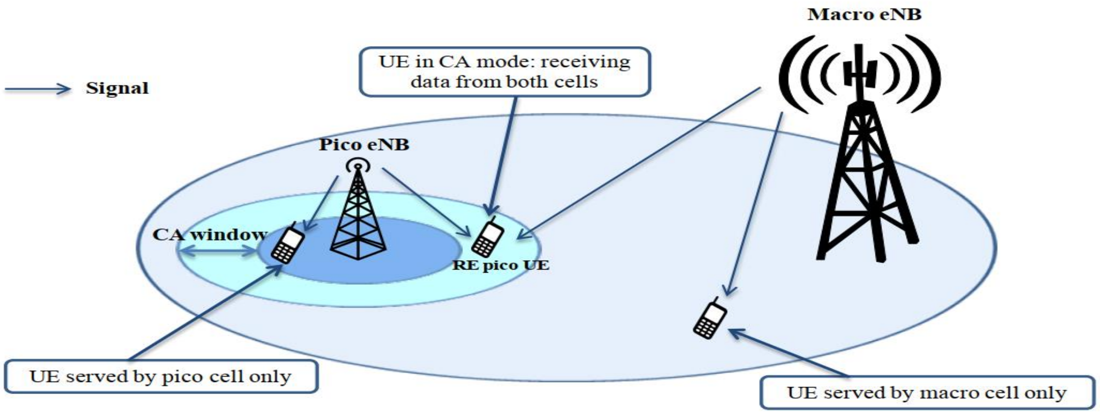


Figure 2.7 Diagram of connection in CA mode showing CA window concept [36]

For legacy UEs that do not support inter-site CA, only one serving cell may service them. CA capable UEs have the option of being serviced simultaneously by a macro cell and a small cell, allowing them to benefit from the availability of ideally double transmission bandwidth. However, some users may experience bad signal quality at one of the layers. In those situations, inter-site CA is not beneficial, since it costs the network and UE more in terms of signaling and power consumption than the advantages received by CA [36]. Two different conditions could be utilized to assess whether or not CA capable UEs should operate inter-site CA. CA window and RSRQ

(Reference Signal Received Quality) threshold are two techniques used to determine if a certain CA capable UE should operate in CA mode.

2.5.3. Advantages and Challenge of Heterogeneous Networks

The objectives of HetNet deployment are to offload data from potentially overloaded macro cells to LPCs, to improve outdoor/indoor coverage, to maximize spectrum reuse, and to enhance network performance for cell-edge users. Additionally, it improves link quality and reduces power consumption by shortening the path between the transmitter and receiver. The key technical challenges facing HetNets include self-organization, backhauling, handover, and interference [27]. The deployment of self-organizing HetNets is a complicated task due to the variety of coexisting cell types and the increasing number of network parameters to consider. The random, unequal, and time-varying character of user arrivals and the resulting traffic burden worsens the challenges inherent in implementing a fully self-organized HetNet.

Backhaul network design will be a significant challenge due to the complicated architecture of the coexisting cell types. For example, the implementation of picocells would need access to utility infrastructure capable of providing electricity and wired network backhauling, which might be prohibitively costly. Femtocells, on the other hand, has lower cost of backhaul but may have challenges sustaining quality of service (QoS), since backhauls depend on customers broadband connections. As a result, operators must carefully design HetNet backhaul in order to select the most cost-effective and QoS-assured option.

Handovers are important to provide unbroken service as users move into or out of cell coverage. Additionally, handovers are effective in balancing traffic loads by rerouting users at the boundary of adjacent/overlapping cells from more crowded to less congested cells. However, this comes at the expense of system overhead, which is anticipated to be considerable in HetNets owing to the high density of small cells and the variety of backhaul links available for each type of cell. Additionally, the probability of a failed handover raises the likelihood of a user outage [37].

LTE's new physical layer architecture enables resource partitioning across cells of various power classes, resulting in optimal resource utilization. However, since interference is a significant problem affecting the operation of HetNets, advanced interference management strategies should be carefully selected. ICIC is used to mitigate downlink interference between cells in LTE Release 8 [1]. As a result, ICIC techniques were effectively enhanced in subsequent releases, mainly to support co-channel deployment in heterogeneous networks.

3. Overview of Inter cell interference mitigation

3.1. Interference Scenarios in HetNets

Although HetNet deployment solves the problem of coverage by adding pico cells to cover areas where the macro-eNBs signal cannot reach or the areas receiving weak signal, it is also beneficial to deploy them in hotspots for bursty traffic. However, it creates the inter-cell interference. Different interference scenarios can be identified as following:

In downlink (DL): pico cells and macro-eNBs typically use the same frequency band (frequency reuse 1). Thus, a macro UE close to pico cell may receive a stronger signal from the pico-eNB than from its serving BS (Base Station) which causes low SINR and inversely for pico UEs closer to macro cell[27].These scenarios are called macro-LPNs (Low Power Nodes) and LPNs macro interference respectively.

In uplink (UL): the pico cell is subjected to interference from macro UEs; the farther a UE gets from serving eNB the higher power it transmits to reach the eNB. Also, when pico cell is close to macro-eNB, the pico UEs can generate interference towards macro-eNB .eNBs in a HetNet setting could be in any of the three cases [38]:

Coverage-limited environment: The cells are located far from each other. For example, the rural and high way cells. Signal levels near to the cell edges are very weak; therefore, the out-of-cell interference levels are also very low.

Interference-limited environment: The cells are packed very close to each other. Examples are dense suburban, urban or dense urban with small cells. Normally the cell edge composite signal level is very high, but the out-of-cell interference level is also very high. Accordingly, the cell edge SINR is still poor.

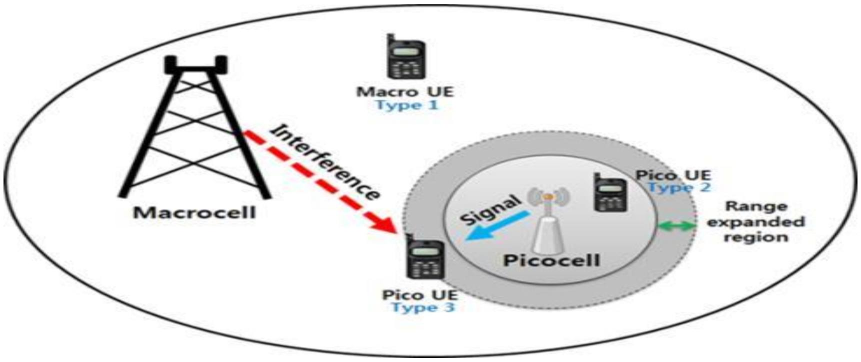


Figure 3.1 Cross-tier interference scenario in HetNet **[39]**

Despite the significant network performance leap expected from deploying picocells, there are numerous challenging technical problems that need to be overcome. One of these major problems is interference management between the macro cell and picocell. Cross-tier interference problems are significantly challenging in co-channel HetNet deployment. For example, the User Equipment (UE) connected to the picocell through CRE suffers severe interference from macro cell, since the received signal power of the macrocell is higher than that of the connecting picocell for such UE, as shown in Figure 3.1. As a result, inter-cell interference management is critical to HetNet deployment [27].

In the third Generation Partnership Project (3GPP) with its REL-8/9, the interference management method did not consider the HetNet, and does not provide a suitable dominant interference scenario in HetNet. Therefore, REL-10 has introduced time-domain based interference management. The basic idea with time domain interference management is that creates "protected" subframes for a victim layer, by reducing its transmission activity in certain subframes. To do so, the eNodeB reduces its transmission power of some downlink signals (or alternatively, mutes their transmission) during a set of low interference subframes designated as ABS, whose

occurrences are known a priori at the coordinating eNodeBs. When pedestrian UEs are connected to the picocell in its range-expanded region, the microcell uses ABS, in order to mitigate macro cell to picocell UE interference [27].

The next section describes eICIC algorithm and the design approach taken to achieve the thesis objectives

3.2. Interference Management in LTE-A HetNet

When small cells under the macro eNodeB's (Evolved Node B) coverage use the same transmit power and bandwidth as the macro eNodeB, inter cell interference occurs, for example, interference between pico cells and macro cells, or between pico cells and neighboring pico cells. Interference affects the throughput of the cell edge users. Thus, the main challenge to HetNet deployment is inter-cell interference. Numerous intercell interference coordination techniques based on TDM resource partitioning are available to mitigate ICI in HetNets [3].

3.3. TDM based Enhanced ICIC Techniques

TDM-based ICIC techniques are designed to utilize spectrum throughout HetNet layers. The objective of TDM-based enhanced ICIC (eICIC) methods is to limit transmissions in certain subframes of the base station (macro cell) that have a high probability of interfering with the small cell. As of 3GPP Release 10, the following TDM-based eICIC schemes were introduced.

- Almost Blank Subframes based eICIC

An ABS is a minimal transmission subframe in which no data signal is transmitted from the macro cell and only the most critical information needed to support legacy LTE (Release 8/9) UEs is transmitted. As a result, the main signals sent during ABS are common reference signals (CRS) and other obligatory system information.

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

The macro cell does not completely blank the power on eICIC subframes when using reduced power almost blank subframes (RP-ABS), since it may use these subframes to serve cell center users in the macro cell. Thus, the full subframe is well used, but intelligent scheduling and coordination between the macro cell and coordinated small cells is required.

- Further Enhanced Inter-Cell Interference Coordination (FeICIC)

FeICIC was introduced in 3GPP Release 11 and is able to manage CRS interference solutions based on transmitter and receiver actions. The following approaches are discussed.

- Transmitter based FeICIC:

The transmitter-based FeICIC technique is based on muting PDSCH resource components inside a small cell ABS that is subjected to significant macro-CRS interference. To compensate for the modest PDSCH resource loss, a rate matching algorithm is then used to adjust the rate of coding and rate matching. In a FeICIC with a transmitter, the transmitter mutes PDSCH resource components that are vulnerable to strong CRS interference. However, due to the need to maintain legacy UEs, this form of muting is not yet practical for the downlink control channels, since the PDCCH resource cannot be muted or rate matched.

- FDM Based ICIC

The fundamental principle of FDM-based ICIC is to divide the available spectrum into parts and assign interfering cells to a unique frequency spectrum. However, 3GPP Release 10 introduced a novel technology known as Carrier Aggregation (CA) that enables multicarrier scheduling in LTE-Advanced systems. This section discusses the development of CA and ICIC in CA-based HetNets[3]

- Carrier Aggregation (CA) based ICIC

CA is a critical component of LTE-Advanced (Release 10). This requires that the UE have access to a total bandwidth of at least 100 MHz. Due to the fact that LTE's maximum supported bandwidth is 20 MHz, bandwidth is expanded through aggregating up to five component carriers (CCs). Furthermore, CA is developed to be backward compatible, which means that the same CC deployed by the Release 10 eNodeB (eNB) may support both LTE (Release 8/9) and LTE-Advanced UEs. CA-based interference management is based on the division of the full spectrum into two parts, referred to as primary cell (PCell) and secondary cell (SCell). Several deployment scenarios are shown to illustrate how HetNets may be designed using CA to successfully mitigate the interference effect[3].

- Coordinated Multi-Point (CoMP) based ICIC

CoMP's fundamental principle is to use multiple transmit and receive antennas from multiple antenna site locations that may or may not be part of the same physical cell. CoMP has been designed mainly to improve the UE experience at the cell edge, but regardless of the location, it is used to enhance the system throughput of UEs that experience strong signals from different cells. CoMP is classified into two types: inter-site CoMP, which provides coordination between cells located in different geographical areas, and intra-site CoMP, which provides coordination between sectors within the same eNB. Additionally, CoMP transmissions are categorised as Coordinated Beam-Switching (CBSCoMP), Coordinated Scheduling (CS-CoMP), Joint Transmission (JT-CoMP), and Dynamic Point Selection (DPS-CoMP) in downlink scenarios (DPS-CoMP).

Ethiotelecom has deployed Long Term Evolution (LTE) and LTE-A in order to accommodate the increasing demand for mobile data. 694 eNodeBs comprise the Addis Ababa network. The cells are small in size, with an inter-site distance of less than 300m between neighboring cells. Each cell allocated a 20 MHz uplink and downlink bandwidth. The system uses frequency division duplex (FDD) and operates at 1800MHz and 2600MHz with a frequency reuse factor 1. A reuse factor of 1 indicates that in addition to the desired signal from a cell to a user, signals with similar radio resources arrive to the receiver from all neighboring cells. While reusing the full spectrum across all cells increases system capacity, it also network be interference limited[40].

This indicates that achieving high bandwidth utilization, which requires a high SINR, is difficult. One way to increase user data rate is to reduce the cell size such that cells transmit at a lower signal power to users, which also reduces the relative interference level between neighboring cells. However, the increased user data rates that result are available only at the cell center, not throughout the cell. One of the issues with LTE is achieving better bandwidth at the cell edge, when the user is subjected to two or more signals with about the same power level. In actual deployed networks, like as the AA LTE-A network, where base station distribution is not uniform, the overlapping area between two cells may be considerable. This indicates that the probability of a user receiving interference signals at almost the same power level as the desired signal is higher, resulting in reduced user throughput.

As described above numerous intercell interference coordination techniques based on TDM resource partitioning are available to mitigate ICI in HetNet. In this thesis work I am going to use TDM based eICIC and detail description is discussed in the following subsection.

3.4. Overview of eICIC Algorithm

3GPP Release 10 provides an enhanced Inter-Cell Interference Coordination (eICIC) technique, to solve cell interference in HetNet. It contains CRE and ABS schemes.

3.4.1. Cell Range Expansion

A UE selects a cell based on its measurements of Reference Signal Received Power (RSRP) or SINR of the downlink signal. The highest offering eNB is being selected as the serving eNB[41]. However, if the exact same notion is being applied to the heterogeneous networks with a macro-pico scenario, macro-eNB will end up enticing many UEs, since UEs will choose the higher power eNB. Whereas, pico-eNB would be serving a very few UEs due to its low transmit power[26]. The load balancing purpose would not be served if the cell selection were based on this approach. Consequently, macro-eNB could be overloaded. pico-eNB would be under-utilized, as they are serving very few users even when they have shortest path loss distance, unevenly and unfairly distributing the traffic load in the network. Hence to balance the load between macro and pico-eNBs, a bias can be added into the RSRP or SINR measured from pico-eNB.

This offset value would, in some way act to neutralize or correct the power difference between macro and pico-eNB. Applying an offset to pico-eNB's SINR would also make the pico coverage area wider, where pico-eNB can be connected as the serving base station [57]. Figure 3.3 explains Pico-cell Range Extension (PRE)

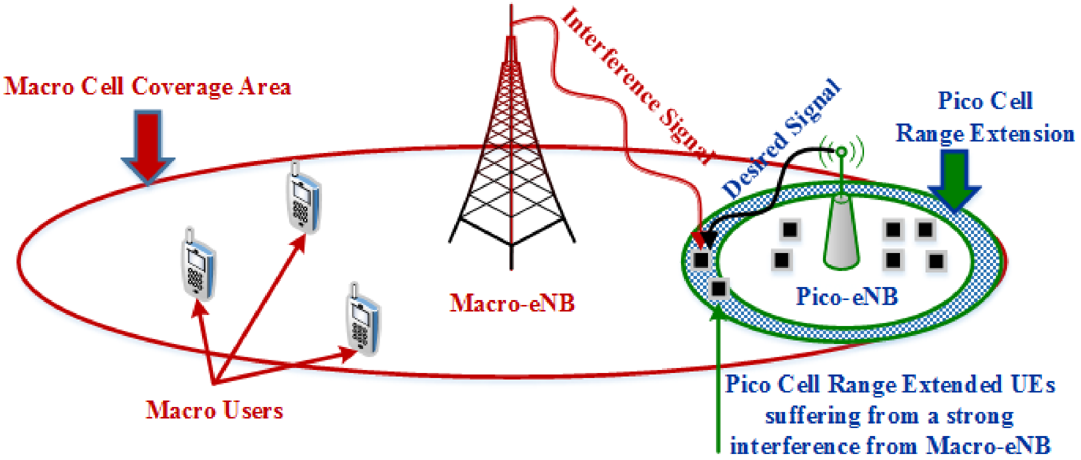


Figure 3.2 Pico-cell Range Extension (PRE) **[42]**

Cell selection criteria based on RE is given by,

$$\text{Serving cell selected} = \text{argmax}[\text{SINR} + \text{bias}]$$

Where bias = 0 for macro-eNB and a few dBs for pico-eNB. On the other hand, the transmit power differences between macro and pico-eNB do not have an impact on the uplink coverage, as the transmitter is the UEs. When pico-eNB is biased with a predetermined offset, as the offsetvalue increases, the offloaded UEs will experience severe interference from the macro eNB[43].That limits the offloading gain. Hence, the range extended pico UEs will experience poor SINR values as results of a strong interference from the high transmit power macro-eNB. Without any interference management solution, very small values of the range extension, a few dBs could be used for pico UEs. The most favorable offset value depends on different factors such as, different geographical locations of macro and pico-eNBs as well as UEs and the interference levels from the macro and pico-eNBs. If the offload value is low, very few users will be connected to pico-eNB and it will be underutilized. Whereas, if the bias is high, pico cell coverage is expanded to attract more users. In this case, due to very strong interference from macro-eNB, the range extended pico users will experience a scheduling delay as well as very low and insignificant SINR values Therefore, the approach under investigation would reduce the DL quality of the users in the extended pico region. However, the sole purpose of introducing pico cells in hotspots is not only load balancing but also to bring the user closer to the base stations, reduce the path loss, improving QoS and experience.

CRE scheme is to allow the user receive signal from the small cell, even macro cell’s signal is higher than that of the small cell. Uses a bias value for cell range expansion, let offload user from the macro cell to the small cells, when UE are unevenly distributed or the macro cells are in heavy load, the constant CRE bias value may let UE offload to a busy small cell, as a result, the throughput might be worse than if it would stay in the macro cell. In[9] they collected the macro cell user’s SINR to compute CDF and then decides the SINR threshold. The pico cell’s SINR threshold is decided from the SINR CDF of all users in the pico cell. The CRE scheme will let user stay in the small cell to transmit data.

An important benefit of range expansion is that, since the cochannel picocell nodeBs (pNBs) have same amount of spectrum resources as the eNB, the spectrum resources in the overall network are more uniformly distributed to the users. This implies that the throughputs achieved by the UEs in the network will enjoy a better fairness. Another important merit of range expansion is that due to uplink power control, it reduces the total uplink interference observed in the network.

The purpose behind utilizing the LTE-A eICIC concept is to efficiently deploy and utilize the pico cells in an interfering macro network to increase the overall system capacity and QoS of the user, and to significantly increase the offload from macro cell to pico cell to balance the network load.

3.4.2. Almost Blank Subframe (ABS)

With TDM eICIC, the macro cell sends almost-blank subframes (ABSs) that contain no data or signaling, with the exception of common reference signals (CRS) to preserve support to legacy terminals. This gives the small cell the opportunity to successfully send a subframe that does contain data.

The main idea of ABS scheme is to let high transmit power macro cell to decrease interference to small cells, and increase system network efficiency by improving small cells throughput. ABS scheme inserts a number of blank subframes to protect small cells transmission signal quality in blank subframes time interval. It is important to choose a suitable ABS ratio to let macro cell decrease throughput and small cells increase throughput to increase the overall system throughput.

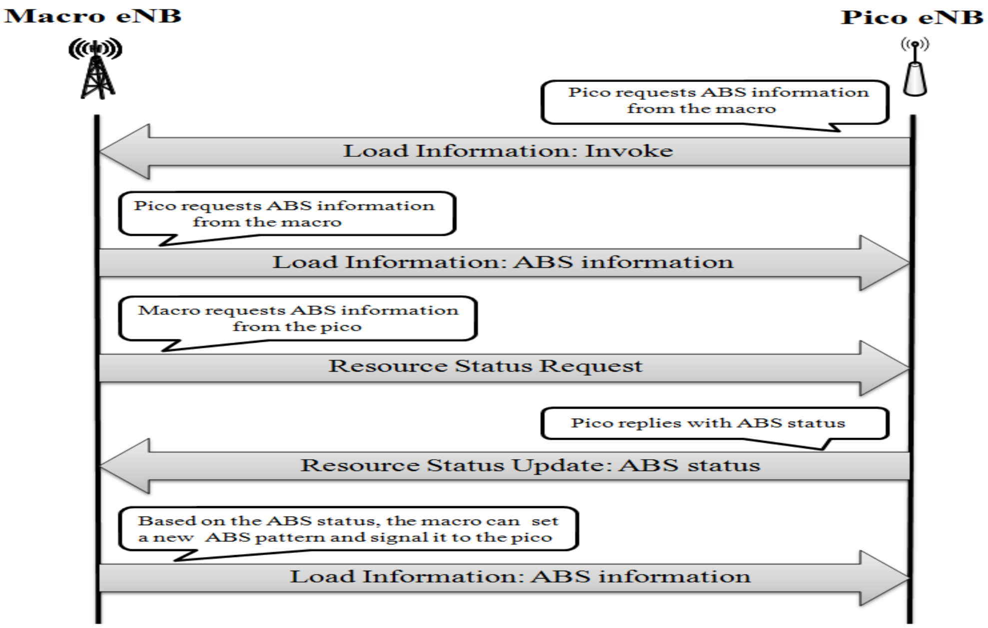


Figure 3.3 X2 Signaling of ABS Muting Pattern **[3]**

As depicted in Figure 3.3, the pico cell initiate ABS request by sending load information (LI) with information element (IE) to macro cell. The macro-cell answers by sending back another LI message with IE ABS information which includes the current ABS muting pattern used at macro-cell. In addition, the macro-cell can ask the pico cell to communicate the utilization of the allocated ABS resources by starting a resource status (RS) reporting initialization mechanism. The pico cell responds and provides the required information with a RS update with IE ABS status. Based on the ABS status from the pico cell, the macro cell has sufficient information to determine whether to use more or less subframes as ABS before deciding on a new ABS muting patter. If the macro cell makes the decision of changing the ABS muting pattern, it informs the small cells within the cluster by means of an ABS information message.

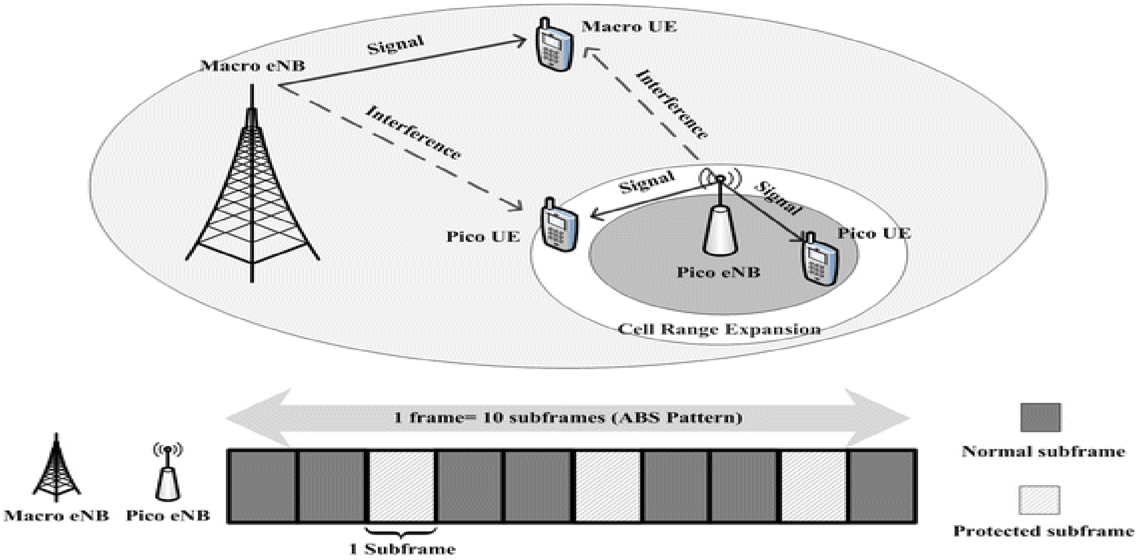


Figure 3.4 eICIC technology: ABS, CRE[44]

In Figure 3.4, the ABS scheme inserts a number of blank subframe to protect small cell transmission signal quality in blank subframes time interval. It is important to choose a suitable ABS ratio to let macro cell decrease throughput and small cells increase throughput to increase benefit and increase overall system throughput.

4. System Models and Simulation Assumptions

4.1. Introduction

The concept of incorporating pico cells into the macro cell network has been studied in previous chapters, and so has the study of intercell interference between macro and pico cells as a result of sharing the same OFDM channel. A UE either belongs to macro-eNB or pico-eNB. The signal received from the pico-eNB is referred to as the desired signal for a pico UE, whereas the signal received from the macro-eNB and other pico cells is referred to as the interfering signal. The signal to interference and noise ratio received at a UE are calculated using the following assumptions:

- Pico-eNB transmit power is much lower than the macro-eNB
- Placement of a pico cell is at the low SINR place or low coverage area of macro cell (edege of macro cell)
- The pico and UE antennas are omni-directional

4.2. Simulation tools

In this thesis work, radio propagation simulation and network simulation are performed. The two tools used in this work are WinProp and MatLab. WinProp is used for radio simulation and the MatLab is for system level simulation and plotting. WinProp is radio propagation and network planning tool used for obtaining pathloss in different environmental scenarios (rural, urban, indoor,etc...). The radio simulation first done for existing macro BSs in the area of interest and by adding small cell in macro coverage. Winprop output or pathloss is feed to matlab for seeing the effect of eICIC algorithm.

4.3. Interference Model

By modeling interferences, we can get the impact of the interferer in the UE when users are serving from the base station. In interference scenario, one base station is the serving node others are the interfering node.

The SINR received by a user connected to either cell can be independently calculated. The user SINR and throughput associated with either of the cells are explained mathematically in order to describe the proposed Macro-Pico scenario's performance.

4.3.1. Signal to Interference plus Noise Ratio (SINR)

SINR is basic performance metrics of mobile network which is used to determine user and cell throughput.

The downlink of ethiotelecom LTE-Advanced networks with picocells is considered, Figure 5.3 shows heterogeneous network having macro cell and Pico cell, Pico cells are randomly deployed under the existing macro cell coverage area.

The SINR of UE associated to cell i is determined as[11]

$$SINR_i = \frac{P^i G^i}{\sum_{j \neq i} P^j G^j \delta^j + N_o} \text{...}4.1$$

Where P^i in the downlink transmission power is allocated by the base station (serving node) i, G^i is channel antenna gain for UE by base station i , N_o is the thermal noise power. P^j, the interference comes from neighboring base station (interfering node) j and G^j ,the neighboring base station channel antenna gain for UE interfered by base station j.

The SINR of UE associated to macro cell is determined as [11]:

$$SINR_m = \frac{P_t^m G^m}{\sum P_t^{m'} G^{m'} + \sum p_t^{p'} G^{p'} + N_o} \text{...}4.2$$

Where P_t^m, $P_t^{m'}$, $p_t^{p'}$ transmission power of serving macro cell, interfering macro cell and interfering Pico cell respectively whereas G^m, $G^{m'}$, $G^{p'}$ channel gain between eNB of serving cell , interfering macro ,Pico and UE respectively and NO is thermal noise. Channel gain from macro eNB to MUE is calculated as:

Channel gain fof macro eNB to MUE can be calculated as below:

$G^{m}\ (dB)$ = GM + GMUE – LM

Where GM, GMUE is antenna gain of macro eNB and MUE respectively LM is pathloss. The SINR of UE associated to Pico cell is determined as [11]:

$$SINR_{p} = \frac{P_{t}^{p} G^{p}}{\sum P_{t}^{m'} G^{m'} + \sum p_{t}^{p'} G^{p'} + N_{o}} \quad \ldots\ldots 4.3$$

Where P_{t}^{p}, $p_{t}^{p'}$, and $P_{t}^{m'}$ is transmission power of serving Pico cell ,interfering Pico cells and interfering macro neighbor cell respectively whereas G^{p}, $G^{p'}$ and $G^{m'}$ represents channel gains of serving Pico cell, interfering Pico cell and neighboring macro respectively Lp is pathloss of pico.

Channel gain of Pico cell to PUE is calculated as below:

$G^{p}\ (dB)$ = GP + GPUE – LP

Where GP pico cell antenna gain, GPUE is pico user antenna gain LM is pathloss.

4.3.2. Throughput Calculation

One of performance matrix in cellular network is throughput. The theoretical data rate of a channel for a certain level of noise can be calculated using a modified Shannon's capacity theorem. Due to use of ABS in HetNet, different parameters are integrated on modified Shannon capacity theorem to achieve objective of thesis work. Throughput of user equipment associated with macro and Pico cells is calculated separately as the following equation by assuming ideal link adaptation (the suitable modulation and coding rate is selected according to channel quality) and equal sharing of resources between all users.

$$Throughput_{macro} = physical\_Resource\_Block * Total\_Resource\_Block * eff\_BW * \left(\log 2 \left(1 + \left(\frac{SINR\_Macro(i)}{SINR\_eff} \right) \right) \right) \ldots\ldots 4.4$$

Where eff_BW is effective bandwidth, SINR_Macro is macro cell SINR and SINR_eff is SINR effective

4.4. Proposed Algorithm

In this thesis, we focus on the inter-cell interference management. the ABS ratio will increase system capacity. The CRE scheme can offload UE from the macro cell to the pico cell when the macro cell is busy. Hence, we combine both ABS ratio and CRE schemes to improve the system throughput. The proposed scheme consists of two phases, first phase focuses on deciding a CRE bias value based on small cell resource utilization. Second phase is to adjust the macro cell ABS ratio and let small cells increase throughput more than the throughput loss of the macro cell.

The flowchart of the proposed scheme is illustrated in Figure 4.1. We describe each step in details. First, the system calculates users SINR to decide the CRE bias value in a period of time.

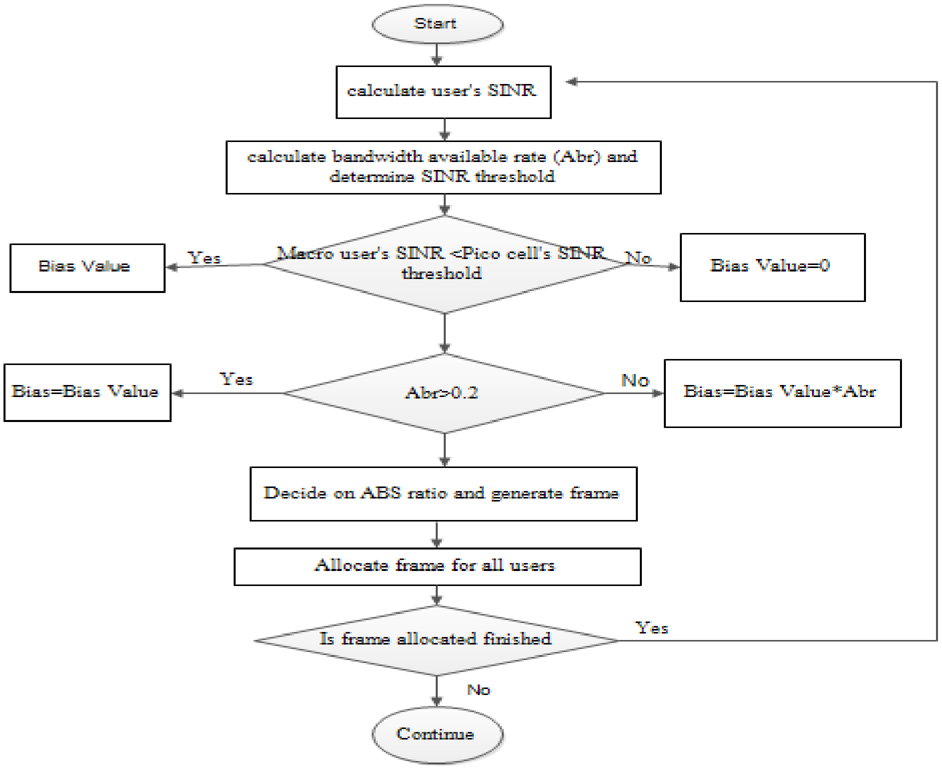


Figure 4.1 The flowchart of the proposed scheme

The SINR for users is calculated in considering the interference from other cells and SINR threshold is determined by using mean of users SINR. Bias value is added to each user when the user SINR is lower than the threshold value.

$$\text{Bias}=[Bias; if\ SINR < SINR_{thr} \text{ ………………………………..4.5}$$

This SINR threshold is used to set the bias value with bandwidth available rate so the next step is to calculates bandwidth available rate. By bandwidth available rate we evaluate the small cell resource utilization. Abr is available bandwidth resource of the target cell, which is calculated by using the number of active users in the target cell and RB is resource block allocated from the target cell to users.

$$Abr = \frac{(B - \sum_{J=1}^{N} RB)}{B} \text{……………………………………………..…...…4.6}$$

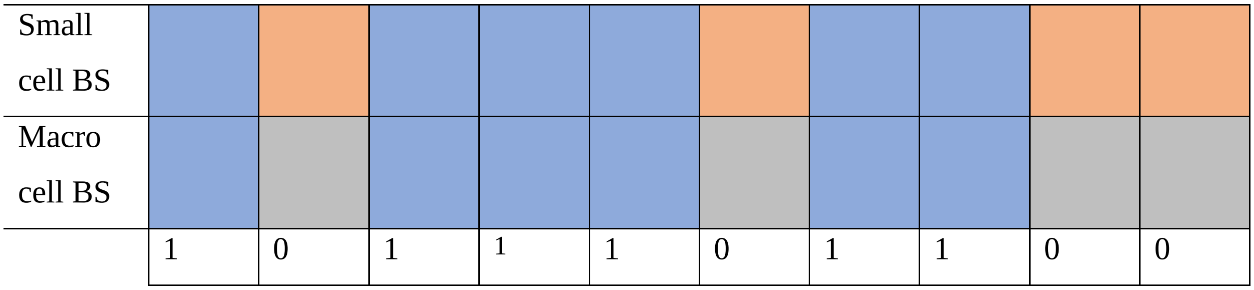
When the available bandwidth is lower than a threshold, it shows that the target cell traffic is heavy. Under the circumstance, if more and more users are offloaded to this target cell by the CRE scheme, these offloaded users will not get enough resource to transmit. The value of Abr is between zero and one[45].

When Abr is low, the bias value will decrease in other words, the target cell has few bandwidths resource available, the CRE region will become smaller and decrease the probability to offload the user to the target cell. In contrast, if Abr is high, the target cell has a lot of available resource to use. The bias value maintains the same value to allow more users to offload to the small cell.

$$Bias = \begin{cases} \arg\max(SINR + Bias); & if\, SINR < SINR_{thr} \\ 0 & for\ macro\ cell\ ID \end{cases} \text{ ………………………………………..4.7}$$

Bias=Bias*Abr or Bias=Bias value depending of the bandwidth available rate.

As eICIC scheme illustrated in Figure 4.2 there are 10 subframes in a radio frame and each subframe occupies 1ms.



Small cell BS	🟦	🟧	🟦	🟦	🟦	🟧	🟦	🟦	🟧	🟧
Macro cell BS	🟦	⬜	🟦	🟦	🟦	⬜	🟦	🟦	⬜	⬜
	1	0	1	1	1	0	1	1	0	0

Figure 4.2 ABS schema

For blue subframes both the macro cell and the small cell will transmit data simultaneously and for orange subframes macro cell will not transmit data. For the gray cell ABS subframes only small cell can transmit. In Figure 4.1, there are 4 ABS subframes, so the ABS ratio is 0.4.

The optimal ABS ratio usage is critical and in [45] it shows ABS ratio 0.4 has higher capacity improvement. In this thesis work ABS ratio 0.4 is used.

4.5. Simulation Parameters

The AA LTE-A network operates at a 20MHz bandwidth and uses an OFDMA-with Frequency \Division Duplex (FDD). Both 1800MHz and 2600MHz are used in the network, with some sites at 1800MHz and some other sites uses 2600MHz. For 1800MHz, the uplink and downlink frequencies are 1765 MHz and 1860 MHz, respectively, whereas for 2600MHz, the uplink and downlink frequencies are 2590 MHz and 2650 MHz, respectively. Each macro cell has a maximum transmitted power of 46 dBm in the network. For simulation, engineering parameters from ethiotelecom side are used and fed to the propagation modeling software (winprop) to generate pathloss. Table 4.1 lists necessary parameters and their assumed values considered to simulate the macro-pico network.

Parameter	Value
Bandwidth	20MHz
Initial Macro users	600 Macro user
Initial Pico users	204 Pico user
Noise power spectral density	-174dBm/Hz
Frequency	1800KHz,2600KHz
Transmitting power (Macro)	46dBm
Transmitting power (Pico)	30dBm
Transmitting antenna gain (Macro)	18dBi
Transmitting antenna gain (Pico)	5dBi
Antenna gain (UE)	0dBi
Radio frame	10msec
Sub frame	1msec
MIMO	8x8
User distribution	Randomly distributed within the coverage area

Table 4.1 simulation parameters and their values

4.6. Performance Metrix

The comparison considers the following performance metrics:

- SINR.
- Throughput

1- **SINR:** The SINR received by the user connected to both of the cell is computed independently. By using interference mitigation SINR of edge user is increased.

2- **Throughput**: Inter-cell interference degrades the system performance of any mobile network in terms of throughput, so the main aim of inter-cell interference mitigation is to improve the network throughput for both users and cells of the mobile network.

5. Simulation Result and Discussion

As explained in the previous section, HetNets is important solution to improve the system performance especially in cell edges and hotspot areas and interference is big challenge. This section discusses the effect of interference seen in the simulation results and the gain achieved by using interference mitigation technique.

5.1. Macro-Pico Scenario

The data traffic collected in every base station of Addis Ababa for the month of December 2020 shows that the Bole area has high data traffic and among the highest traffic Base stations 19 eNodeB has highest traffic and are selected for this simulation. The below graph shows their data traffic for one month.

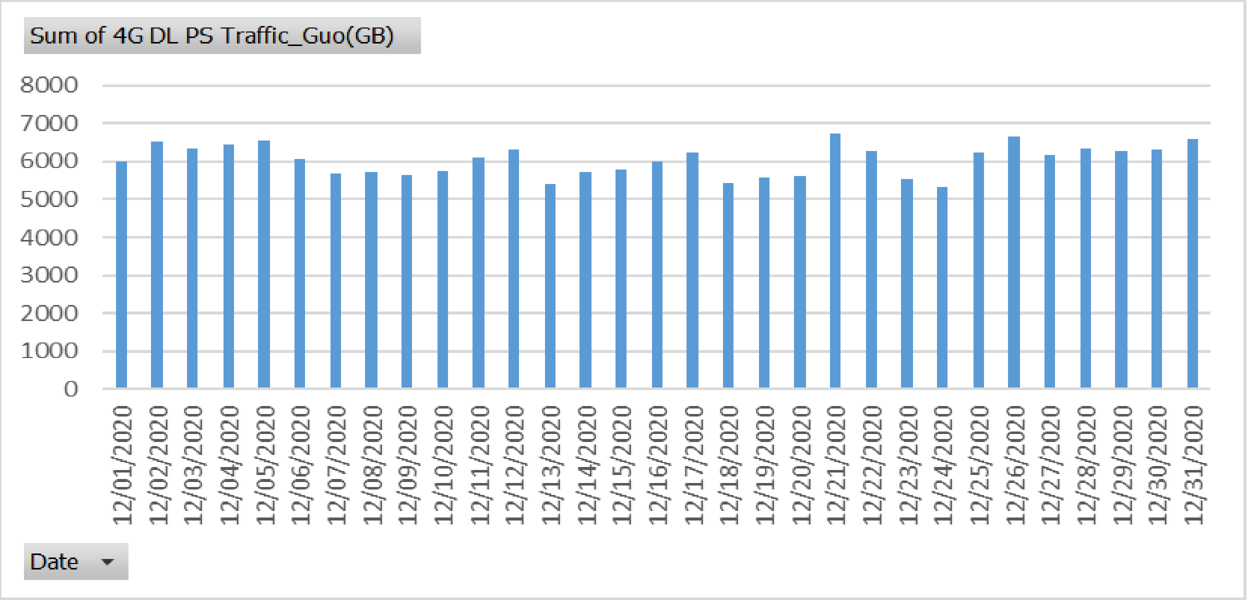


Figure 5.1 shows the 17eNodeB data traffic for the month of December 2020

The selected area is a part of the AA LTE-A network and contains 19 eNodeBs. The eNodeBs are located around the Bole area. Ethiotelecom carefully plans the macro-eNB, considering the coverage demands and capacity. The satellite image of the selected area is shown in Figure 5.2, using of Google Earth®. Each cell (sector of an eNodeB) in the network is identified by its unique ID. The area of interest can be considered as "Hotzone," that refers to an area with highly intensive mobile data usage.

Figure 5.2 View for Selected Area for the study in AA bole area (Google Earth)

5.1.1. Small Cells Deployment Strategy

The selected eNodeB are deployed in winprop simulator using an operational LTE-A network deployed by ethiotelecom and generated pathloss. For the purposes of this study, an area of 8.9 km2 is selected in the city's central business area. Due to the high volume of mobile data traffic in this area, the macro eNB density is high. While existing macro cells are used in our evaluation, pico cells have yet to be deployed in reality. As a result, the pico locations were manually incorporated into the network planning tool. We carefully selected 26 challenging sites for our picos, which have poor macro SINR. Macro site locations, antenna heights and tilts, and other parameters used in the simulation are obtained from real network deployment and correspond to already existing LTE-A macro sites in the operator-specific network, which are considered to be reused for Hetnet deployment. Small cells were randomly placed under the macro cell. The main objective was to increase the SINR and throughput value as shown in the simulator (Winprop) output Figure 5.4

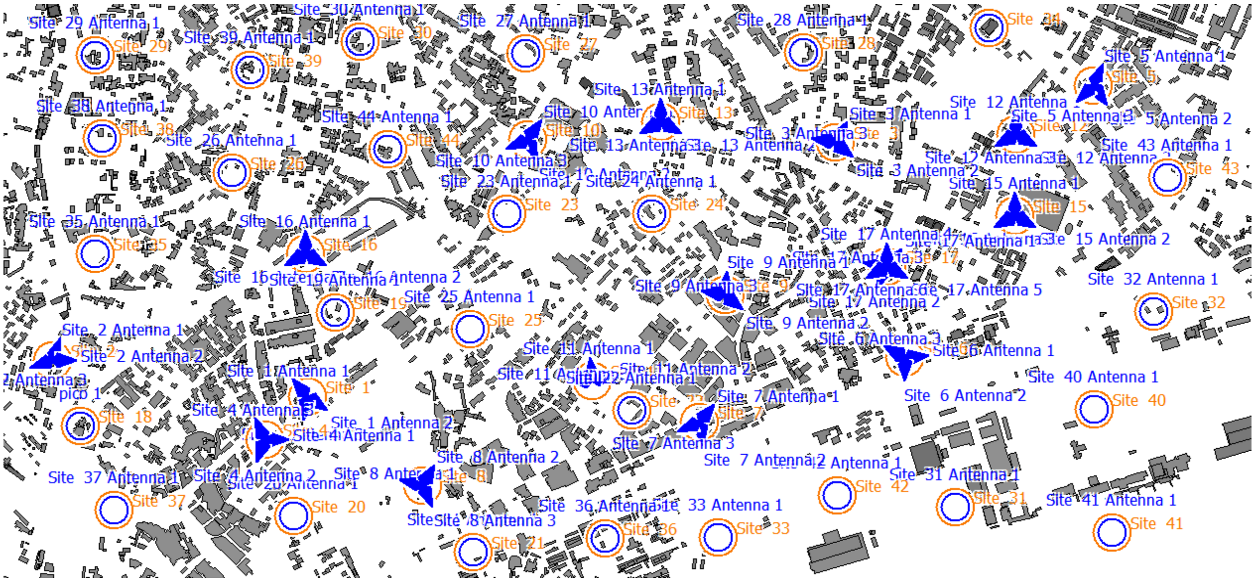


Figure 5.3 Pico cell deployed under macro cell

The locations with the lowest SINR are selected as candidate locations for the pico cell. The optimal positions were determined by shifting the pico cells to new locations within the candidate area until SINR is improved. The small cells were finally placed in feasible locations, as seen in Figure 5.3.

While we used existing macros and randomly placed pico cells to simulate a real network in our evaluation, UE are randomly located between macro and pico cells.

In order to compute the pathloss, the appropriate configuration parameters from ethio telecom's documents which are listed in Table 4.1 are used for both existing macro and small cells. Finally, by using the Altair WinProp simulation tool the pathloss value for each of 19 macro-BSs and 26 Pico cells is computed. The resulted pathlosses have been converted to ". mat" file using MATLAB. Then, the converted pathloss of each cell is given to MATLAB coded eICIC algorithm for further investigation.

Figure 5.4 Throughput of Hetnet

To this end, simulation results are carried out to illustrate the user performance with and without Pico cell in the system. The simulation result mainly demonstrates the performance of HetNet using performance metrics. Simulation shows the effect of inter cell interference and improvement made by using eICIC.

5.2. Results and Discussion

User SINR and user throughput are considered as performance metrics to evaluate proposed interference mitigation technique(eICIC).

The total network throughput without deploying pico cell was analyzed and then pico cell add to the existing macro cell and the throughput is shown in Figure 5.4 Further analysis is done in MATLAB by using SINR and throughput calculation discussed in section 4. The throughput of users served by macro cell and also after deploying HetNet is investigated and the resulting CDF curve is shown in Figure 5.5.

Only a limited number of users can be served from Pico cell due to low transmit power and also experience strong interference from macro cell. This leads to coverage and load imbalance between macro-pico scenario. Due to this, CRE technique has been employed to offload the macro cell traffic to low power Pico eNBs and improve DL coverage imbalance. In order to evaluate the CRE impact on the system performance different CRE bias value that depend on the bandwidth available rate and SINR of user is used.

In general, as CRE rises, macro user throughput rises as well. This is due to an increase in the number of users being offloaded from the congested macro cell to the pico cell. In this demonstration the number of offloaded users is 135. The use of almost blank cell will degrade the throughput gain of CRE because of the macro cell transmission is blocked for specific subframes but still there is performance gain for macro users.

The 135 range expansion users or offloaded users from macro cell affected by interference from high power macro cell so using ABS is mandatory to avoid sever inter cell interface which are originated from high power macro cell.

In this simulation 10 percentile of user throughput on Macro-Pico scenario is considered as cell edge users. and the 50-percentile user are considered as cell average users and 90 percentile users are considered as center users.

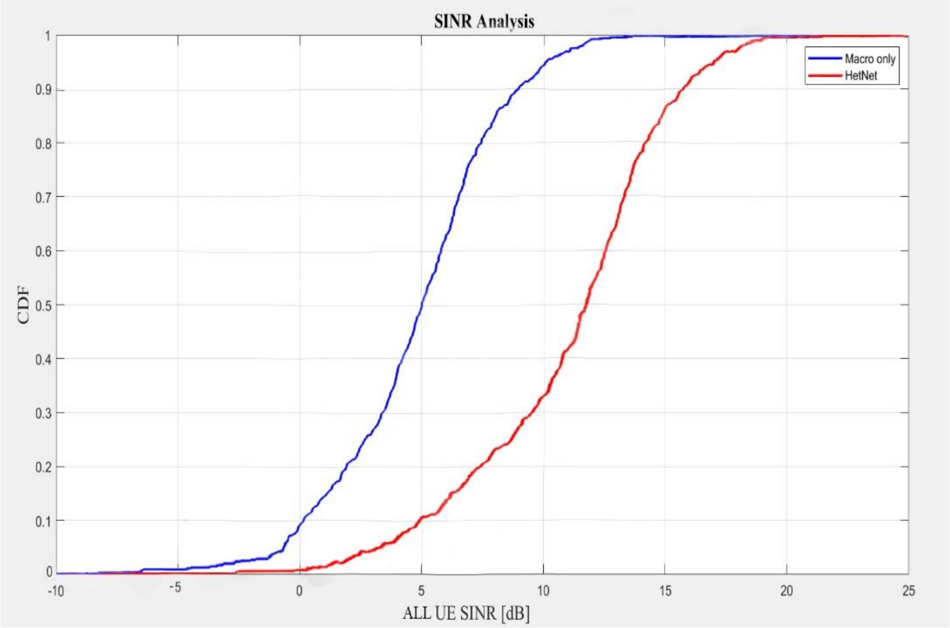


Figure 5.5 CDF of user throughput with and without implementing Pico cells

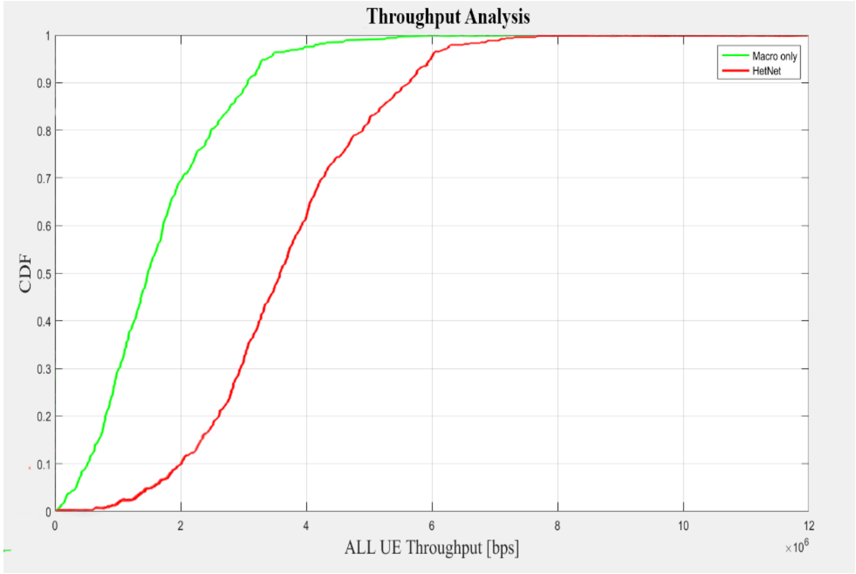


Figure 5.6 CDF of user SINR with and without implementing Pico cells

The Figure 5.5 and Figure 5.6 shows user throughput of the system with and without addition of Pico cell. The result graph of macro cell throughput shows that macro cell serves users with the lowest throughput compared to HetNet system. As a result, HetNet appears to be a promising approach for increasing system performance. The simulation result shows Hetnet improves both cell edge and cell average users' performance. After showing the importance of Hetnet proceed to use interference mitigation technique proposed in Section 4.4.

According to 3GPP's standardizations and as it has been described in the previous chapters of this thesis, the neighboring MeNB (macro eNodeB) and PeNB (pico eNodeB) should exchange channel and UE information over the X2 interface, before the MeNB decides and generates the ABS pattern to be used. But for the simulation scenario in this thesis a static ABS pattern and semi static CRE has been used.

In the eICIC scheme, cross-tier inter cell interference between macro cell and Pico cells is handled via ABS algorithm. We evaluate improvement made by using eICIC with network performance evaluation metrics.

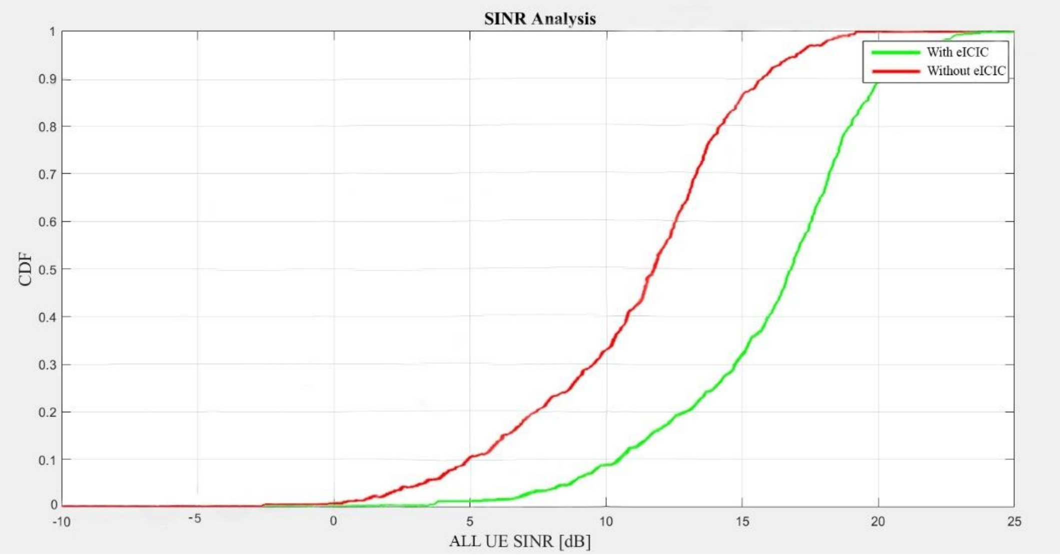


Figure 5.7 All user SINR with and without using eICIC

The Figure 5.7 red color shows, cell edge user performance is low and more cell edge users has negative SINR but using eICIC improves performance and cell edge users get 3-5dB SINR increase by using eICIC.

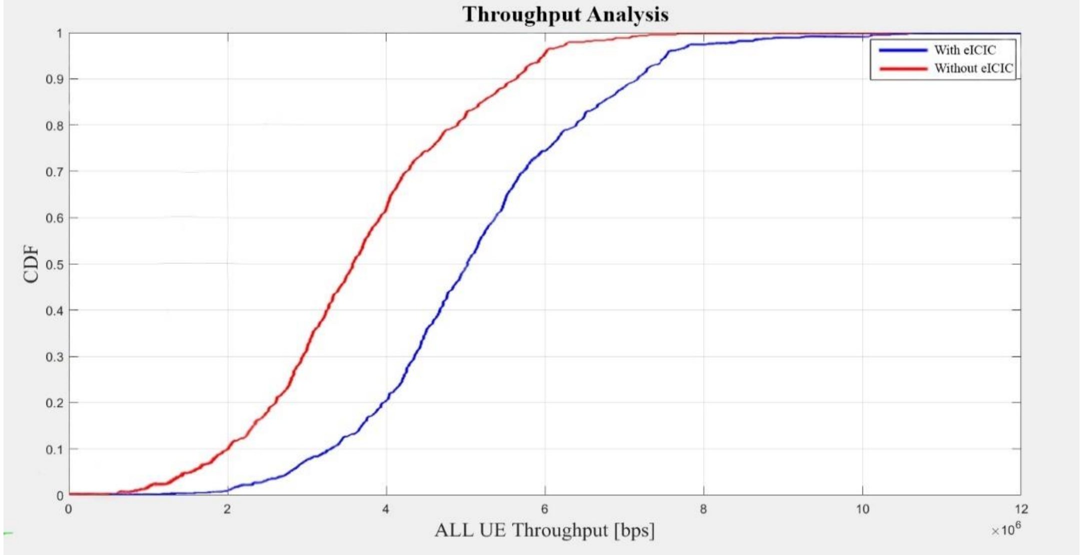


Figure 5.8 All user throughput with and without using eICIC

The Figure 5.8 red color shows, cell edge user performance is low and using eICIC is required for better performance and even average users have optimum (not maximum) throughput. By using eICIC cell edge and also average user throughput increases. There is 1Mbps to 2M increase in cell edge and cell average user throughput by using eICIC.

From the Figure 5.8 the below bar graph is drawn to show the clear gain achieved by using eICIC.

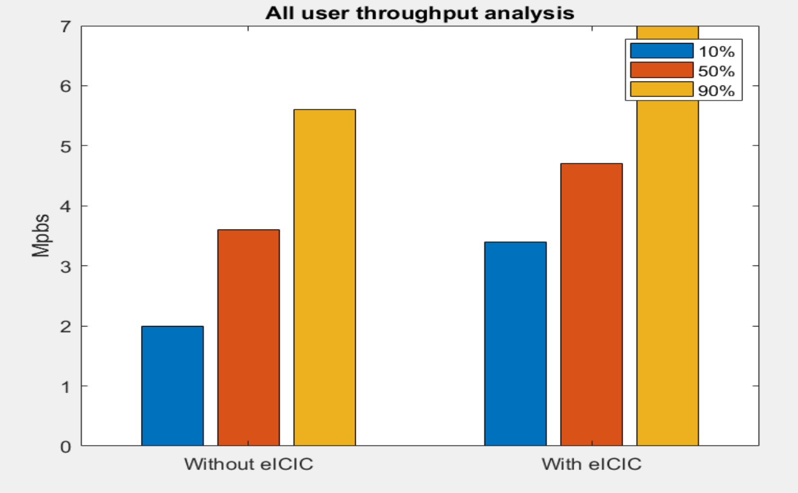


Figure 5.9 Bar graph for pico user throughput with and without eICIC

The bar graph in Figure 5.9 shows 10 percentile users or cell edge users has throughput improvement of 70% because of using eICIC algorithm.

6. Conclusion and Future Works

6.1. Conclusion

HetNet is one of the best recommended technologies to improve the cell edge user performance. However, cross-tier interference is a serious challenge due to co-channel deployment and transmission power difference between macro eNBs and Pico eNBs. This thesis work studied the impact of cross-tier interference in the performance of LTE-A HetNet scenario. It mainly demonstrates the effect of sever inter cell interference on users and the interference mitigation technique using eICIC. The study also analyzed the impact of overlaid low power Pico cells on macro user in terms of SINR, throughput. Additionally, CRE concept has been employed to increase capacity of Pico cell and to obtain load balance between high power and low power node by offloading congested macro users toward the pico cells. Using eICIC notable performance improvements are achieved for both cell edge and cell average users. The throughput of Pico user decreases when CRE increase. Theses is due to users are offloaded to Pico cell increases and but pico user's throughput increasing as ABS ratio increases and cell expanded users will have advantage by using eICIC.

6.2. Future Works

This thesis work mainly concentrates on the analysis of eICIC on HetNet performance. The eICIC muting pattern should be instantaneously adapted to follow the time-variant load fluctuations but in this thesis a fixed muting pattern is used this implies that muting patterns cannot track fast traffic fluctuations. So, recommend as a future work that CRE and ABS shall be dynamic. In addition, recommend to investigate performance of HetNet by applying different bias value and ABS ratio.

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