Addis Ababa University
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School of Electrical and Computer Engineering
Telecommunication Engineering Graduate Program

Inter-Cell Interference Mitigation in LTE-Advanced Network by Using Coordinated Multipoint Transmission Technique: The Case of Addis Ababa, Ethiopia

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Place Date of Submission

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Abstract

The number of mobile broadband subscribers is increasing along with mobile data traffic on the Ethiopian mobile network. Mobile customers are facing dissatisfied service quality as the number of subscribers is increasing due to resource sharing as well as increasing interference. To improve service quality, network optimization and expansion work has been continuously performed. In order to maximize network capacity and coverage, ethio telecom upgrading the cellular network by using Long Term Evolution Advanced (LTE-A), an indoor building solution system, and adding base stations/transmitters. In such networks, Inter-Cell Interference (ICI) becomes more challenging, which mainly affects network performance. So, to overcome the aforementioned problem, operators are required to develop an effective approach that adopts different interference mitigation techniques.

This thesis study presents a Coordinated MultiPoint (CoMP) transmission technique that can be considered as an effective way to improve spectral efficiency and system throughput performance. The thesis focused on downlink ICI mitigation in the LTE-A network within Addis Ababa. Comparative analyses and evaluations were performed for various CoMP and non-CoMP schemes. Taking into account performance metrics such as Signal to Interference plus Noise Ratio (SINR), spectral efficiency, and system throughput by performing radio propagation using WinProp and system-level simulation using the static simulator Matlab.

The performance evaluation of the simulation study results obtained that the SINR gain improves 1.2dB and 1.4dB for the intra-site CoMP system, the Dynamic Point Blanking (DPB) CoMP system improves up to 3dB and 1.9dB, and the Joint Transmission (JT) CoMP system improves 3.7dB and 2.8dB for the cell edge and average users respectively. Spectral efficiency gain improved by 1.4bps/Hz, 2.4bps/Hz, and 3.2bps/Hz for intra-site CoMP, DPB CoMP, and JT CoMP scenarios, respectively. In addition, the throughput gain was achieved at 33% and 15% for intra-site CoMP, 70%, and 45% for DPB CoMP, and 97% and 70% for JT CoMP for the cell edge and average users, respectively. Therefore, the proposed interference mitigation solutions have been proven to provide a significant performance improvement for the LTE-A network and are worthy of deployment on the existing Addis Ababa LTE-A networks.

Keywords: *LTE-Advanced network, Inter-cell interference, Interference management technique, Coordinated multipoint, Joint processing, SINR, Throughput, Addis Ababa*

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List of Acronyms

3GPP	Third Generation Partnership Project
5G	Fifth Generation
ABS	Almost Blank Sub frame
AL	Antenna Loss
BS	Base Station
CA	Carrier Aggregation
CDF	Cumulative Distribution Functions
CoMP	Coordinated Multipoint Transmission
CQI	Channel Quality Indicator
CS/B	Coordinated Scheduling and Beamforming
CSI	Channel State Information
DAS	Distributed Antenna System
dB	Deci Bell
DL	Downlink
DPB	Dynamic Point Blanking
DPS	Dynamic Point Selection
eICIC	Enhanced Inter Cell Interference
eNB	Enhanced Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-UTRAN	Evolved-Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FFR	Fractional Frequency Reuse
HetNet	Heterogeneous Network
HFR	Hard Frequency Reuse
IBS	Indoor Building Solution
ICI	Inter Cell Interference
ICIC	Inter Cell Interference Coordination
IP	Internet Protocol
ISD	Inter-Site Distance

ITU	International Telecommunication Union
JP	Joint Processing
JR	Joint Reception
JT	Joint Transmission
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
MIMO	Multiple Input and Multiple Output
MME	Mobility Management Entity
OFDMA	Orthogonal Frequency Division Multiple Access
PCI	Physical Cell Identities
PL	Path Loss
PMI	Precoding Matrix Index
PRB	Physical Resource Block
QAM	Quadrature Amplitude Modulation
QOS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RAT	Radio Access Technology
RI	Rank Indicator
RR	Round Robin
RRH	Radio Relay Heads
RSRP	Reference Signal Received Power
RSS	Received Signal Strength
SAE	System Architecture Evolution
SE	Spectral Efficiency
S-GW	Serving Gateway
SINR	Signal to Interference plus Noise Ratio
TP	Throughput
UDP	Urban Dominant Path
UE	User Equipment

Chapter 1

Introduction

1.1 Background and Motivation

In recent years, the number of worldwide mobile users has grown rapidly, and the number of mobile broadband subscribers and their demands has increased exponentially [1]. Thus, due to the introduction of mobile application services into the market and the increase in people's behaviors using the Internet for social networking, web surfing, instant messaging, and video streaming. This data traffic transmitted over cellular networks is a serious concern for the mobile communications industry with mobile network congestion. The increase in mobile data traffic and user demand is prompting mobile network operators, including ethio telecom, to consider various network upgrade options. Because of the enormous demand, the Third-Generation Partnership Project (3GPP) developed Long Term Evolution (LTE) and LTE-Advanced (LTE-A) cellular networks [2].

In spite of the high-speed connectivity of LTE-A, the data traffic demand has still increased exponentially in recent years [1]. Furthermore, according to researchers and industry, more than 80% of data traffic originates indoors. However, due to low signal penetration through walls or total loss of signal in situations where there is a relatively longer propagation distance, indoor users receive the power of a very weak signal. Therefore, service quality for indoor and cell-edge customers was unsatisfied with traditional cellular networks based on macro cells only [3, 4]. In addition, it is unable to satisfy the traffic demands of users in hotspot areas. To meet these requirements, deployment of Heterogeneous Networks (HetNets) has emerged as a solution and has been adopted in 3GPP specifications [5]. In HetNet, there are many various network architectures, transmitting powers, and frequency reuse, all of which cause harmful interference. As a result, compared to homogeneous networks, HetNet makes the network topology denser and the interference schemes more challenging [6]. In the LTE-A network, mainly two types of interference are taken into consideration, such as intra-cell interference and Inter-Cell Interference (ICI). The LTE-A network uses Orthogonal Frequency Division Multiple

Access (OFDMA) radio access technology, where the sub-carriers are mutually orthogonal to each other. So, intra-cell interference is significantly reduced. Whereas, ICI from reusing the same frequency between neighboring cells is a major problem [7].

In the case of actually deployed networks, like the ethio telecom LTE-A network, the frequency reuse factor is one and the cells get smaller. In addition to the LTE-A network, ethio telecom deployed an Indoor Building Solution (IBS) system using a Distributed Antenna System (DAS) on selected high-rise building sites in order to increase coverage and capacity. DAS is considered one of the candidates for HetNet [3]. However, this architecture does not fundamentally solve capacity due to limited interference [8]. A large volume of interference (ICI) reports generated by dense base stations is one of the key bottlenecks in such a network architecture [6]. Therefore, there is a need for interference mitigation techniques for the mass deployment of cells between serving and interfering cells in the same spectrum.

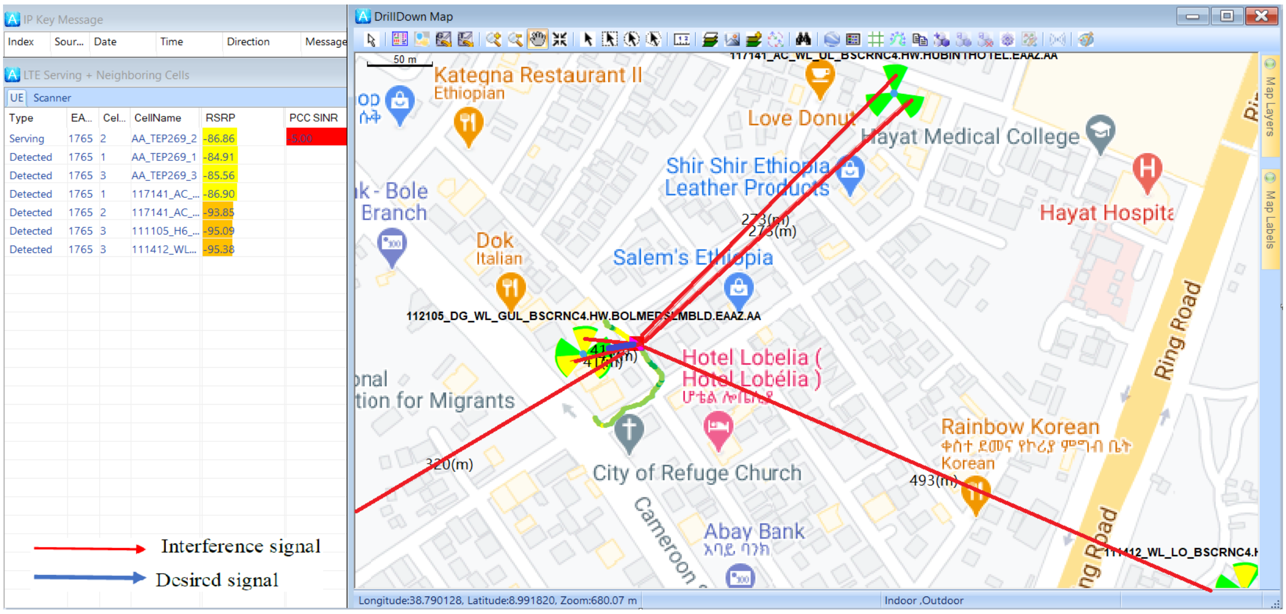
As a result, 3GPP proposed different kinds of advanced interference mitigation techniques to be used to resolve the ICI impact between neighboring cells [7]. These interference mitigation techniques are Inter-Cell Interference Coordination (ICIC) and its enhanced version (eICIC), which reduce the interference at cell borders in homogeneous and heterogeneous networks, respectively. Nevertheless, these approaches present some limitations in the case of saturation. Because of this constraint, the Coordinated Multipoint (CoMP) transmission/reception technique is thought to be the most optimal and promising solution for LTE-A [9, 10]. With CoMP technology, the user connects to more than one Base Station (BS) in a coordinated way to better mitigate the ICI. As a result, it either converts the interference signal into useful information or eliminates the interfering signals between adjacent cells [11, 12]. Generally, the CoMP technique is an advanced technology used to improve cell-edge throughput, improve the average data rate, mitigate interference, and increase spectral efficiency through enhanced NodeBs (eNBs) coordination [13]. CoMP transmission is divided into two broad categories: Coordinated Scheduling/Beamforming (CS/B) and Joint Processing (JP) [14].

The research study presented in this thesis provides a novel interference mitigation scheme, mainly focused on the CoMP technique, more precisely the JP one, to improve cell average and cell edge users' performance. As the main performance metrics, SINR, throughput, and spectral efficiency are used. In the thesis work, the initial study focused on the current Downlink (DL) LTE-A networks to implement the JP CoMP technique in Addis Ababa. Furthermore, the study more thoroughly considers the IBS system in OFDMA network operation.

1.2 Statement of the Problem

To satisfy the increasing demand for mobile data traffic, ethio telecom has deployed an LTE-A network and an IBS system with a passive DAS in Addis Ababa. The IBS deployment is an alternative solution in areas where the macro BSs have poor coverage in all cellular network types. The LTE-A network system uses Frequency Division Duplex (FDD) and cells are allocated 20MHz of bandwidth that operates at 2.6 GHz with a frequency reuse factor of one. Despite the significant benefits of deploying LTE-A networks and IBS systems to increase the network capacity or to extend the coverage in a cost-effective way, interference is one of the most serious obstacles. This is due to full-spectrum reuse and the distribution of BSs being non-uniform in such network deployments. Thus, in each cellular network, a major interference problem degrades the coverage and capacity performance of the networks, which is unsatisfactory for customer demands, especially those located near a cell edge.

To address the DL LTE-A network interference problem, ethio telecom utilized one of the more realistic methods. They used a drive test measurement to obtain the total DL interference level within a particular cell of the LTE-A system. To do this, the data was extracted and evaluated from a three-month Addis Ababa LTE-A network log file for one sample site selection. Then we made the log file analysis report as shown in Figure 1.1, and the SINR was too low, which is below 0dBm. From the figure, the user treats one signal (the blue line) as its intended signal, but the rest of the signals (the red one) as interference.



Type	EA...	Cel...	CellName	RSRP	PCC SINR
Serving	1765	2	AA_TEP269_2	-86.86	-5.00
Detected	1765	1	AA_TEP269_1	-84.91	
Detected	1765	3	AA_TEP269_3	-85.56	
Detected	1765	1	117141_AC_...	-86.90	
Detected	1765	2	117141_AC_...	-93.85	
Detected	1765	3	111105_H6_...	-95.09	
Detected	1765	3	111412_WL...	-95.38	

Figure 1.1: Downlink LTE-A network interference drive test analysis

The figure shows a very strong interference pattern with a low SINR. This suggests that interference has become a serious limiting factor for LTE-A network performance in certain locations. Especially, ICI is one of the largest challenges, which mainly affects system performance and causes significant network performance degradation. This is particularly true for cell-edge users. Managing this problem using the existing (traditional) interference management approaches is becoming a challenge in ethio telecom. Consequently, ICI has been identified as a research topic for the deployment of LTE-A networks in Addis Ababa. Therefore, this thesis is an analysis of techniques for the management of interference (ICI) in the DL LTE-A network. Thus, a thorough understanding of interference and its various management techniques is very important. Like ethio telecom needs advanced interference management to efficiently manage the network for effective utilization. In this regard, we suggest and show well-known innovative interference management techniques considering the current LTE-A network deployment.

1.3 Objective

1.3.1 General Objective

The main objective of this thesis research is to improve the performance of the DL LTE-A network by mitigating ICI for cell-edge and average users in the case of Addis Ababa. This aim can be fulfilled by developing an efficient JP CoMP scheme with powerful coordination of BSs for cooperative transmission user scheduling techniques.

1.3.2 Specific Objectives

The following specific objectives have been specified in order to attain the overall goal:

- Study the impact of interference on the ethio telecom LTE-A network's performance and explore the current interference management approaches.
- Understand different ICI mitigation approaches in the LTE-A by using a literature review.
- Review the most recent CoMP schemes and their deployments based on the literature.
- Design LTE-A network propagation models in WinProp for path loss analysis.

- Different CoMP methods and non-CoMP techniques have been used to design a system model using Matlab-based simulation work.
- Investigate how the JP CoMP scheme can increase SINR, throughput, and spectral efficiency in both intra-site and inter-site scenarios.
- The proposed scheme's performance gain can be analyzed and evaluated according to the predefined performance of the baseline non-CoMP system.

1.4 Literature Review

To find a novel solution to the research problem, an extensive study was necessary. So far, a number of studies have been performed, many of which have been suggested by 3GPP and performed by researchers to mitigate ICI in the LTE-A network. As a result, the main technique with relevance to this thesis is CoMP, and related works are reviewed as follows.

The authors [9], discussed the practical deployment of CoMP and its gains in SINR for inter-site and intra-site coordination scenarios. The authors investigated the performance of DL CoMP in the LTE-A network under real-practical constraints. To evaluate the real CoMP network, they used topography and terrain data from Al-Khobar city, Saudi Arabia. The simulation was done using the DL LTE-A system-level model using WinProp and Matlab simulators. They did the evaluation using the received power and SINR from real CoMP networks in different types of clustering. The results showed that inter-site CoMP SINR exceeded intra-site CoMP by 6 dB and non-CoMP by 15 dB at average users. In addition, they investigated the effect of clustering on the SINR and found that small clusters performed better than large clusters. This study showed that CoMP performance in realistic networks by using clustering could enhance the SINR to noticeable levels as in ideal CoMP networks. Note that the paperwork did not include the effect of user scheduling on the CoMP performance.

The authors [10], CoMP technology has been offered as a possible solution to improve LTE network cell-edge spectrum efficiency, energy efficiency, and ICI mitigation. The paper focused on homogeneous macro-cell network CoMP, which is considered high-capacity backhauling for inter-site BSs at different site locations. The simulation was done using the DL LTE system-level model using WinProp and Matlab simulator tools. The CoMP technique utilized is JT algorithms and simulates the number of CoMP UEs as a fraction of all UEs for different

CoMP thresholds. They analyzed that a larger number of UEs could become CoMP enabled with a high threshold setting and that the number of CoMP users is limited by setting a low threshold. The demonstrated results show an optimum CoMP threshold setting that would allow for the benefits of CoMP spectral efficiency gains to be afforded to an optimum number of UE. From this perspective, they showed the highest spectral efficiency gains were for CoMP UEs experiencing a low CoMP threshold.

ICI is one of the most critical issues limiting the performance of the LTE-A network [11]. As a result, the authors proposed a number of mitigation approaches, including ICIC, eICIC, and CoMP transmission and reception, as well as a comparison of these techniques was made. ICIC reduces ICI by affecting different frequencies of resources on cell-edge users for homogeneous networks. eCIC is applied to cell edge users in neighboring cells to use the same frequency resource but at different time intervals for HetNet. CoMP technology consists of coordinating different BSs in order to enhance the performance of edge users' utilization of ICI in a constructive manner. The comparison simulation results in terms of SINR and capacity coordinated with distance. The results obtained from the study show that the SINR value reaches 15 dB and can increase the system capacity by up to 80 Mbps for a distance of 0.5 km between the user equipment and the serving BS by using CoMP technology, and 12 dB, 74 Mbps, 9 dB, and 66.5 Mbps for eICIC and ICIC approaches respectively.

The authors [12] investigated the CoMP transmission method proposed to improve spectral efficiency and system throughput in interference-limited mobile networks. In the joint transmission CoMP technique, multiple BSs coordinate transmitting data streams to each UE. As more than two BSs are involved, the backhaul architecture for CoMP joint processing is crucial to provide low latency feedback, high capacity, small power consumption, and perfect synchronization among the base stations. Therefore, to address these kinds of issues, they proposed an efficient algorithm and a set of principles that could reduce these complexity requirements. This is of great interest in the field of joint processing. To achieve this goal, solutions that restrict the use of joint processing techniques to a limited number of BSs or areas of the system are typically divided into clusters of cells. The network is typically divided into clusters of cells, and the joint processing schemes are implemented within the BSs included in each cluster. The simulation was done using the DL LTE-A system-level model using Monte Carlo and Matlab simulations are considered a static cluster of BSs. They proposed a mechanism to compare JT CoMP with non-CoMP, and to produce average per-user SINR, average per-user spectral efficiency, and average per-user throughput as a function of distance from BS, as well as the CDFs of different parameters. Therefore, the authors' simulation results show that CoMP gives high SINR, increased spectral efficiency, and throughput improvements.

In [13], the authors analyzed ICI as a serious issue in the LTE-A system, and CoMP operation has been considered as a proposed solution targeted for the LTE-A standard. This is the purpose of reducing interference, improving spectrum efficiency, enhancing data throughput, and enhancing effective coverage area, especially for cell-edge users, by exploiting the interference signals from different transmission points. They presented a simulation of the types of DL CoMP operations recently proposed for LTE-A radio network standards. The key issue of CoMP implementation in real networks is also emphasized. Discussed, it seems that a coherent JT CoMP provides optimal performance, but it is challenging on backhaul overhead. On the other hand, CS CoMP provides a great release from these challenges but is unable to meet desirable throughput for cell-edge users. In terms of information sharing among CoMP set BSs, the fully distributed architecture is the most durable but requires full mesh reliable connectivity between the BSs. The performance evaluations show that cooperative transmission techniques have the potential to improve the performance of cellular system throughput gains.

To summarize the above studies, many of the authors have investigated that CoMP schemes are the most promising method for managing ICI and improving the performance of the LTE/LTE-A networks. Each author followed different approaches and input data assumptions to evaluate the performance gain of using the CoMP scheme. Their simulation results differ from one another depending on the environment, cell size, data set, BS coordination techniques, algorithms, and methodology. In this thesis research, from the above-related paper, methods for system-level simulation have to be taken. As a case study, from the literature, no one has investigated LTE-A network interference mitigation by approaching CoMP, considering ethio telecom.

1.5 Methodology

This thesis work adopts a research methodology that mainly relies on the improvement and evaluation of the proposed scheme. Feedback from my advisor and the examiners at meetings and their assessments also worked as a guideline during the long journey of the thesis research. The methods for achieving the objectives of the research follow research program steps.

The research work started by studying the current ethio telecom LTE-A network and IBS system deployment that has been completed in Addis Ababa. A comprehensive review of the literature on the LTE-A network was conducted in order to identify the recently deployed technologies and their limitations. The next step is gathering the necessary relevant data for the LTE-A network parameters and digital map. Based on data collection from ethio telecom network management system by using tools, we identify target deployment working areas. The areas that are considered more interference are limited and high data traffic is generated.

For the selected study area, the candidate location for BSs deployment is to be obtained and configured using the WinProp ray-tracing simulation software tool. Then, the path loss is computed, and using the Matlab static simulation DL LTE-A network system simulation is performed. The simulations were performed to investigate network performance for different CoMP schemes and non-CoMP scenarios. The network performance metrics are SINR, throughput, and spectral efficiency. The results from the simulations are analyzed and the performance of the system is evaluated and reported. A summary of the general methodological stages for the thesis work is illustrated in Figure 1.2.

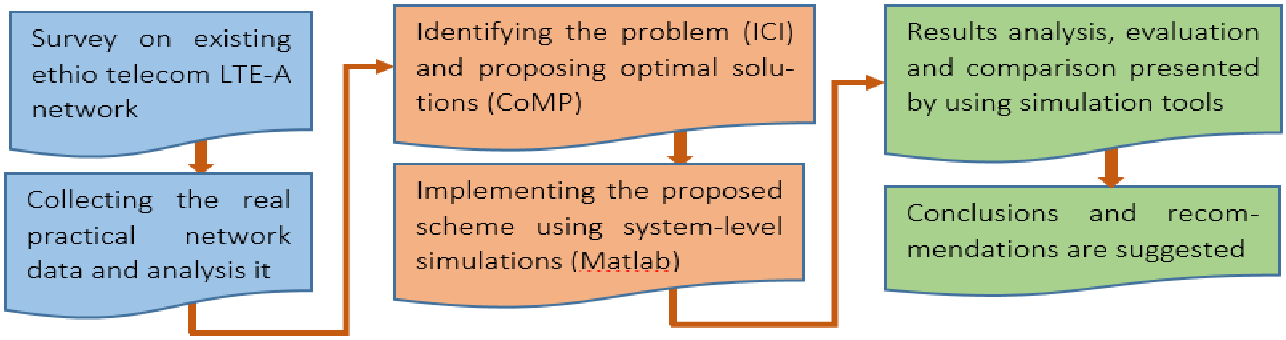


Figure 1.2: Methodology of the thesis used

1.6 Contribution of the Study

In this thesis, the ICI mitigation technique for the CoMP LTE-A network has been proposed. This shows that interference management techniques are key to improving the coverage and capacity performance of a cellular network. The research study contributes to the domain of ICI management techniques that can be achieved by applying the CoMP technique to the ethio telecom LTE-A networks. These techniques are very important for operators because they can address coverage and provide increased DL network performance in terms of users and cell throughput, which results in total network improvements without requiring additional BS investment. Moreover, the study includes the current ethio telecom interference management status and the effect of overall network performance. This analysis contributes by providing insight into the impact of interference and trying to show the performance of different interference management techniques. Besides this, ethio telecom can give more attention to the concept of how interference limits the performance of the network and show a CoMP technique that promises to improve spectral efficiency, enhance throughput and provide better coverage.

1.7 Scope and Limitations

The main scope of this thesis is to study ICI management techniques for improving the overall DL capacity performance of the LTE-A network deployment in the Addis Ababa scenario for selective areas. The technique is carried out by considering the IBS system. These are conducted only on JP CoMP transmission as the vital solution to ICI mitigation techniques.

Furthermore, our simulation considers the ideal backhaul with an infinite capacity of operation in the LTE-A network, where it is difficult to get the full picture of the data traffic on the current network performance and proposed improvements, which is the limitation of the study. The datasets are limited to the LTE-A network DL data service only and use an old digital map of Addis Ababa city for propagation, which is difficult to get the full picture of topography.

1.8 Thesis Outline

The outline of this thesis study work is organized into six chapters. Chapter 2 gives a general overview of the LTE-A network, the interference scenario, and management techniques. Chapter 3 introduces the CoMP transmission and reception technique overview, implementation scenarios, and architectures. In addition, it explains the CoMP types of transmission schemes, their contribution, and the challenges of CoMP. Chapter 4 depicts the system model, key performance metrics, and propagation models are discussed in the system-level simulation network. Furthermore, all the necessary equations for network modeling have been specified according to the standards. The results of the proposed scheme's analysis, evaluation, and comparison with the existing system are provided and discussed in Chapter 5. The simulation setup and parameters are also described. Finally, in Chapter 6, the thesis work's main ideas are summarized, and further research projects are suggested.

Chapter 2

Interference Scenario and Management Techniques in LTE-Advanced Networks

2.1 LTE-Advanced Network Overview

Nowadays, the telecommunications industry has grown explosively [1, 2, 15]. This is due to the technological evolution of mobile networks and devices, such as the availability of affordable application-oriented services. As well as a wide range of services, including web browsing, streaming, and interactive file transfer, has resulted in significant growth in mobile data traffic. In order to meet subscriber expectations, cellular operators must assess coverage and capacity challenges on their existing networks due to the rapid development of mobile data needs. For this reason, there was a need to provide higher peak and sustained throughput, larger user capacity, and greater spectral efficiency in mobile networks. In order to meet these demands, 3GPP developed a new mobile communication standard referred to as LTE. Its aim is to fulfill the international mobile telecommunication advanced requirements defined by the International Telecommunication Union (ITU) [2].

Nevertheless, the data traffic has still increased exponentially [1]. What is offered by LTE is not enough to fulfill all the requirements for these potential demands. To meet this and the ITU's requirements, 3GPP started to study how to enhance the capabilities of LTE [2]. The main requirements were to deliver a peak data rate of 1 Gbps in the DL and 500 Mbps in the uplink. Furthermore, 3GPP keeps working on further enhancements to LTE and the output from the study was a specification for a system known as LTE-A. This is an evolved version of LTE Release 10 and beyond. Which is all about even higher data rates and higher efficiencies. Additional features and refinements to the standard were introduced with Release 11 and Release 12. Release 13 introduced great potential and paved the way for Fifth Generation (5G) technology to emerge. Some of the unique features that are included as part of the LTE-A requirements are Carrier Aggregation (CA), advanced Multiple Input Multiple Outputs (MIMO) with 8x8, CoMP, relaying, and HetNets [2, 10, 15].

2.1.1 Network Architecture

The success of the LTE-A network is due to the advanced technology deployed, as well as the network's design based on completely switching data packets [15]. In Release 8, two important aspects are specified by 3GPP. These are the Radio Access Network (RAN), known as the Evolved Universal Terrestrial Radio Access Network (E-UTRAN), and the System Architecture Evolution (SAE). The SAE includes the Evolved Packet Core (EPC) network, and together with the E-UTRAN, they comprise the Evolved Packet System (EPS). It is designed to support solely packet-based services and is responsible for the seamless connectivity of users with the external packet data network that provides data services. In the context of LTE-A network systems, both the air interface and the radio access network are being enhanced. However, the core network architecture has passed through minor changes from the already standardized SAE architecture [2]. The SAE is made up of a core network (EPC) and a radio access network (E-UTRAN) as shown in Figure 2.1.

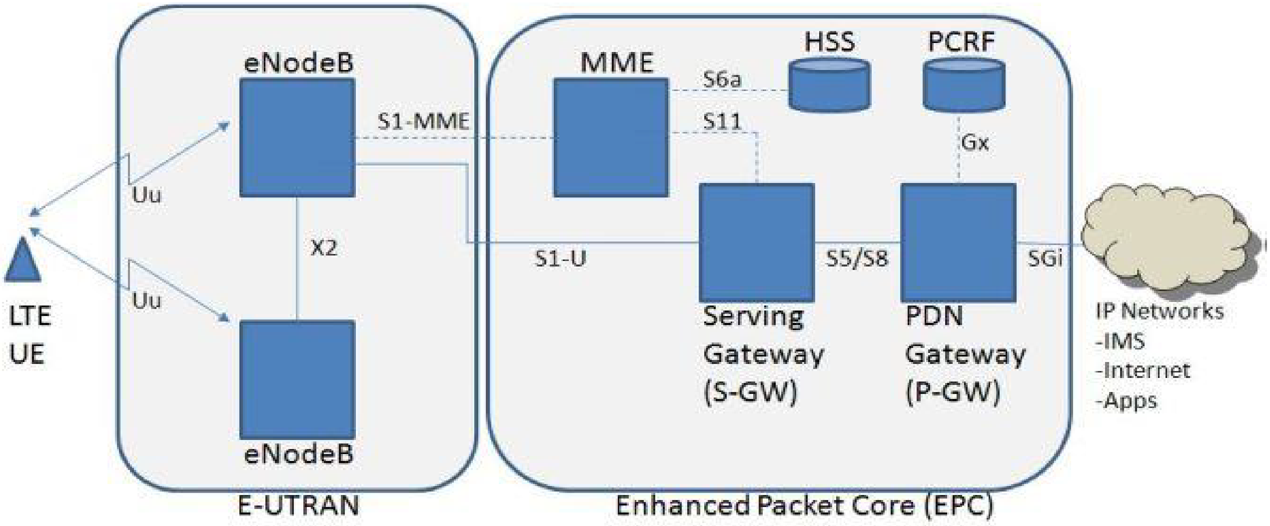


Figure 2.1: LTE-A network architecture [15]

The E-UTRAN is made up of the UE and eNBs as shown in the figure, and the eNB to eNB nodes are directly connected via the X2 linking interface (speeds up signaling processes). The EPC is an all-IP-based core network quantified to support the E-UTRAN with a decrease in the number of network components and simpler functionality, most significantly allowing for connections and handover approaches to other fixed-line and wireless access systems. The EPC comprises the components that are desirable to connect the eNBs to the IP core. The mobility management entity, serving gateway, packet data network gateway, network management system, eNB, S1, and X2 link are the components of the evolved networks.

2.1.2 Frame Structure and Transmission Scheme

For the LTE-A network, DL transmission is based on OFDMA, and a Physical Resource Block (PRB) is the smallest unit of radio resource that can be given to a user for data transmission during packet scheduling [2]. Radio resources are defined as the time-frequency grid resources in the LTE-A network when a short cyclic prefix is used, as shown in Figure 2.2.

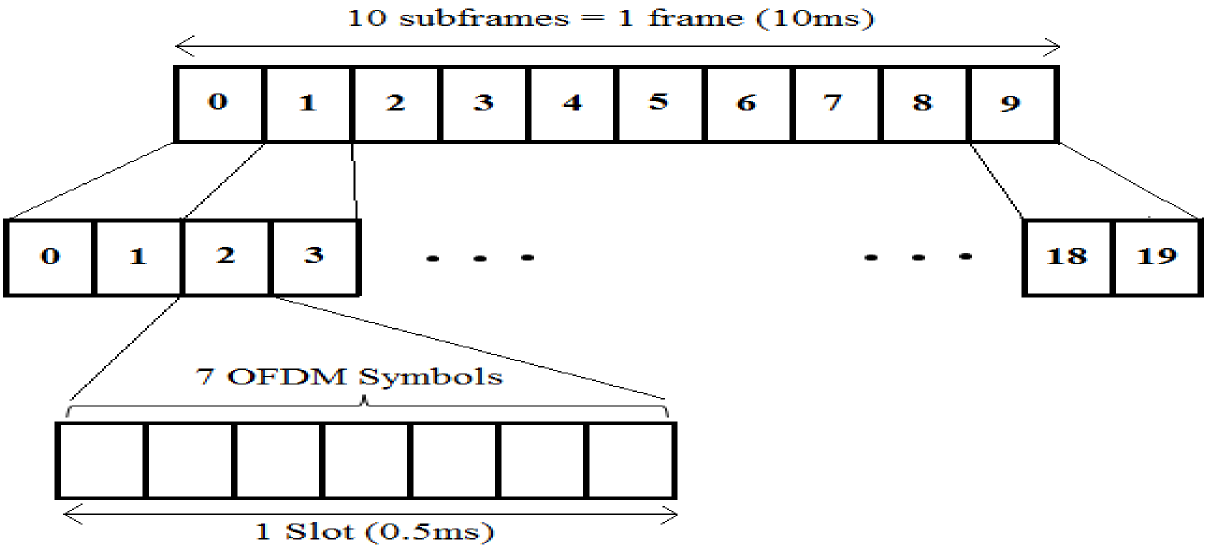


Figure 2.2: LTE-A network frame structure [2]

In the frequency domain, the radio spectrum is divided into a number of narrow subcarriers of 15 kHz spacing. In the time domain, a frame of 10ms duration is divided into 10 subframes of 1ms each. The sub-frames are allocated into 2-time slots of 0.5ms and each time slot consists of 6 or 7 OFDM symbols depending on the length of the cyclic prefix, as shown in the figure. One resource element is a grid of 1 sub-carrier (15 kHz) in the frequency domain and 1 OFDM symbol (0.5ms) in the time domain, while a grid of 12 adjacent sub-carriers (180 kHz) is the minimum bandwidth allocation [15].

The RB is also known as a sub-channel. Depending on the transmission bandwidth, a DL carrier comprises a variable number of sub-channels in the frequency domain. The scheduler resolves which users are permitted to transmit on which sub-channel. It is well known that the least resource-scheduling unit that the scheduler can allocate to a user is comprised of two consecutive RBs and thus spans a whole sub-frame. In addition, the LTE-A network can work on flexible bandwidth as defined in [2], and assign the number of accessible PRBs to be allocated for the UEs shown in Table 2.1.

Table 2.1: Summarizes the different scaling factors for LTE-A bandwidth available

Transmission Bandwidth (MHz)	1.4	3	5	10	15	20
Number of Available PRBs	6	15	25	50	75	100

Moreover, the LTE-A network uses three types of modulation schemes: Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM) on 16-QAM and 64-QAM, in addition to different code rates. Using a low order modulation scheme (QPSK), the eNB guarantees stronger transmission coverage, but with the lowest capacity per bandwidth. On the contrary, with a high-order modulation system (64QAM), the eNB permits a larger data rate with less coverage [2].

2.2 Heterogeneous Network

With the increased use of data-oriented devices, users' high data rate demand is constantly increasing on mobile networks [1]. Where they expect to appreciate outstanding network performance. As a result, advanced solutions are needed to meet the ever-increasing demands using different capacity-enhancing technologies. In particular, users at the cell edge face massive path loss and highly interfered-with signals. To meet these requirements, the deployment of HetNets has emerged as a solution and has been adopted in 3GPP specifications [5]. Multi-antenna technology contains existing macro cells (high power) covered with small cells (low power), known as HetNet [7, 16]. Significant advancements have been achieved in this approach. Hence, the migration from traditional homogeneous macro only networks to the HetNet to achieve optimum spectrum and network efficiencies.

A HetNet is composed of several layers of networks of different cell sizes containing a combination of macro nodes and low transmit power nodes. Such BSs have a reduced transmit power (typically 10–20 dB) [5, 17]. The small eNBs are customarily used in offices, shopping malls, sports, and hotspot areas to offload traffic from the macro layer and to bring the user closer to the BS node to improve the data rate. Small cells can be deployed either at a different carrier frequency than macrocells or at the same carrier frequency. In the same carrier scenario, interference is highly limited [6, 18]. A comprehensive overview of typical HetNet deployments is shown in Figure 2.3.

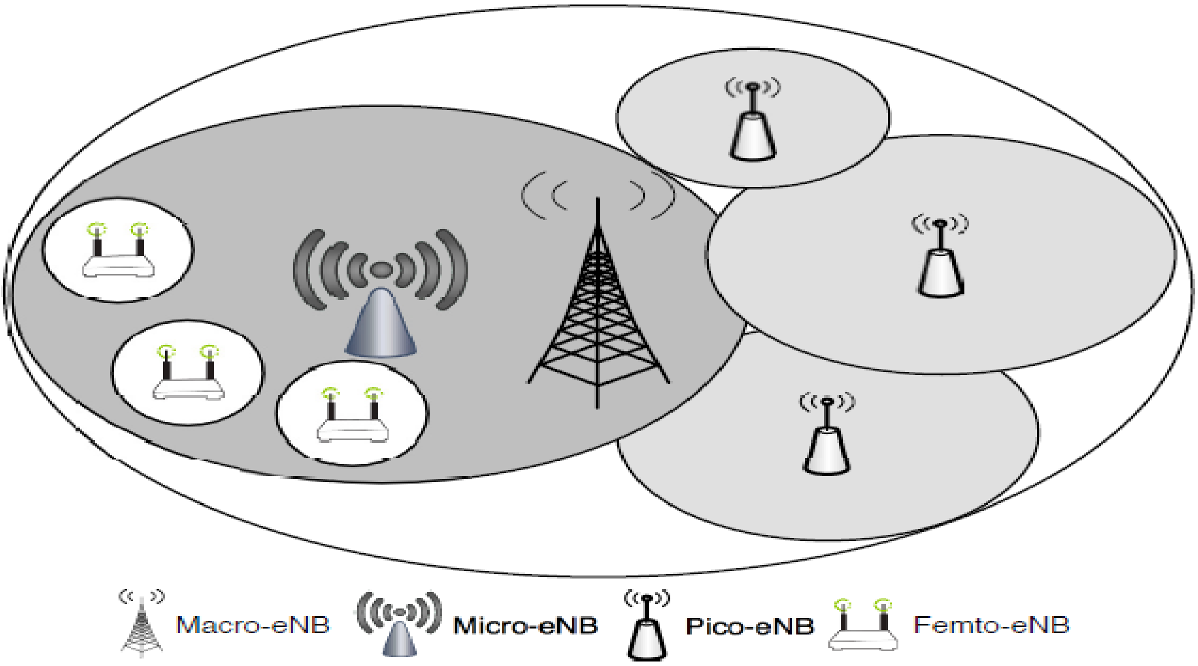


Figure 2.3: Heterogeneous networks consist of Macro, Micro, Pico, and Femto eNBs [18]

Based on the figure and 3GPP standardization, HetNet consists of the following elements [18]:

Macro cell: It is a conventional operator-installed BS network architecture. The transmit power consumption is greater than 40dBm and the area covered is about a few kilometers.

Micro-cell: A cell in a mobile phone network served by a low-power eNB (inter-site distance of 250m), covering a small area such as a mall or an airport.

Pico cell: It has the capability of providing a coverage area of 300m and is used to serve a small number of users. It is used to increase the capacity and coverage with a power of 30dBm.

Femtocell: Considered as low-power user-deployed access points, which use consumers' broadband connections for data traffic offloading on digital subscriber lines. The area of coverage of a femtocell is less than 50m and the transmitting power is less than 23 dBm.

Relay: Operators' deployed access points are used to improve the signal strength in poor coverage areas, inside tunnels, and on cell edges, depending on their position in the existing network.

Remote Radio Heads (RRH): They are high-power, compact-sized, and low-weight units that are associated with a conventional macro BS. This is done with the assistance of fiber.

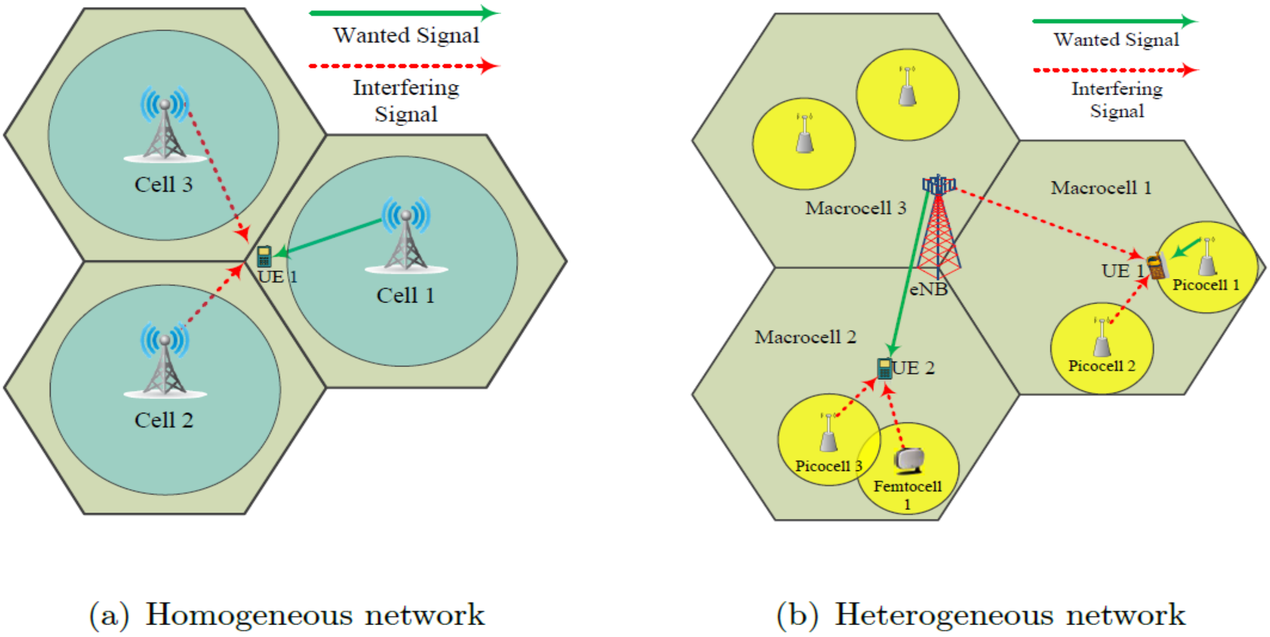
DAS: DASs are in the midst of a transformation from pure coverage to a joint coverage and capacity solution. It is now morphing to encompass concepts like single MIMO and multiuser MIMO, where antennas can transmit mutually independent signals [19].

2.3 Interference Scenarios in the LTE-A Network

Interference is the possibility of receiving undesired signals as they travel along a channel in different network technologies between a transmitter and a receiver [6, 20]. It is a result of the superposition and broadcast nature of wireless transmission, along with the spectrum shared among multiple cells. In a conventional cellular system, the BS is located in the cell center and serves only the users in its coverage area. As evidenced by the planned use of HetNets in LTE-A, simultaneous use of the same spectrum in different layers and the cell sizes are expected to be reduced, which implies more interference-limited [18, 21]. Signal quality is quantified by SINR, which is high interference leads to low SINR, meaning the low quality of the wanted signal. Thus, interference is a major limiting factor in the performance of cellular networks, like capacity, coverage, and increased dropped calls.

The sources of interference are created by colocated BSs or neighboring BS cell sites transmitting various carriers on the same frequency band. It is more severe in urban areas due to the greater radio frequency noise floor and a greater number of users and BS. Two types of interference are mainly distinguished in LTE-A networks [6, 22]. Such as intra-cell interference that happens among users of the same cell in one BS and the ICI that happens when the UE receives signals that are used for the same resources from different BSs. The LTE-A networks are highly reduced in intra-cell interference due to the use of OFDM, which guarantees orthogonality. However, ICI remains a challenge that limits system performance, especially for cell-edge users, since these users have higher overlapping areas and are more susceptible to intervention. Depending on the geographic areas of the network infrastructure, interference situations happen between macrocells, small cells, and macro and small cells [18, 21, 22], as shown in figure 2.4.

Homogeneous networks and high power and low power nodes (HetNet) that use the same frequency, as shown in the figure. Therefore, HetNets present more complex interference scenarios than homogeneous networks [18]. In homogeneous networks, a UE connects to a cell based on the maximum Reference Signal Received Power (RSRP) by the surrounding cells. All the nodes have the same transmission power, so the signal received with more strength usually has lower path loss. However, because HetNets use different transmission powers, a transmission point signal received in a terminal with greater strength may have a higher path loss than another low-power node signal. As a result of the transmit power imbalance between cells of different classes in the HetNets, most UEs tend to choose the macro cells as their serving cells. Due to the high transmit power, leaving the small cell is underutilized.



(a) Homogeneous network (b) Heterogeneous network

Figure 2.4: Different inter-cell interference scenarios [22]

In the case of ethio telecom LTE-A networks in Addis Ababa, such as Meskel Square, Bole, and Megenagna, are the locations of macro BSs, and DAS sites are very closely deployed. Such a deployment can support the increasing traffic to a certain magnitude by guaranteeing suitable signal coverage over the serving area. However, interference significantly increases and affects the capacity of the network [8]. While closely examining the spatial data traffic distribution of BSs, it reveals that BSs with high data downloads are neighbors to each other with a minimum Inter-Site Distance (ISD) of less than 250m. For a situation of this kind, ICI is highly limited and the gain from further densification with macro BS is limited. Therefore, careful management of this interference is very important to improve system performance [23].

2.4 Inter-Cell Interference Management Techniques

Interference management in a mobile cellular network is a non-trivial task and plays an important role in achieving the optimal overall performance enhancement of the network [6, 24]. As previously stated, ICI is a key concern in cellular mobile communication systems and has been one of the main factors in good Quality of Service (QoS), so it is necessary to reduce it. This would enable mobile networks to increase the capacity of the system without degrading the users' quality of service. As a result, in order to obtain the best system performance, it is critical to understand and mitigate interference.

The methods of mitigating ICI can be classified as interference randomization, interference cancellation, and interference avoidance [25]. In interference cancellation, the interfering signal is regenerated over signal processing is subtracted from the received signal (desired + interference). Despite the fact of achieving high capacity, the implementation of interference cancellation in mobile systems may result in high process complexity for estimate planning, power control, and antenna planning. As a result, interference mitigation has gained more attention to prevent interference before its occurrence. This mitigation can always be achieved by using frequency spectrum bands, which should be carefully utilized to achieve higher capacity as a minimum level of ICI is preserved for particular areas. Because of their strong backward compatibility and ease of implementation, the majority of interference management operations in LTE-A network systems are carried out on the network side [26, 27].

In particular, 3GPP proposed different specific classification standards and criteria for interference management techniques in cellular networks. Most of the interference management techniques are designed in combination with resource allocation systems. To find a novel solution to this research problem, an extensive study was necessary of the state-of-art solutions, analyzing their advantages and their limitations. From the literature, several ICIC schemes were found to solve the problem of ICI, based on different air interface technologies [18, 21, 27]. Some of which are discussed in the below subsection.

2.4.1 Inter-Cell Interference Coordination (ICIC)

ICIC is standardized by 3GPP and aims at reducing interference for cell-edge users. The main idea of ICIC is to use different radio resources for cell-edge users than those used for cell center users [28], as shown in Figure 2.5. To provide the necessary received signal, a coordination technique is required to make a decision on the maximum power. The UE calculates the maximum tolerable ICI, target SINR, and the noise power, to measure the maximum power and the RB index that can be used by any conservative cell. One of the main challenges is how to maintain the required throughput of all attached UEs when using different power allocations on the same RBs [22]. The following techniques are used by ICIC to assign frequency [25, 28]:

Hard Frequency Reuse: This method is based on the notion that neighboring BSs have distinct resource scheduling policies. Therefore, throughout the cell, at a given time they will not be using the same resource.

Soft Frequency Reuse: In this technique, frequency reuse with factor 1 is used in the central region of a cell. However, in cell edges, a factor greater than 1 is used, as shown in the figure.

Fractional Frequency Reuse: The principle of this technique is that all frequency resources are used in each cell. The condition that must be checked in this technique is that a frequency band used at the center of a given cell will be used at the edge region of its neighboring cell.

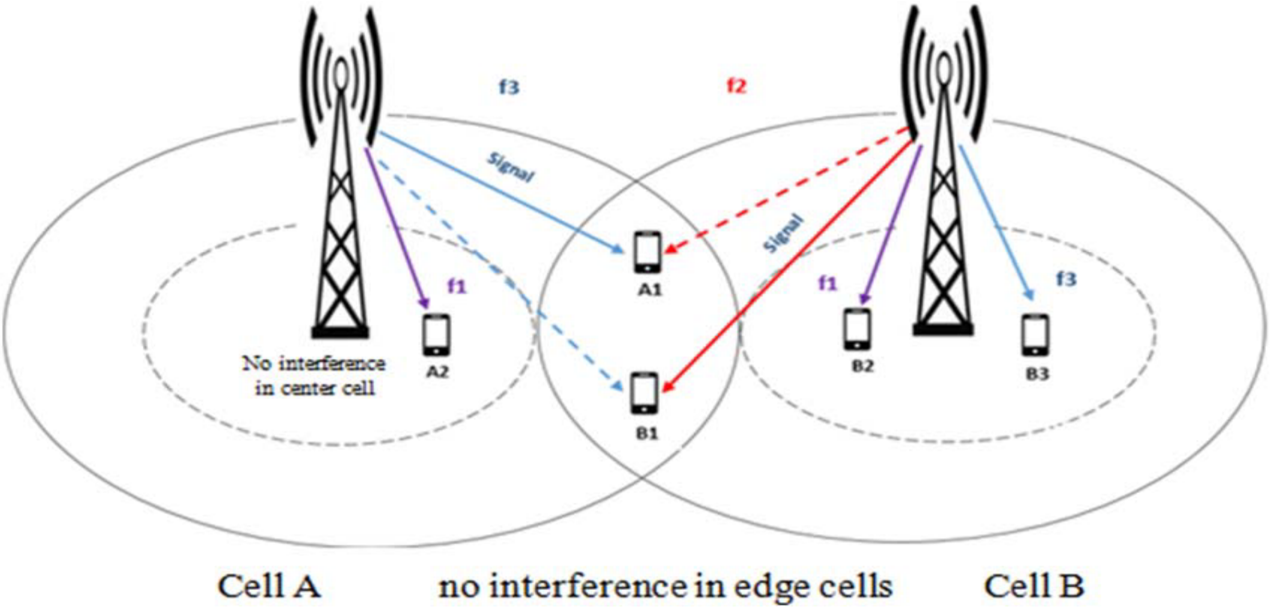


Figure 2.5: ICIC concept with the same frequency resource [11]

2.4.2 Enhanced Inter-Cell Interference Coordination (eICIC)

Traditional ICIC techniques may not always be suitable in the case of HetNets because their design implicitly presumes that deployments will be homogeneous. In the framework of the LTE-A network, eICIC techniques are adopted that take into account the heterogeneity of the network. A good introduction to eICIC can be found in [24, 27] and the types of eICIC are:

Power Control Techniques: These approaches differ from those employed in macro cells in that they regulate the power of small cells. The control of the power is carried out by taking into account parameters such as the power received by a small cell from the strongest interfering macro cell, the path loss, and the SINR of the macro cell and the small cell users.

Time-Domain Techniques: The time domain-based ICIC schemes rely on reducing the transmission activity on certain subframes by each of the cell layers to minimize interference. Time-domain ICIC is considered as one of the most promising ICIC schemes to employ for the LTE-A network because it is appropriate to implement and can successfully improve the ICI on both the data and control layers. These techniques are based on the Almost Blank Sub-frame (ABS) concept [21], as shown in Figure 2.6 (a).

Frequency-Domain Techniques: The goal is to schedule the control channels and reference signals at lower bandwidths in order to carry out orthogonal user transmissions of the affected cells. These techniques are based on carrier aggregation. The concept of carrier aggregation in the LTE-A network HetNet is to partition the available spectrum into separate component carriers, which are a primary (f1) and a second (f2) component carrier [11]. Therefore, f1 is assigned to the macro cell and f2 is the small cell layer illustrated in Figure 2.6 (b).

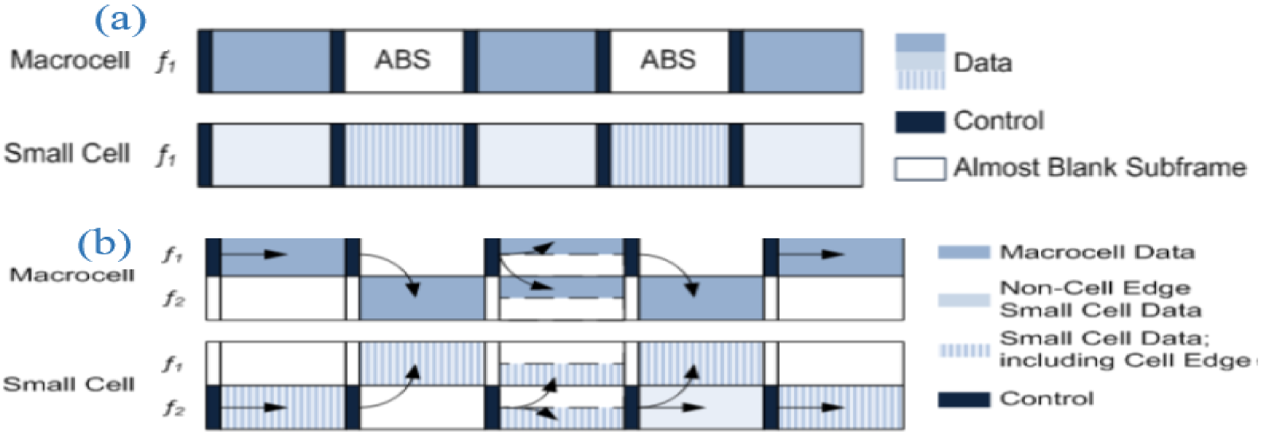


Figure 2.6: Time-domain technique (a) and frequency-domain technique (b) [11]

ICIC reduces inter-cell interference by allocating different frequency resources (RBs) to UEs at the cell edge. eICIC, on the other hand, does the same work in the time domain by allocating different time resources (sub-frames) through HetNet technology collaboration between macro cells and small cells. The ICIC and eICIC approaches present some limitations, which can not actually improve their throughput. That is because they restrict radio resource usage in the frequency domain (ICIC) and time-domain (eICIC) to mitigate interference. Hence, fast-changing channel conditions are not performed and are limited in the case of dynamic interference [11, 22, 28]. CoMP, recognized as the most advanced ICI mitigation technique by using inter-cell cooperation technology so far, will be discussed in detail in the next chapter.

Chapter 3

Coordinated Multipoint Transmission/Reception System

3.1 Overview of the Coordinated Multipoint Technique

A coordination technique between more than one cell sector in 3GPP standardization is called CoMP transmission/reception [4, 29]. The goal of coordination is to make the nodes or users in the network cooperate with each other to transmit, forward, or receive information using different technologies to mitigate ICI and increase received signal power. As mentioned in Chapter 2, the ICIC and eICIC approaches present some limitations in the case of saturation. When the terminal number grows, it induces a serious issue with throughput reduction and is limited in the case of dynamic interference. Because of this limitation, CoMP is the optimal solution proposed by the 3GPP standard for LTE-A technology [7, 30]. To improve spectral efficiency, it employs radio resources not only in the frequency/time domain but also in the spatial domain under both homogeneous and heterogeneous networks. CoMP is a major performance enhancement feature that aims to achieve LTE-A network standard throughput at the cell edges by coordinating transmission and reception [31].

The main concept of the CoMP ICI mitigation technique is to enable dynamic coordination of transmission and reception over two or more BS to turn the interference problem into a useful signal or mitigate it without changing the BS parameters and existing locations [32, 33]. This technology requires the network to collect Channel State Information (CSI) from the distributed transmission points to the UE and smart radio resource management and multipoint collaboration are performed. Several techniques are available for the CoMP technique, but all the approaches require sharing some scheduling information regarding the UE data with coordination BSs. This sharing results in increased complexity and signaling overhead on the X2 interface [34]. To reduce signaling overhead, these constraints are quantized and transmitted to eNB targeting [35]. In the CoMP system, to indicate the possible channel states in both transmitter and receiver, a set of pre-defined precoding matrices are used [30].

3.2 Coordinated Multipoint Architecture

The CoMP architecture depends on the way eNBs perform coordination among them. The implementation of CoMP has a large impact on the architecture of the LTE-A network radio interface and affects the performance of network systems. Two main CoMP network architectures are typically considered [4]: centralized and distributed as shown in Figure 3.1. This thesis work emphasizes the centralized CoMP architecture.

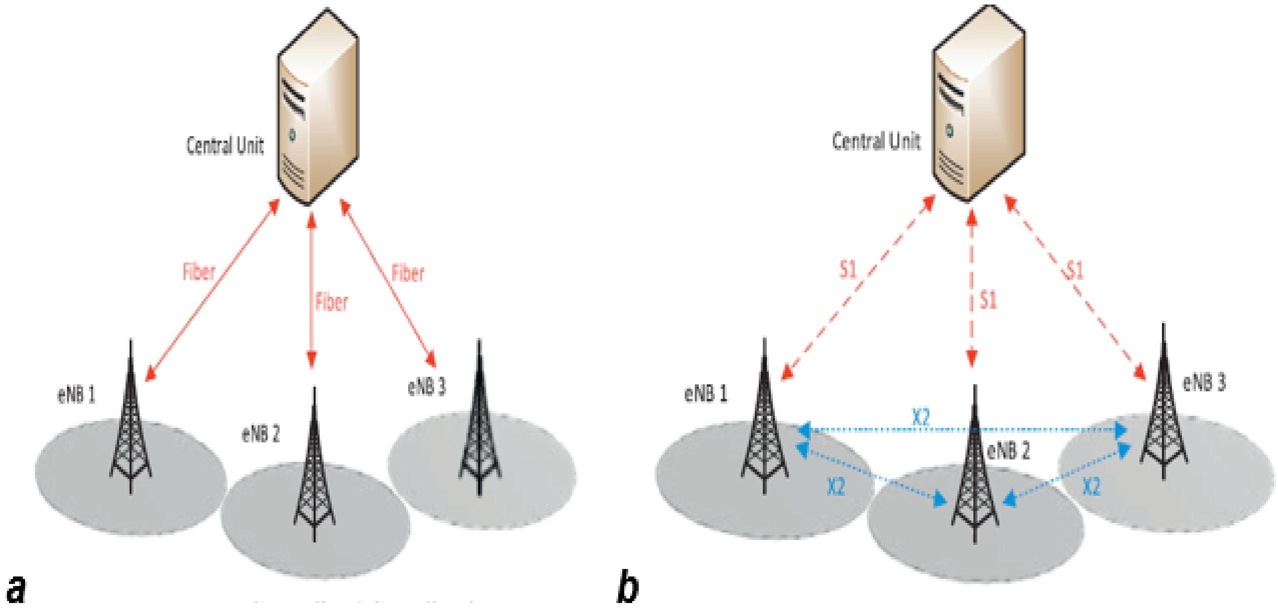


Figure 3.1: CoMP for centralized architecture (a) and distributed architecture (b) [4]

Centralized Architectures: All administration tasks are controlled by a central unit called centralized coordination, as shown in Figure 3.1 a. Advanced resource management and scheduling techniques are executed, and CSI, along with user information, is transmitted in the star-like structure to the targeted eNB. The central controller is connected to multiple BSs via backhaul links in the case of a centralized CoMP for the use of feedback information from different eNBs [36]. Based on the gathered channel matrix, the CU constructs a precoding matrix or designs scheduling decisions for the CoMP scheme to reduce ICI. The designed precoding/scheduling decisions are then forwarded to cooperative BSs. Finally, the coordination of eNBs is set to transmit information to their serving UEs as per CoMP techniques. However, the major drawback of this architecture is the delay factor and large backhaul overhead, which are the main significant concerns of the design [4].

Distributed Architectures: In the case of utilizing the X2 interface over a mesh-based architecture, it is called distributed coordination, as shown in Figure 3.1 b. In this methodology, one of the cooperating eNBs in the cluster serves as a master cell, performing all resource management and communication functions [37]. While the other coordination eNBs behave as if they are slaves. For the CoMP case, each BS based on the information exchanged with neighboring eNBs individually makes decisions. Transmission points based on the CSI received from their cooperating eNBs do the scheduling process independently. The UE sends all the CSIs to all the cooperating cells. In this case, high coordination gains are achievable at the expense of high computational complexity and large signaling overhead. This architecture requires significantly less information exchange with lower coordination gains relative to the centralized one [38].

3.3 Coordinated Multipoint Deployment Scenarios

The CoMP deployment scenario depends on the way eNBs cell coordination is handled in the geographical location. According to the locations of the cooperating eNBs, CoMP technology is classified into two types, namely intra-site, where the cooperating sectors return to the same eNB, and inter-site, where the cooperating eNBs occupy different geographic locations [14, 29]. CoMP deployment scenarios depend largely on what the operators need. The general possible deployment scenarios are illustrated in Figure 3.2. From the figure, we see that the two most important topologies for CoMP deployments are homogeneous and heterogeneous networks.

CoMP in Homogeneous Deployment: CoMP evaluations can be performed in two ways in this deployment:

- Scenario 1: Homogeneous networks with intra-site CoMP.
- Scenario 2: Homogeneous networks with high transmit power RRHs (inter-site CoMP).

The CoMP deployment of a homogeneous network on the intra-site is shown in Figure 3.2 scenario 1. The coordination area is among the cells of their own eNB. In such a deployment, where all the coordinating cells are colocated and the cells do not require any interface, the performance of CoMP would be faster. The inter-site CoMP deployment of the homogeneous network, as shown in Figure 3.2, scenario 2. The coordination area is between different eNB and the distributed RRH, which are connected to their eNB via optical fiber.

CoMP in Heterogeneous Deployment: Two options for CoMP evaluations in this deployment:

- Scenario 3: Heterogeneous networks have different cell identities.
- Scenario 4: Heterogeneous networks with low transmit power RRHs within the cell coverage have the same cell identities as macro cells.

Figure 3.2 scenario 3 shows a heterogeneous deployment scenario of low-power nodes (small cells) within a cell having different cell identities. Figure 3.2 scenario 4 depicts a situation where each of the low-power nodes has the same cell identity as that of the macrocells (eNBs). In this scenario, there are three kinds of technologies, such as relay, DAS, and multi-cell coordination. DAS could resemble a CoMP scenario with the antennas or RRHs being geographically distributed. However, the important aspect to note in DAS is that with distributed antennas, the propagation distance is reduced. Hence, DAS is a competing technology compared to fixed relays and small cells [19]. The primary goal of DAS is to achieve coverage and then throughput. While the coverage is available, the throughput is limited due to interference, and CoMP enables us to overcome this interference [39].

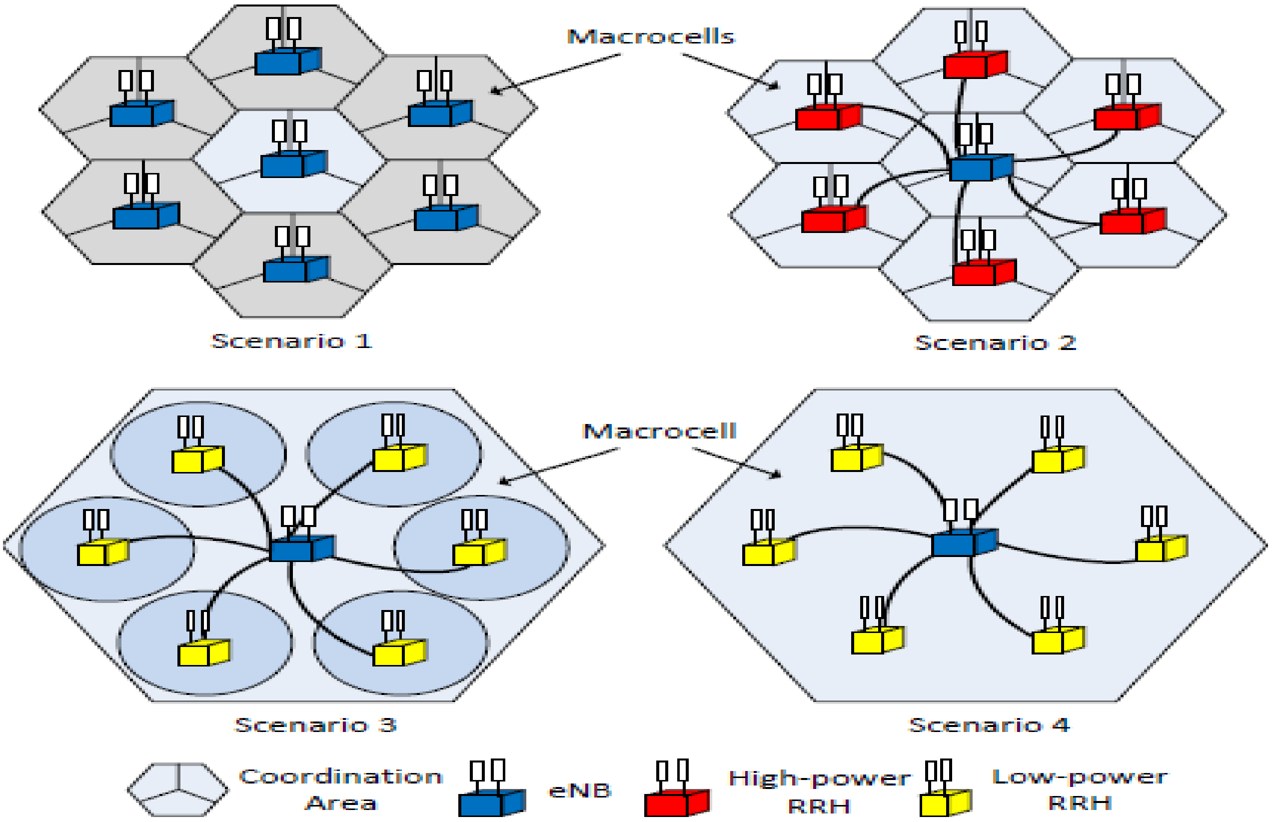


Figure 3.2: CoMP deployment scenarios in the 3GPP LTE-A networks [29]

3.4 Coordinated Multipoint Transmission Schemes

3GPP visualizes different possible CoMP transmission schemes in the LTE-A network that are intended to mitigate ICI with better network capacity at the cell-edge areas [30, 40]. When the eNB sends information to UE, it applies one of the connected CoMP transmission types dependent on the degree of coordination among cells and the active load. For CoMP transmission techniques, we can retain a classification of CoMP methods into two categories [4]: DL CoMP techniques and uplink CoMP techniques, as shown in Figure 3.3. The CoMP techniques for the DL and uplink are quite similar but with little difference, which results from the fact that the eNBs are in a network, connected to other eNBs, whereas the UEs are separate components [14, 29].

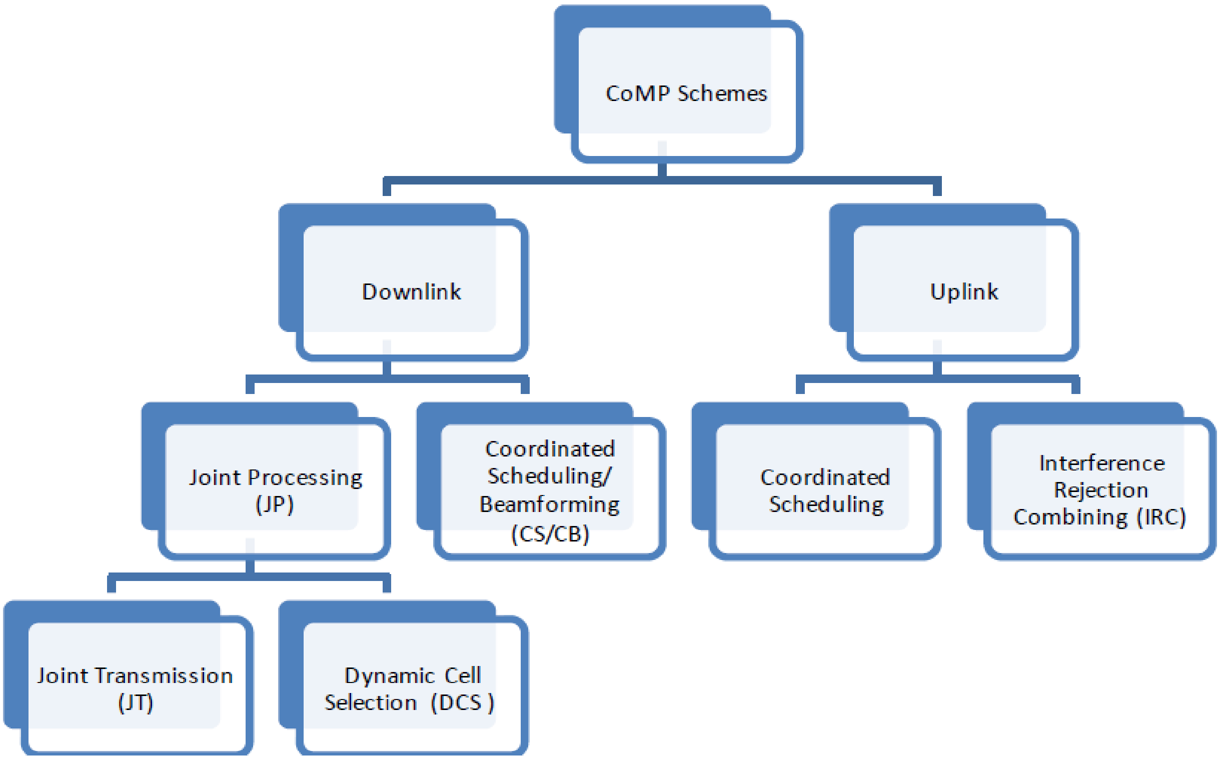


Figure 3.3: Different types of CoMP transmission schemes

3.4.1 Downlink Coordinated Multipoint Transmission Schemes

DL CoMP techniques imply dynamic coordination among numerous geographically separated transmission cells into a single UE. This will result in an increase in the received signal power and a decrease in the interference power at the UE [41]. According to the 3GPP standard, DL CoMP schemes are classified as CS/B and JP.

A. Coordinated Scheduling/Beamforming

CS/B involves coordinating transmission decisions between the transmission points by sharing control information to reduce the interference levels. In CS/B, data for a UE is only available at and transmitted from one point in the time instance [37, 42]. However, based on the channel condition, decisions for selecting the transmission point are made in coordination with the multiple transmitters in the cooperating set with different angles of beams. It dynamically prevents transmission at a certain time-frequency resource in a cell to reduce the interference that will be experienced in other cells. Figure 3.4 shows the principle of CS/B.

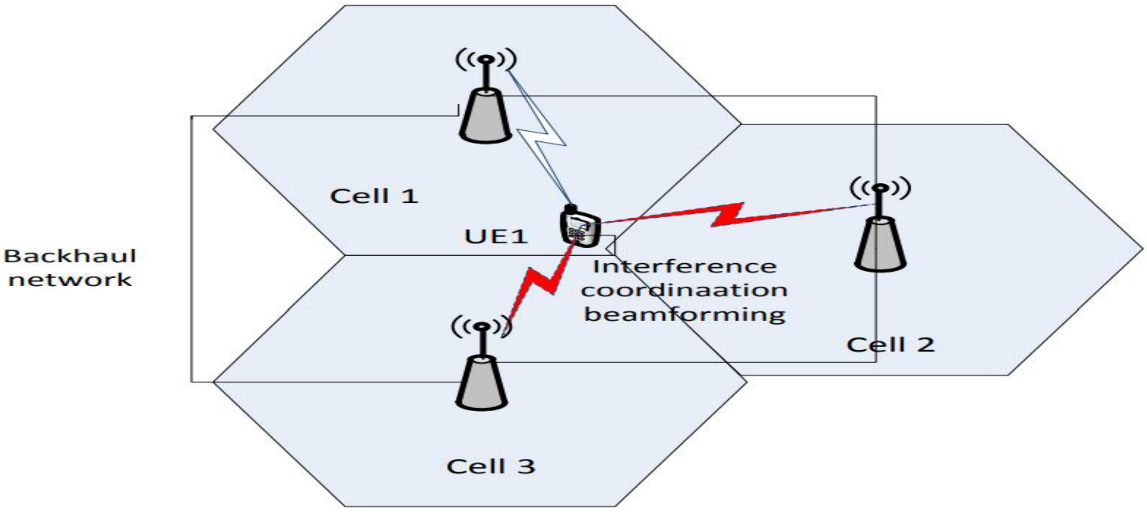


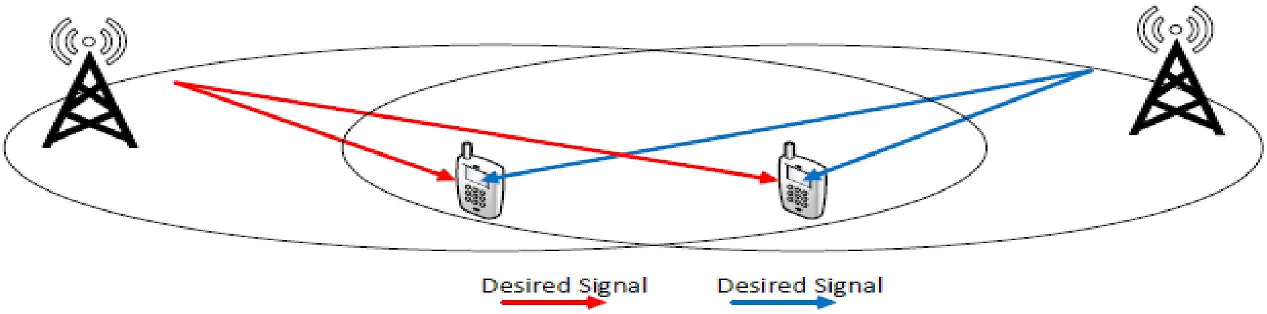
Figure 3.4: Downlink coordinated scheduling/beamforming [42]

B. Joint Processing

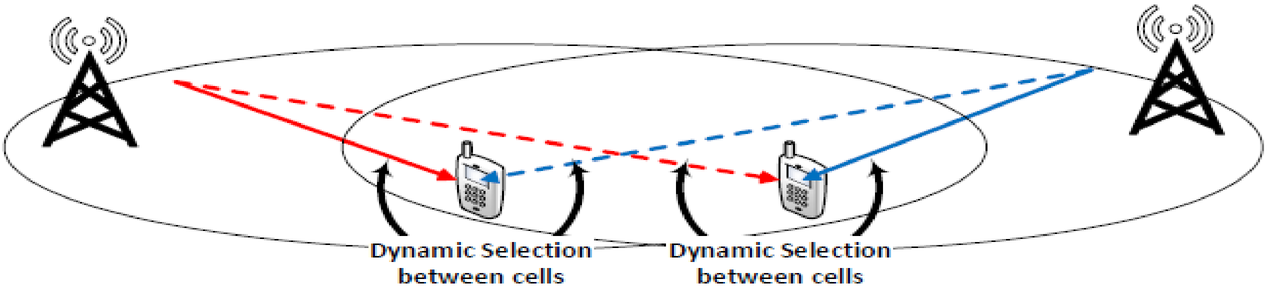
In JP CoMP, for a particular time-frequency resource scheduling, both data and control information for UEs are available at several points in the cooperating sector sizes [12, 29]. JP CoMP is the most advanced CoMP scheme that improves throughput, data rate and spectral efficiency, particularly for cell-edge users. Here, data for a UE is available at more than one point in the coordination, providing higher throughput of the system than CS/B [13, 43]. In terms of cooperation mechanisms, JP CoMP is sub-classified into two main groups shown in Figure 3.5, namely Joint Transmission (JT) CoMP and Dynamic Point Selection (DPS) CoMP [30].

JT: In the JT CoMP, multiple BSs in the network cooperatively transmit signals to a user end terminal, as shown in Figure 3.5 (a). The data intended for a UE is shared and jointly transmitted from all BSs in the CoMP network and the received signals at the UE will be added up together. The main idea of this class of transmission scheme is that the interfering signals from coordination cells are transformed into useful signals. This increases the power of the intended received power signal. At the same time, they decrease the level of interference. According to the CSI report, the transmission modes are further classified into two types: coherent JT CoMP and non-coherent JT CoMP [35].

DPS/muting: It is a special JP CoMP scheme in which UE's have the opportunity to reselect serving BS from the coordination set based on the highest received signal power, as shown in Figure 3.5 (b). The UE dynamically selects the greatest serving BS for the next frame and reports it to all cooperating BSs of the CoMP established. Dynamic Point Blanking (DPB) selects BS with the highest average received power. DPB is usually employed in conjunction with DPS so that both the serving point and blanked points are selected dynamically [44]. After a UE is identified as a victim UE, the BS sending the highest power signal is set to be the transmitter, and the BS with the other sectors blanks those resource blocks at the same time. Consequently, the received signal power is maximized due to the absence of interference received from other cells. Furthermore, because of the lower volume of transmission, the backhaul network requirements were greatly reduced [40].



(a) Joint Transmission (JT)



(b) Dynamic Point Selection (DPS)

Figure 3.5: Downlink JP CoMP types for LTE-A network [30]

3.4.2 Uplink Coordinated Multipoint Transmission Schemes

In uplink CoMP, the different reception points coordinate in order to receive the signal from a UE. It is categorized into Joint Reception (JR) and CS [29, 42]. Figure 3.6 shows the basic principle of uplink CoMP for JR and CS.

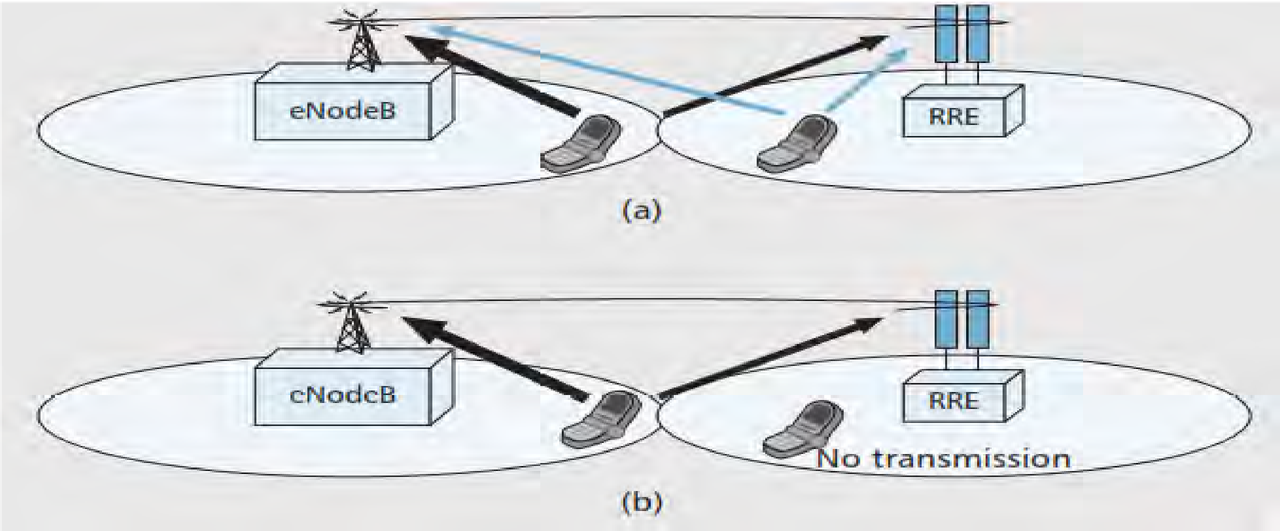


Figure 3.6: Uplink CoMP Joint reception (a) and coordinated scheduling (b) [42]

Joint Reception: In JR, the multiple reception points receive the signal transmitted by a UE as shown in Figure 3.6 (a). Then the signals from the different reception points are jointly processed to produce better performance for the final output.

Coordinated Scheduling: In uplink CS, UE scheduling and precoder selection decisions are made with coordination among the multiple reception points in the CoMP. Only one reception point is used to receive the signal from a UE, as shown in Figure 3.6 (b). In CS, only CSI and user scheduling are exchanged among the cooperating cells.

3.5 Coordinated Multipoint Advantages

Through coordinating and combining signals from several antennas, CoMP enables UEs to benefit from high-quality services and consistent performance when they access and share videos, photos, and other high-bandwidth services [4, 34, 45]. Whether they are far from the center of the BS or around the cell border. We can summarize its main advantages as follows:

- BSs coordination is considered an effective solution to increase the system performance and signal level in the UE. That improves the total system performance as well.

- Interference mitigation: Coordination between BSs converts undesired signals from conventional networks into useful signals or avoids them properly. This is used to enhance the network performance.
- Network utilization: BSs that are exchanging channel information using CoMP can send the data streams through the BS that has the lowest traffic load.
- Enhancing the spectral efficiency: Cell edge UE spectral efficiency will be increased after applying CoMP due to receiving desired signals from more than one BS.

3.6 Challenges of Coordinated Multipoint Deployment

Before receiving the performance gain by CoMP, various implementation challenges have to be considered. These are demonstrated and have been shown by different simulations and fields [4, 14]. The most common challenges in implementing CoMP are discussed in the below subsections.

3.6.1 Clustering

In a practical implementation of CoMP, only a limited number of BSs can coordinate transmission to a UE. This is because serving all UE with the best set of cells is unfeasible due to the backhaul problem and the amount of feedback required [30]. Therefore, the network is divided into multiple clusters and a UE can only communicate with the cells in a cluster. To overcome the signaling overhead resulting from a large cooperating set, clustering was introduced. Once applying the different CoMP approaches, different BSs operate together to choose the best possible channel for data sharing by mitigating interference. The size of the cluster should not reach the threshold level of backhaul capacity and feedback; otherwise, it causes a delay in the system performance [4]. The cluster techniques are static or dynamic. Static clustering requires little signal overhead and is less complex compared to dynamic clustering. A major disadvantage for a given UE with a static cell clustering mechanism occurs when the cells that have the strongest link gain may not lie in the same cluster, which causes strong interference and dynamic clustering solves these issues [9].

3.6.2 Synchronization

Another significant problem is the synchronization of cooperating serving devices [4]. In order to avoid ICI, cooperating BSs should be synchronized both in the frequency and time domain. Precise synchronization simplifies the scheduling of communication resources and interference avoidance in multi-access networks. The techniques can be used separately or in conjunction to facilitate the establishment of a common notion of frequency and time to a desired level of accuracy. Several types of synchronization techniques in the CoMP network are elaborated upon [13]. They can be either jointly or separately applied to ensure synchronization.

3.6.3 Channel Estimation Feedback

Accurate channel estimation is the basis for any CoMP transmission scheme [4]. Precoding accuracy is influenced by channel estimation, which sets an upper limit on potential performance benefits. The CoMP scheme faces a high number of channel components to be estimated, and high sensitivity of joint precoding with respect to estimating errors combined with the need for frequency-selective transmission systems. The accuracy of channel knowledge indirectly affects the performance of CoMP [37]. Especially in the downlink, as it leads to CSIs being at the same level of accuracy that is subsequently regarded as a reference for precoding like phase/amplitude adjustment (JT) or coordinated decisions (CS/B).

3.6.4 Backhaul

In terms of practical implementation, the availability of an ideal backhaul with zero latency path links is not possible. The term non-ideal backhaul link is used to describe this kind of path, which is one of the most significant limitations of CoMP transmission [46]. These schemes utilize the subsets of UEs along with a joint transmission strategy, which divides the network into little subsystems. Based on different types of CoMP schemes, the backhaul requirements may vary. Either alleviating the amount of exchanged data or applying an advanced backhaul technique is the way to overcome the backhaul challenge. Depending on the existing infrastructure of a mobile operator, both the backhaul capacity and latency requirements are the principal cost drivers on the road map towards some CoMP schemes [12, 13].

Chapter 4

System Model

4.1 Model Overview

In this chapter, an overview of the development and implementation of the model is presented in detail for simulation procedures. A simplified representation of a system as processes, mathematical formulations, and implementations is designed to assist in the study of the real system. The actual distribution of BS in the Addis Ababa LTE-A network and the topography of the city are used for the study of the JP CoMP system, which is proposed to overcome the ICI problems. We consider the physical layer of the DL LTE-A network for FDD operation where the transmission scheme is OFDM. The network is designed and deployed to provide users allocated to a BS based on the received signal strength. Thus, in order to achieve the simulation objective, the system process is organized as a method and ingredients as shown in Figure 4.1.

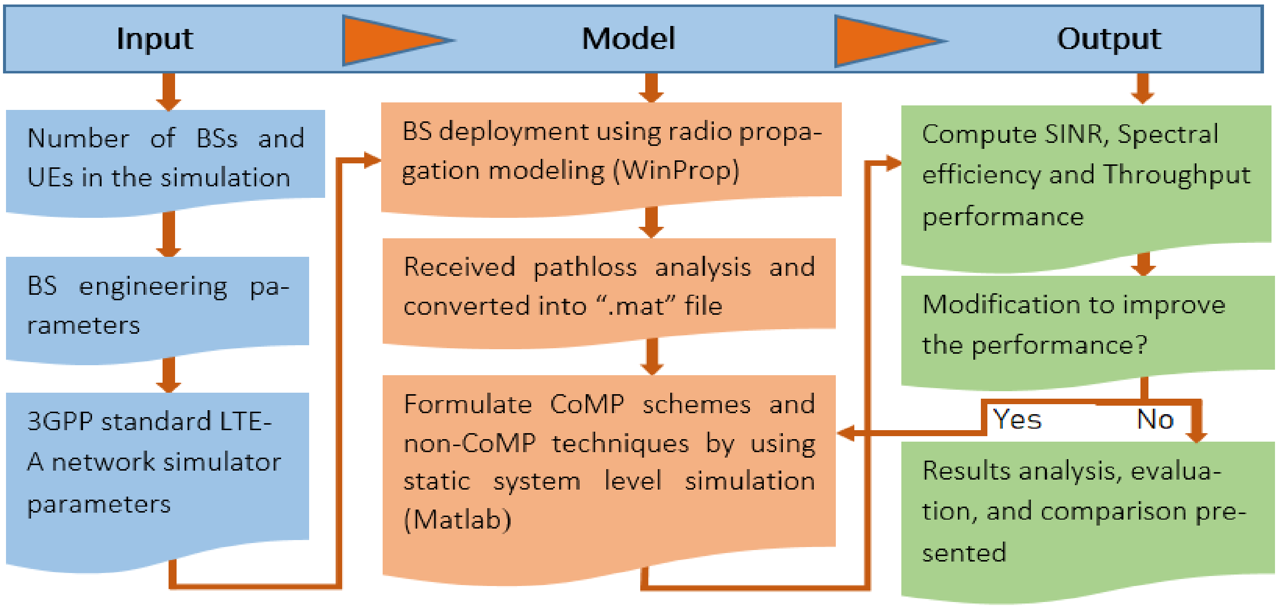


Figure 4.1: System model overview approach for simulation procedure

The figure shows the system model overview and the model reads input parameters. These are propagation model parameters, antenna specifications, frequency bands, and the maximum number of BSs that can be linked simultaneously.

4.2 Network Simulation Tools

The simulation study focused on DL LTE-A network performance. The radio coverage estimations are based on realistic three-dimensional building vectors and geographical data. Wave propagation models are obligatory to determine the propagation characteristics of mobile radio system implementations. To do so, the practical realistic networks are based on a software called WinProp. The Winprop is a planning and design software tool that includes the prediction of the received power and path loss [47], in order to determine the BSs' performance. For this simulation, Winprop was used to predict received power and path loss. ProMan is the software package that is used by WinProp for this purpose.

The WinProp propagation models are three-dimensional, consider 3D object data, and compute all rays. The propagation models include the COST 231 Walfisch Ikegami model, the Urban Dominant Path (UDP) model, and the 3D Ray Tracing model. In order to accelerate the time-consuming path determination, the intelligent Ray Tracing model can be utilized, which is based on a single pre-processing. For pure predictions of radio coverage, the urban dominant path model can be applied, which combines high accuracy with short computation time [48]. An accurate propagation model is required to predict the coverage and interference of a cellular network that can show the performance of the real network. Therefore, in this thesis, the UDP model is used for modeling the propagation. The UDP model was selected because it combines the accuracy of the ray optical propagation models and the speed of empirical models.

System-level simulations are required to create a model of a complex mobile network and to investigate the system performance under certain parameters and assumptions. To achieve this target, Matlab has been used and modified as a DL static system-level simulator to model an LTE-A network with the proposed technique. It has been chosen to implement the proposed scheme because it supports the physical layer of the LTE-A network. The results obtained from the WinProp propagation modeling of the path loss information are used as an input in the Matlab simulation. The path loss is calculated by the UDP model given in (4.1) using ProMan from the WinProp software suite. Then Matlab is used for the analysis of path loss information to obtain the performance of each UE at every location.

4.3 Propagation Model

This study presented a real-dense urban Addis Ababa LTE-A cellular network for a selected area. This means that the location, antenna height, orientation, and configuration of all BSs in the area have been made available for study. A clutter map of the area representing the type of terrain is also used to compute both macro and DAS cells by using the WinProp simulation tool for every pixel, which has a 5m resolution. The cellular propagation of different terminals can be expressed through a multiplicative propagation mechanism of different components.

4.3.1 Path Loss Model

As an electromagnetic wave signal travels through space, its power density (attenuation) decreases. This power loss due to the distance is called Path Loss (PL), which is defined as the linear ratio between the transmitted and received power. Path loss predictions are required for coverage planning, the determination of multipath effects, as well as for interference and cell design, which are the basis for the advanced network planning process. It is influenced by the kind of propagation (macro cell and small cell), the medium environment (outdoor to outdoor, outdoor to indoor, indoor to indoor), the carrier frequency, and the distance from the serving cell. The deterministic UDP model from Winprop tools was used in this study as the propagation model. The dominant path between the transmitter and receiver is [48]:

$$PL = 20 * log(\frac{4\pi}{\lambda}) + 20 * P * log(d) + \sum_{i=0}^{n} \alpha(\Phi, i) - \frac{1}{C} \sum_{i=0}^{n} + wk \tag{4.1}$$

Where PL is the path loss in dB of a path with a length of d (meters) and λ (meter) is the wavelength. P depends on the reflectiveness state between the current pixel and the transmitter. (Φ, i) is a function that determines the loss in dB due to an interaction that changes the direction of propagation. The parameter wk is called the wave-guiding factor.

4.3.2 Base Station Antenna Pattern

The sensitivity of the antenna as a function of direction is described as the antenna pattern. It depends on the angle between the antenna azimuth and UE, the front-to-back ratio of the antenna, the maximum possible attenuation A_m and the main lobe beam-width is θ_{3dB}. The azimuth antenna gain used in the modeling procedure of the macro cell BS antennas is defined as follows [25]:

$$A(\theta)_{3dB} = -min[12(\frac{\theta}{\theta_{3dB}}), A_m] \tag{4.2}$$

The number of sectors per BS affects the design values of θ_{3dB} and (A_m). In this thesis, a 2600MHz antenna with a horizontal beam width of 70 degrees with a gain of 18dBi is used. The Antenna Loss (AL) due to antenna directivity and azimuth can be formulated as [9]:

$$AL = min[12(\frac{\theta}{70}), 20] \tag{4.3}$$

4.3.3 Shadow Fading Model

The clutter from things such as buildings, trees, and topographical conditions along a signal path changes from path to path. As a result, signal attenuation varies as well. Shadow fading is used to model fluctuations in the path loss due to such obstacles between a mobile user and a BS that strongly attenuates the signal power. The effect of shadowing is commonly approximated by a lognormal distribution [10]. The modeling of shadow fading when considering the change of a user's position is more complicated due to spatial autocorrelation between paths. The shadow fading method is autocorrelated in space, which is a moving UE that may see similar shadow fading reductions from the same BS at different but nearby places.

4.4 CoMP Transmission Scheme Selection

The CoMP different techniques have already been discussed in Chapter 3. Based on that, this work considered DL JP CoMP transmission schemes. In order to study CoMP performance under realistic LTE-A network deployment constraints, we focused on three transmission techniques that were measured, such as intra-site CoMP, DPS/DPB CoMP, and JT CoMP. The reason for choosing this technique is that CS/CB CoMP has a high level of complexity and less performance improvement. On the other hand, JP CoMP can be implemented more easily and has better performance improvements [13, 30] in terms of average and cell-edge users' throughput. In addition, the cooperation of cells can be used as intra-site or inter-site coordination. In intra-site coordination, for systems with three sectors, it is used only in macrocells.

4.5 CoMP User Equipment Selection Criteria

In this simulation model, users are classified as CoMP and non-CoMP. Whether a UE applies CoMP or not, two threshold-based methods are mostly used [30], which are signal received power and distance-based techniques. For this study work, we have used the difference between coordination cells' received signal power methods. Therefore, a received signal power threshold is defined as the condition that triggers whether a UE applies CoMP or not. Thus, a UE that will apply CoMP is identified based on the power difference between the strongest and second-highest coordinated received signals. Furthermore, if the power for that BS meets the threshold value, it can be extended to the third-highest received signal and beyond until the cluster size is satisfied. For identifying a CoMP UE, three cluster cells are shown as:

$$P_{rx1} - P_{rx2} < R_x \ \ Power \ \ Threshold \quad or \quad P_{rx1} - P_{rx3} < R_x \ \ Power \ \ Threshold \tag{4.4}$$

Where, P_{rx1} , P_{rx2} and P_{rx3} are the first, second and third strongest Rx signal power.

From (4.4), a UE to apply CoMP is selected based on the difference-received power between the desired and interference signal with the threshold power. At the UE, when the power difference is below the threshold, the UE is regarded as a victim user needing to apply CoMP. As mentioned before, cell edge users are the most affected by interference, thus CoMP is more commonly used for these users. In a theoretical scenario, one user could be covered by three sectors (middle of three eNBs) [9]. Thus, as for coordination, a maximum of three sectors was defined in this simulation work. Then, if the received power for a user is less than the threshold, the user is served by either two or three BSs.

4.6 Resource Scheduling

The performance of a network depends on how efficiently the available resources are allocated to the UE. The packet scheduler is the entity responsible for allocating transmission and re-transmission requests over the available resources. The radio resources in each cell are divided between the non-CoMP and CoMP UEs. As all macro and DAS cells have the same cell IDs, each cell is scheduled together. The UEs for each cell are randomly distributed in the coverage area. The well-known resource scheduling algorithms are Round Robin (RR), maximum rate, and proportional fair [49]. In overall system performance evaluations, scheduling algorithms play a crucial role, and the RR type scheduler is the baseline scheduler model in this thesis work. In RR scheduling, UEs are assigned the resource blocks in a round fashion (one after another) without considering CQI. It is a simple procedure to give the best fairness [49].

4.7 Performance Evaluation Metrics

In this section, we define performance metrics for the network that can be obtained using network system simulation result evaluation. SINR, spectral efficiency, and throughput were used to evaluate the performance of the proposed scheme in this model and other indications were taken into account. LTE-A system-level simulations generate and assess those performance parameters at various user locations, and validate them with the theoretical results. The performance metrics that have been used to evaluate the performance of our proposed schemes are discussed in the following subsections.

4.7.1 Signal to Interference Plus Noise Ratio

SINR is a very important metric to be considered in the performance evaluation of any mobile network. It is considered the main concern to measure the reliability of mobile communication systems, which require relatively high SINR levels and a quantity used to estimate the theoretical rate of information transfer in cellular technology. Choosing the serving cell in this model depends on the highest received power of all carriers in the network with the minimum threshold. The minimum amount of resources allocated to a user in LTE-A is called a PRB, with a total bandwidth of 180 kHz. In each cell, for a 20MHz bandwidth, there are 100 PRBs. Then the assigned bandwidth for a UE in a cell is given as [32]:

$$BW_{UE} = \frac{PRB * BW_{RB}}{N_{UE}} \tag{4.5}$$

Where, N_{UE} is the number of UE in a cell, BW_{UE} is the BW assigned to a UE, and BW_{RB} is the bandwidth of a PRB (180 kHz). Then the power at the receiver for a UE can be found from its allocated resource in DL is given by [24]:

$$P_{Rx[dBm]} = P_r[d_{Bm}] - L_u[d_{Bm}] \tag{4.6}$$

Where P_r power of the received signal, L_u is losses due to user. The received signal for user k from a single cell l using path loss and transmitted power is given as [34]:

$$P_r(_{k,l}) = P_{Tx}[_{dBm}] - PL_{k,l} - AL_{k,l}[dBi]) + G_r[_{dBi}] - L_c[_{dB}] \tag{4.7}$$

Where P_{Tx} transmitted power, $PL_{k,l}$ path loss from the transmitter to the receiver, $AL_{K,l}$ BS antenna loss, G_r gain of the receiving antennas, and L_c losses in the cable between transmitter and antenna.

Cell edge users in DL experience higher interference because more than one BS usually covers the area. The goal of interference modeling and analysis is to show the actual signals arriving at the victim user in a cell from the interfering cells with a reasonable capture of the cumulative effect of interference. Modeling of interference is very challenging due to the random nature of the channel state, user mobility, user location, and other parameters. Commonly, it can be formulated in dBm [50]:

$$Interference = 10 * log_{10}(total\ received\ power - desired\ signal\ power) + 30 \tag{4.8}$$

Then SINR can be calculated as the ratio of the desired signal and the sum of the interference power and background noise. The SINR for UE k in a conventional network is given [25, 40]:

$$SINR^l_{k,n} = \frac{P^l_n G^l_{k,n}}{\sum_{j=l} P^j_n G^j_{k,n}\, \sigma^j_n + P_{TN}} \tag{4.9}$$

Where P^l_n the transmission power l, $G^l_{k,n}$ is antenna gain for UE k served by BS l, P_{TN} is the thermal noise power, P^j_n the interference power comes from neighboring BS j, $G^j_{k,n}$ is the neighboring BS antenna gain and σ^j_n is an associated indicator that is about to be one or zero to specify whether the neighboring cell k allocates RB n to UE m or not. UE computes SINR on each RB, converts it to CQI, and reports it to eNB where it is used to select the most suitable modulation and coding scheme for user data transmission in a particular resource block.

Because of having different types of cells in the CoMP system deployment, SINR equations have to be modified to fit the proposed joint scheme. The received signal at the UE k using CoMP joint transmission is given as [12, 50]:

$$P_r(k) = P_{Tx} \sum_{j\varepsilon l} - PL_{k,l} \sum_{j\varepsilon l/L'} - AL_{k,l}[dBi] + G_r[_{dBi}] - L_c[_{dB}] \tag{4.10}$$

The first part indicates the desired signal from CoMP cells represents a useful received signal from L‘ cooperating transmitters. The second part represents ICI signals, where the sum is the Lxl transmitted symbol vector and l length of the data symbol. To evaluate the SINR performance with and without coordination, the coverage probability is measured. We are considering k UEs and M cells. The experienced SINR by a UE k from the serving cluster M’ is formulated as [50]:

$$SINR^{M‘}m_k = \frac{P_n^l \sum_{m\varepsilon M‘} + \lambda_k^m}{P_n^j \sum_{m\varepsilon M/M‘} P_n^j G_{k,n}^j \lambda_k^m + P_{TN}} \tag{4.11}$$

Where,λ_k^m is the path gain. The denominator is the non-coordinated BSs, $m\varepsilon$ (M/M’).

4.7.2 Spectral Efficiency

Spectral Efficiency (SE) is another important metric to take into consideration when evaluating any mobile network performance, and it has a logarithmic relationship with SINR. It is the maximum bandwidth that can be utilized with the lowest number of transmission errors and is measured in bits per second per Hz. It can be used to calculate any potential UE in the coverage area. The SE in the LTE-A network is measured using the modified Shannon formula. The modified Shannon capacity formula is meant to account for the system bandwidth efficiency and the SINR efficiency. The spectral efficiency is calculated based on the modified Shannon formula for user k is given as [51]:

$$SE = \begin{cases} 0, \quad for\ SINR < SINR_{min} \\ min(S_{max}, BW_{eff} log_2(1 + (\frac{SINR}{SINR_{eff}}))), SINR > SINR_{min} \\ SE_{max}, \quad for\ SINR > SINR_{max} \end{cases} \tag{4.12}$$

Where S$_{max}$ the maximum spectral efficiency, BW$_{eff}$ adjusted for the system bandwidth efficiency and SINR$_{eff}$ adjusted for the SINR implementation efficiency of the LTE-A network. We use the best Shannon fit parameters formulated in [51]. Hence, the SINR-spectral efficiency and throughput mapping parameters used are shown in Table 4.1. Where SE is the achievable rate in bps/Hz, S$_{max}$ is a constant value, SINR$_{min}$ is the minimum required SINR to obtain satisfactory QoS, SINR$_{max}$ is the maximum SINR value that can be achieved SE$_{max}$, which is the maximum achievable rate.

Table 4.1: SINR-throughput mapping [51]

Parameter	Assumption
SINR$_{min}$	-10dB
BW$_{eff}$	0.62
SINR$_{eff}$	1.8
S$_{max}$	4.4 b/s/Hz

4.7.3 Throughput Calculation

Users who are attached to the base station with a cell and how much data can be transferred from one location to another in a given amount of time are referred to as Throughput (TP). After obtaining the SINR information and spectral efficiency, it can be used to calculate the throughput for any potential UE in the coverage area. The TP in the LTE-A network is measured using the modified Shannon formula for a specific UE with bandwidth is given as [51, 52]:

$$TP = \begin{cases} 0, \quad for\ \ SINR < SINR_{min} \\ N_{RB} * BW_{PRB} * min(S_{max}, BW_{eff} log_2(1 + (\frac{SINR}{SINR_{eff}})) \\ TP_{max}, \quad for\ \ SINR > SINR_{max} \end{cases} \tag{4.13}$$

Where TP is UE throughput, N$_{RB}$ is the number of PRBs, BW$_{PRB}$ is the bandwidth per PRB. In the LTE-A network, the basic resource unit of eNB is a PRB. This resource can be allocated to users in a number of scheduling techniques. One of the simplest scheduling techniques used in this thesis is the RR. Based on the RR technique and assuming uniform traffic demand per user, the maximum cell capacity is equal to the number of PRBs. The number of PRB is directly related to the bandwidth being used and this is the basic assumption for cell capacity.

Chapter 5

Simulation Results and Discussion

This chapter discusses the simulation results and evaluates the proposed scheme using the simulator tools that were developed to implement the models stated in the previous chapter. The simulation results for the selected LTE-A system were obtained by collecting accurate digital terrain data, identifying network simulation tools for system implementation, configuration process on BSs and network levels, and finally choosing the coordinated sectors in each cluster. The simulator was implemented using Winprop and Matlab simulation tools and analysis presented a part of the simulation results obtained. We are considering the DL MIMO-OFDMA LTE-A network with JP CoMP. This is used to observe the effect of CoMP on network performance. It includes the deployment scenario and the interference situation for the cells are presented. The system parameters and simulation approaches used in the simulation are described. Observations and analysis of the results for the system model are made. Consequently, validation with the theoretical rate is essential to examine the applicability of the proposed scheme in practical life.

5.1 Deployment Scenario

The first simulation is about the general deployment scenario. This study is presented based on data from a realistic environment LTE-A network in Addis Ababa city. To do this, we used the network management system's three-month ethio telecom LTE-A network data performance analysis. BS data traffic, as well as high interference problems, were taken into account when selecting the target investigation area for this study. To observe and identify the nature of BS, high data traffic is utilized by using the U2020 tool. In addition, a high ICI area was identified by analysis of key performance indicators that can be verified by using drive test analysis tool results. The DL interference problem in ethio telecom uses drive test measurement to obtain the total DL interference level within a particular cell of the LTE-A system. Data collection is done by using Nemo Handy, then the simulation is done by using an Actix Analyzer, and evaluations are carried out. Then the areas and sites that are more limited by ICI are identified.

Therefore, by using the traffic intensity map, we identified the investigation area, created BS serving the area, and user distribution was generated.

Thus, considering the morphology, a study area covering 2km by 2.5km was selected in a dense urban area. The reasoning behind limiting the study area to 5km^2 is to reduce the complexity that may arise during simulation computation. The selected area is covered by high-business areas like hotels, shopping malls, restaurants, entertainment malls, and marketing that represent a dense urban scenario with condensed data traffic hotspots, which are located in the Bole sub-city. In this thesis, we identify and simulate an LTE-A network of 20 macro-sites, each equipped with 3 directive sectors and 70 DAS cells. In total, there are 130 cells in the simulation. Where each sector is served by an eNB having its own scheduler, bandwidth, and power distribution strategy. Figure 5.1 depicts a Google Earth® satellite view of the selected LTE-A macro and DAS cell sites. The total channel bandwidth available for each cell is set at frequencies of 2.6 GHz and 20 MHz, to be compatible with the LTE-A network requirements of the 3GPP standard. This means that the PRBs will be 100, which can be repeated in each cell as we consider cochannel deployment with a frequency reuse factor of one. The general network layout of the selected area is shown in the figure.

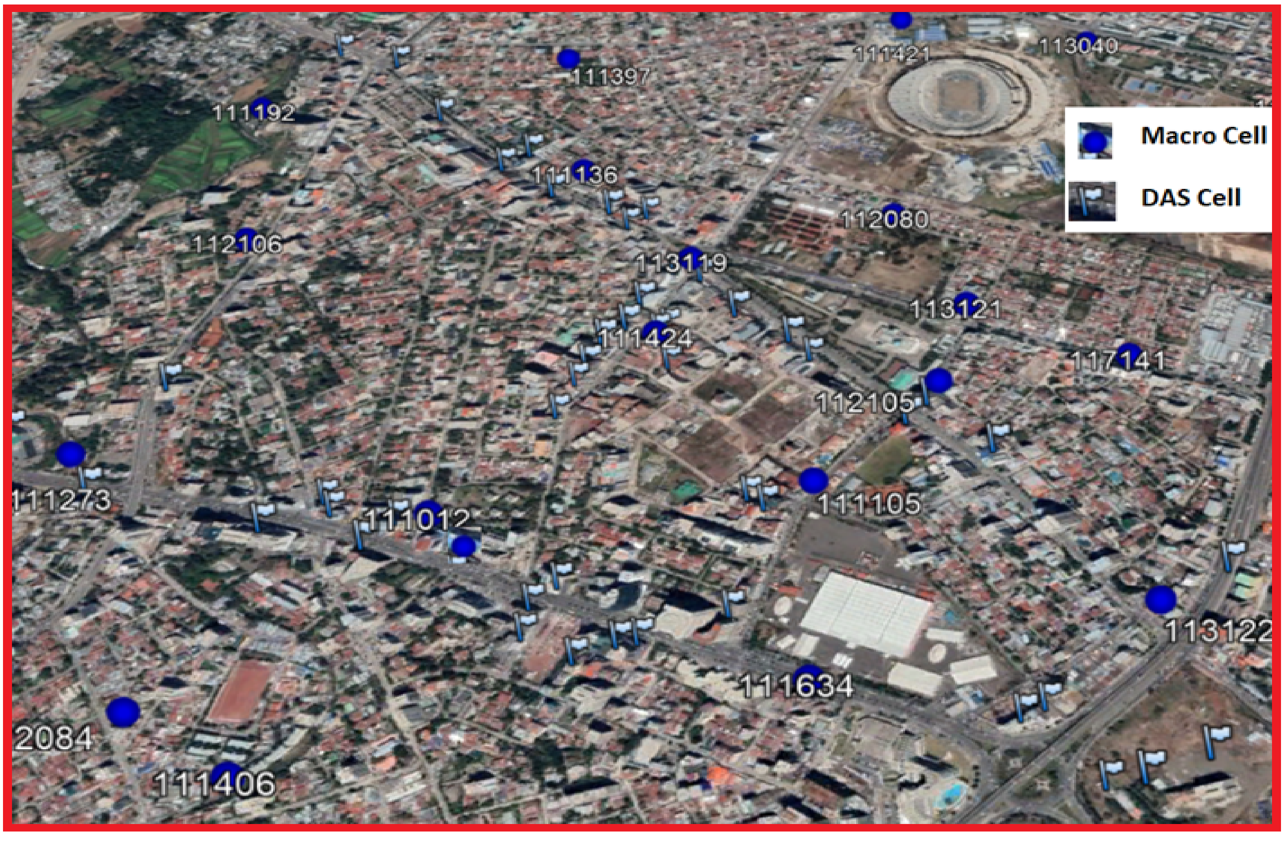


Figure 5.1: Real network layout satellite view from Google Earth in Bole surrounding

5.2 Simulation Approaches

The Winprop software and a 3D vector building database of the selected area in Addis Ababa were used in this simulation work. To accomplish this, relevant data, such as a digital building map and terrain, has to be imported. The transmitter BS sites were placed in the exact positions and all parameters were included in the simulation. The parameters used for this purpose are stated in Table 5.1. After the parameters are properly configured for macro and DAS cells in WinProp for propagation computation to get path loss data in text format. The obtained path loss data is not suitable for the LTE-A network Matlab simulator, it is converted into a ".mat" file format that the simulator can accept. Then the obtained results were used for further analysis of network performance. Thus, Matlab-based static system-level simulation tools are used to investigate network performance for different CoMP and non-CoMP schemes in a static scenario (taking a snapshot of the network). The UE's are distributed at random positions at a given time, and they take a snapshot of traffic for the performance evaluation. The configured LTE-A network along with selected Addis Ababa city building and terrain data within the winprop software is shown in Figure 5.2.

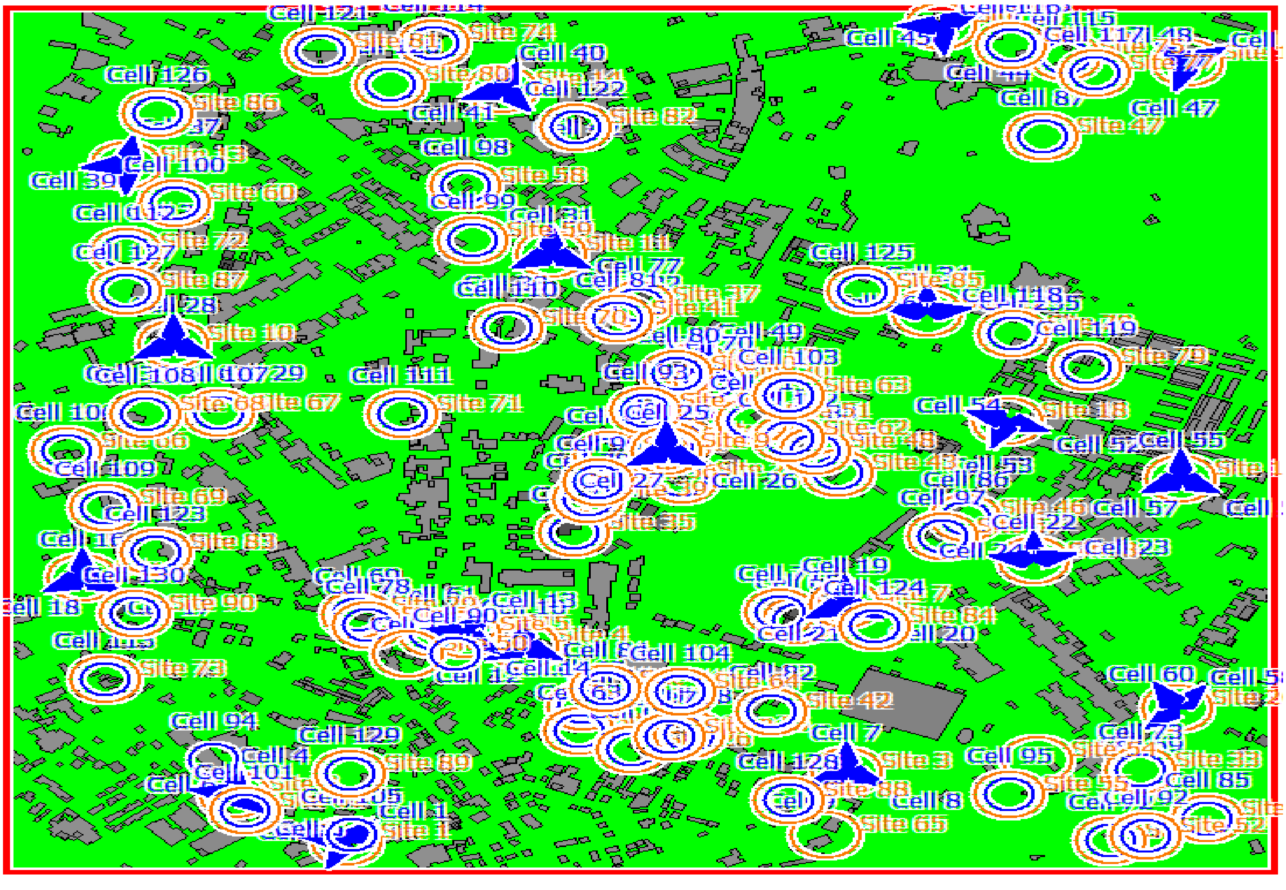


Figure 5.2: Candidate locations along with Macro and DAS cells in WinProp

5.3 Simulation Parameters and Assumptions

This section presents simulation parameters and assumptions that have been used to model the LTE-A network, as shown in Figure 5.2. The main simulation parameters related to macro and DAS cell configuration and network scenarios are summarized in Table 5.1.

Table 5.1: System-level simulation parameters and assumptions

Parameter	**Values/Assumptions**
Deployment scenario	Macro network overlaid on DAS cells
RB bandwidth	180 kHz
Carrier frequency	2600 MHz
System bandwidth	20 MHz (LTE-A)
Resource scheduling	Round Robin
Physical resource block/sectors	100
Simulation scenario	Radio propagation modeling (WinProp) Static system level simulation (Matlab) Resolution of prediction is 5m
CoMP threshold	10 dB
Number of sites	20 Macro, 3 sectors/macro cell and 70 DAS cells
Transmit power	46dBm for macro cell and 20dBm for DAS cell
Antenna pattern	Katherine 742212 / Omni-directional
Transmit antenna gain	18dBi for macro cell and 5dBi for DAS cell
Antenna height/azimuth/tilt	Realistic ethio telecom scenario
Number of UEs	810
UE height	1.5m
UE antenna gain	0dBi
Received power	23dBm
Receiver noise figure	9 dB
Thermal noise density	-174 dBm/Hz
Shadow fading	Log-normal with standard deviation of 8dB
Building penetration loss	20 dB

The implementation of the proposed solution includes system modeling and simulation assumptions to get the implementation results. All system parameters and scientific equations essential for the system model have been determined. The parameters follow the current configuration of ethio telecom network and the 3GPP standard's latest parameters agreed upon.

5.4 Performance Result Analysis

In this section, we begin an analysis of the simulation results of the proposed scheme based on all the assumptions and performance metrics from the preceding sections that have been outlined. Simulations with different scenarios are tried and the corresponding results are analyzed and evaluated. For the system parameters, the simulations strictly follow the evaluation approach established by the 3GPP community. The simulation results compare the performance of the proposed algorithm (CoMP) with those of existing schemes (non-CoMP). The network performance is presented in terms of SINR, spectral efficiency, and throughput parameters as a function of distance from BS. Simulations with various situations are conducted, and the resulting data is examined using Cumulative Distribution Functions (CDF) and bar graph plotting techniques. One of the methods used for plotting the simulation results is using the CDF.

The CDF is a common probabilistic tool used to express the probability of a random variable being equal to or less than a given value [53]. For our simulation, the CDF is used, assuming the SINR or the throughput values as a random variable. We used the CDF to measure the system model performance by applying the formulas addressed in Section 4.7 to simulate the SINR and throughput behavior of the studied CoMP techniques. Therefore, when comparing the obtained CDF graphs, the best one is the one showing the lowest CDF for all values. Performance evaluation of various scenarios and configurations is carried out for some key performance indicators, such as:

- Performance refers to a user's ability to access the DL network parameters.
- 10%-ile performance is the performance at the 10%-ile point of the CDF of the user performance. The 10%-ile level indicates the cell edge user experience in our system.
- Median performance is the performance at the 50%-ile point of the CDF of the user performance. Median performance is related to the cell's average user experience in our

system.

- The performance at the 90%-ile point of CDF of user performance is called the cell center for this simulation work.

5.4.1 SINR Performance Analysis

In this subsection, we examine a mechanism to compare conventional network (non-CoMP) with proposed (CoMP) schemes to find the SINR performance of all the potential UE positions in the LTE-A network, which is the simulation environment being targeted. We can see the impact of the interference signal on the UE when users are served from all BSs. All the signals coming from the BSs other than the serving cell act as interference. Taking into consideration user-assisted interference from adjacent macro and DAS cells. The goal of the mechanism is to show the average per-user SINR as a function of coordination and non-coordination systems in terms of CDF. Simulations with different scenarios are tried and the corresponding results are analyzed. To perform SINR analysis, the CoMP performance under different situations is presented as below.

A. User Equipment and Base Station Positions

Using the U2020 network management system, a three-month ethio telecom LTE-A network active user traffic analysis is used to select the number of users available in the selected area. From the selected sites, on average, the capacity of the network supports around 30 subscribers per site (20 sites with 3 sectors) for macro cells and 3 subscribers per DAS cell [54]. This means our proposed working area has the capacity to support 810 users. Simulating the network using a different number of UEs leads to different results.

We are using row filling to distribute UEs throughout each available pixel. These are randomly distributed inside our network and set to attach to a cell with a higher RSRP as a serving cell and start moving on random routes. Some of the UEs are close to the cell center or average, and some of them are at the cell edge, so that each BS cell will have at least one associated UE. For scheduling, the RR scheduling algorithm is used, where PRBs are assigned to each user equally and in circular order without giving priority to any user. The UE distribution and the site positions are shown in Figure 5.3.

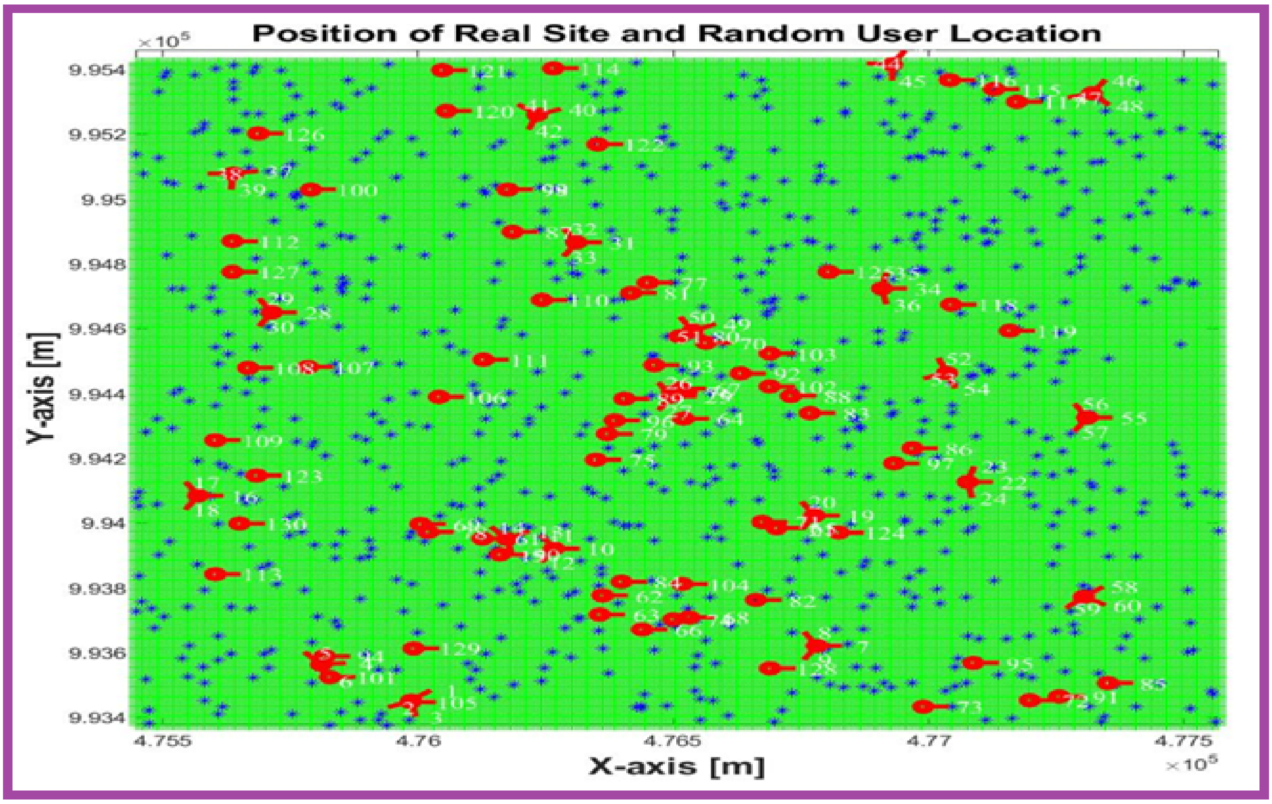


Figure 5.3: Random user location (blue star) in the study area with a real base station (red)

B. CoMP User Equipment Selection Criteria with Different Power Thresholds

As mentioned earlier, the aim of CoMP is to offload more users from the possibly connected one-cell transmission towards two or more coordinated transmission cells. The most important stage of this study is determining which UEs require support from the CoMP cluster. Whether a UE applies CoMP or not is identified based on the power of the received signal threshold. The UEs that have a value below the predefined threshold activate the cells in the cluster. Thus, one of the most significant aspects is determining the threshold value, although there are no exact guidelines or criteria for determining it.

For this simulation work, the initial CoMP UE selection criteria were based on the definitions in Section 4.5. The simulation of the CoMP system shows the effect of the selected power thresholds on the selection of the CoMP UEs. These different power thresholds were selected to evaluate their effects on the CoMP system performance. For the simulation, the received power thresholds are set at 1dB, 3dB, 6dB, and 10dB to observe the effect on the performance. The desired transmission points for the CoMP schemes are selected from the signals with the highest received power. Then, the percentage of CoMP UE that will have 1, 2, or 3 transmission points is shown in Figure 5.4.

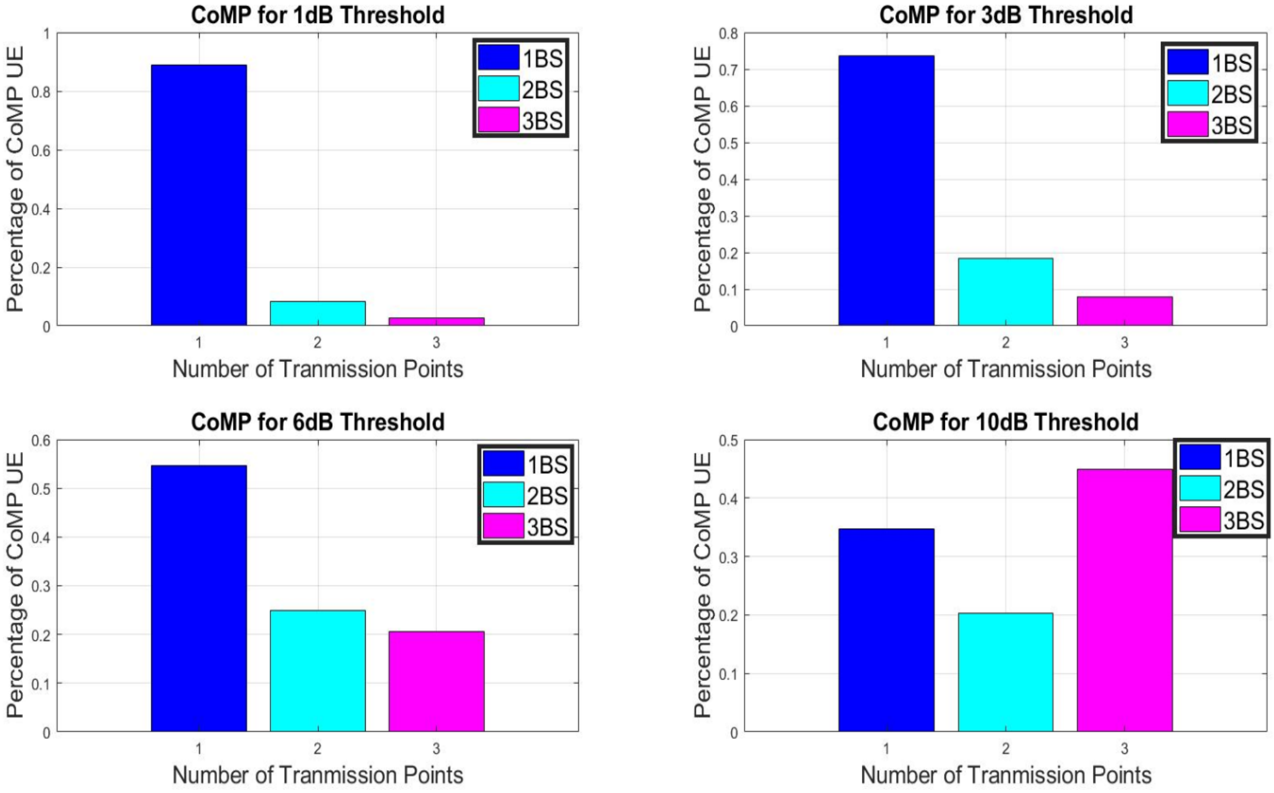
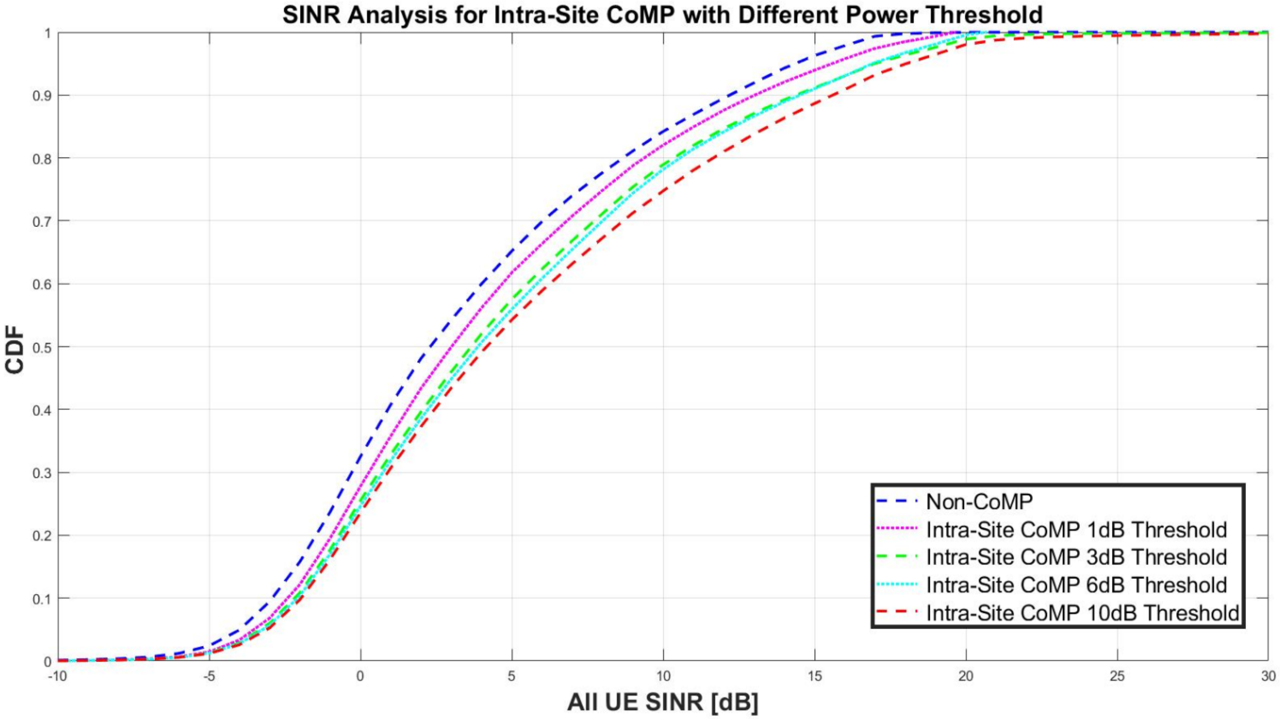


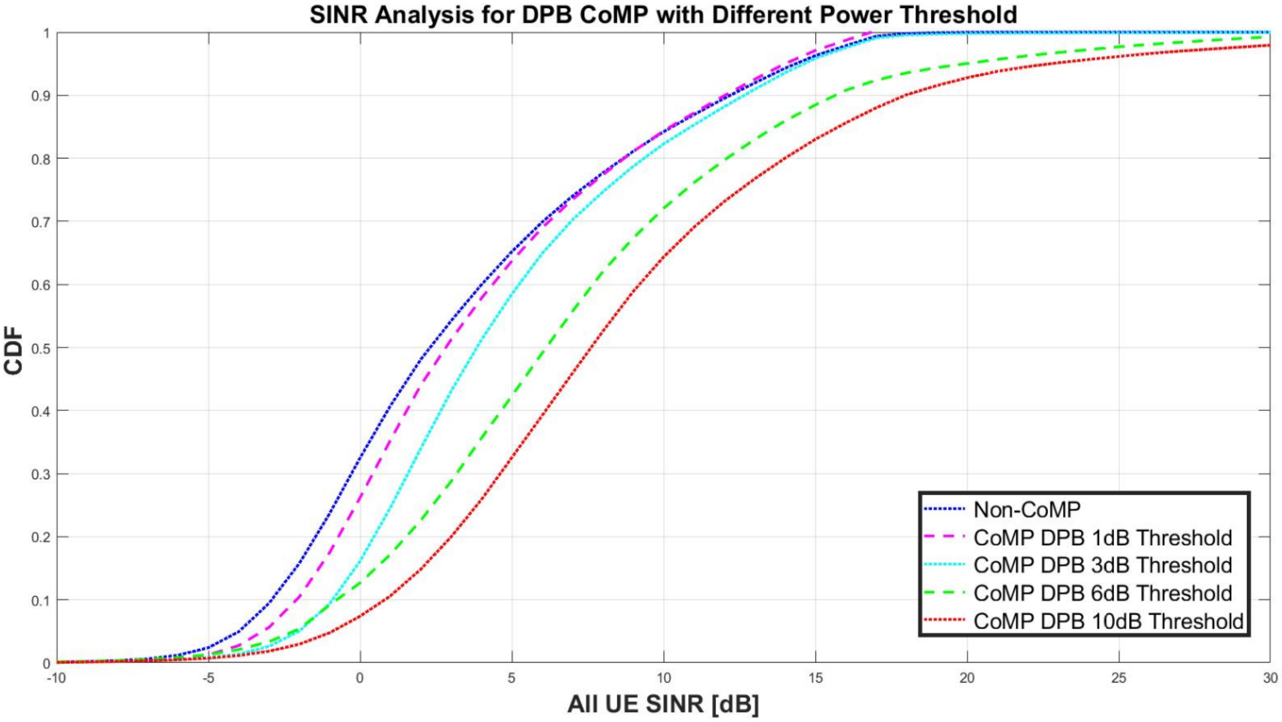
Figure 5.4: Percentage of CoMP UEs for different CoMP thresholds and transmission points

From the figure, the results obtained followed the received power threshold sets. The average proportion of CoMP UE served by 1, 2, or 3 transmission points is illustrated. The proportion of CoMP UEs with both 2 and 3 transmission points almost reaches 12%, 26%, 45% and 65% for the thresholds of 1dB, 3dB, 6dB, and 10dB, respectively. It can be seen that the number of CoMP UEs increased in the case of a larger transmit power threshold, and the UEs served by a single cell became fewer. Consequently, there is less RB. While increasing the power threshold is meant to improve the network performance, how does the performance of the network actually improve? As a result, SINR is one of the effective performance metrics that is utilized to evaluate the threshold performance. To do this, select different CoMP schemes and compare the effective SINR performance of different received power thresholds relative to the baseline (non-CoMP) systems as discussed below.

C. SINR Performance Evaluation with Different Power Thresholds

After the CoMP power threshold comparison process is completed in the selection of CoMP UE, they evaluate the performance of SINR with different CoMP scheme options. In our simulation, intra-site CoMP and two types of inter-site CoMP schemes are applied to make a comparison with and without CoMP schemes. The inter-site CoMP techniques are the DPB and JT scheme. The selection of CoMP schemes has already been set out by the criteria in Section 4.4. The SINR performance evaluation is illustrated in Figure 5.5. From the figure, the CDF plots show the UEs SINR performance comparison between coordinated and non-coordinated networks with the power thresholds of 1dB, 3dB, 6dB, and 10dB. The simulation results are intra-site CoMP, DPB CoMP, and JT CoMP systems, respectively.





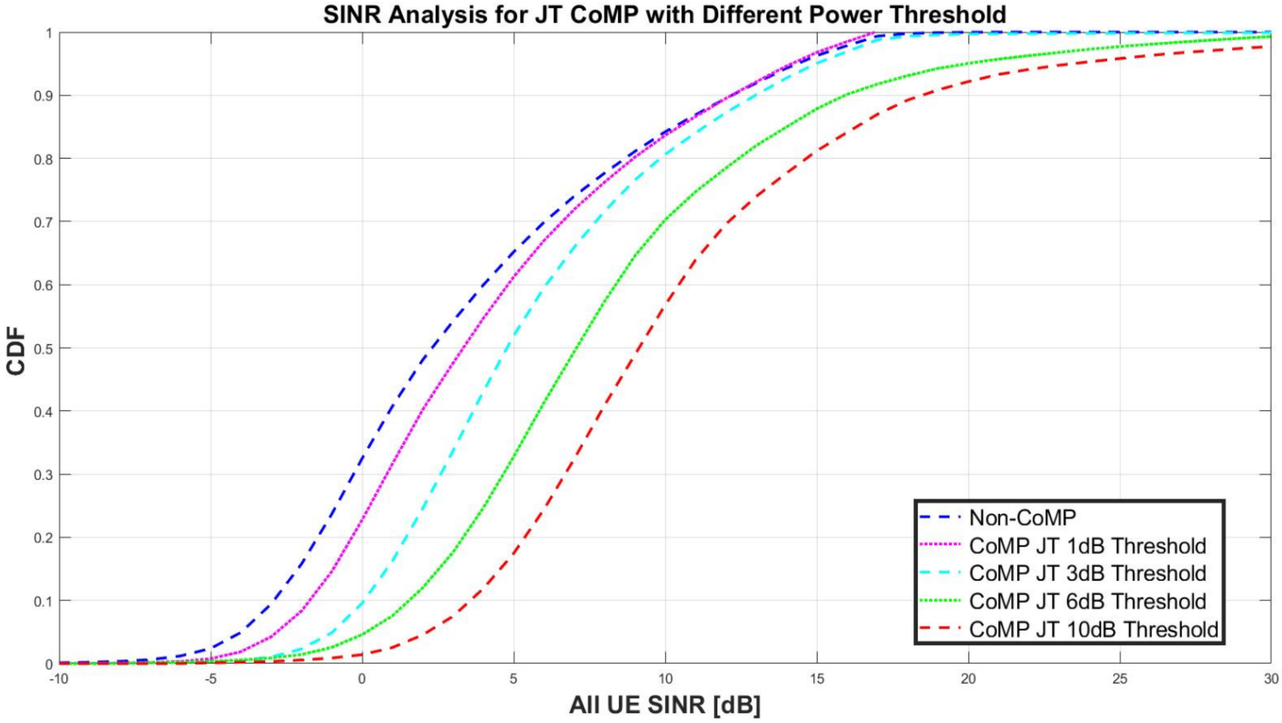


Figure 5.5: UE SINR performance of different CoMP schemes with different power thresholds

According to the figure, the larger value of the threshold leads to a larger SINR as well as higher CoMP UEs meant to bring about better network performance. The reason behind it is that a higher threshold ensures a high power difference between the coordinated received signals. In a non-CoMP case, the second and third strongest signals are the dominant interference, heavily dropping the SINR. In the 10dB threshold CoMP, when a relatively high level of interference is turned into a useful signal or mitigated, then SINR can be extremely high. As a result, the largest power threshold CoMP techniques provide an improvement in UE SINR, and the CDF of all UE SINR values is increased more than the conventional networks (non-CoMP).

Therefore, we can conclude that the higher threshold leads to a larger channel condition and that the SINR value is better. Thus, increasing the power threshold is meant to improve the network performance, which it actually does. Conversely, when the threshold is 10dB, some proportion of UEs have a large gap in received power that becomes high overhead on the backhaul network. Because its average SINR is inherently higher than that provided by other power thresholds. Therefore, when the load on the network is high, degrading the received power threshold will probably be a good strategy to retain the improvement of CoMP systems. As a result, in order to recognize SINR gain, Figure 5.6 shows the cell edge, cell average, and cell center users' performance in comparison to a non-CoMP system as a baseline.

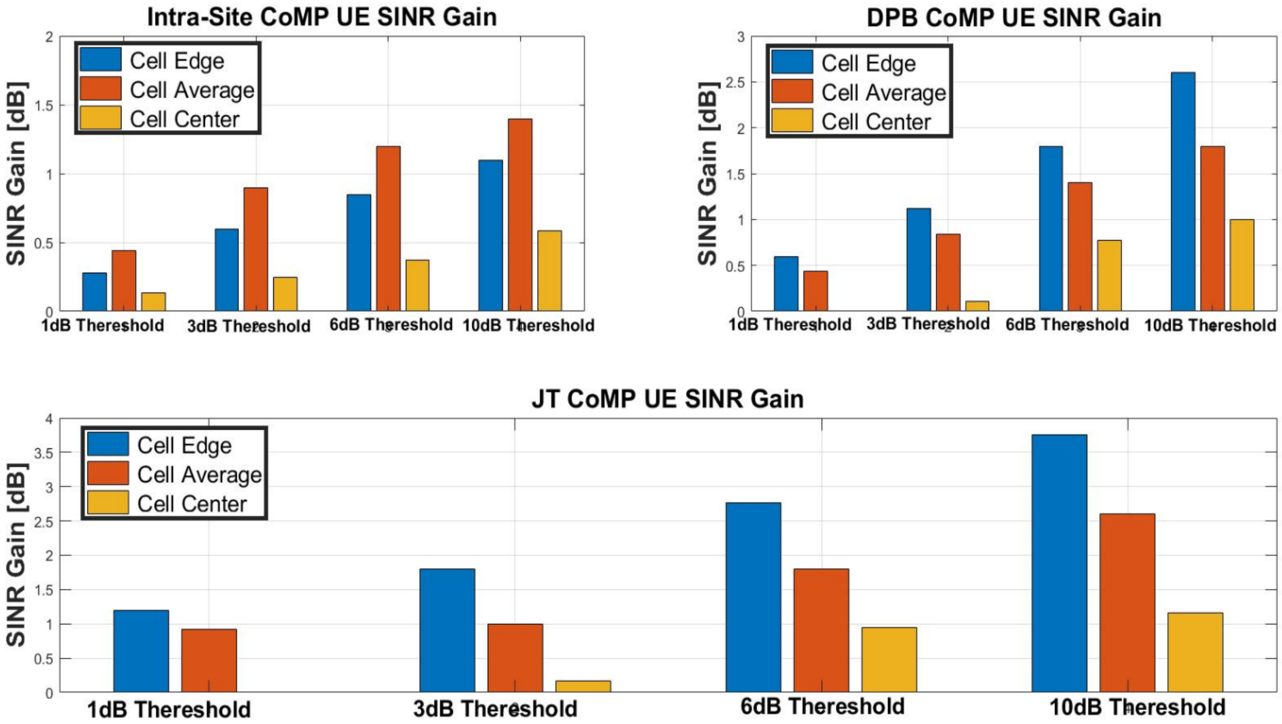


Figure 5.6: Different CoMP scheme UE SINR gain for different power thresholds

The figure shows the actual CoMP UEs SINR gain at the different power threshold values. The result demonstrates that the network with inter-site CoMP and 10dB threshold achieves more cell edge and average user SINR gains and that the value of intra-site CoMP is not as high. However, the SINR gain for the average user who already has a good channel condition is slightly lower. Because in CoMP systems, we are primarily concerned with cell edge UEs. The primary purpose of CoMP transmission is to enhance data rates for cell-edge users, and extending it to the rest of the users will degrade system performance. As a consequence, a 10dB received power threshold was chosen based on UE SINR performance and gain findings and can be used in the latter simulations. After identifying the power threshold value, the CoMP and non-CoMP schemes' UE SINR performances are presented as follows.

D. CoMP and Non-CoMP SINR Performance Analysis

In this activity, CoMP implementation can be done in intra-site and inter-site scenarios. As mentioned before, a maximum of three sectors of macro or DAS participate in transmission to a UE. The cooperating sectors are found on different or the same BS sites, and the transmission mode selection criteria are used at the 10 dB threshold. To verify this viewpoint, the CDF plot of non-CoMP and CoMP UE SINR with a maximum of three static cluster sizes is drawn. The following Figure 5.7 shows the simulation results.

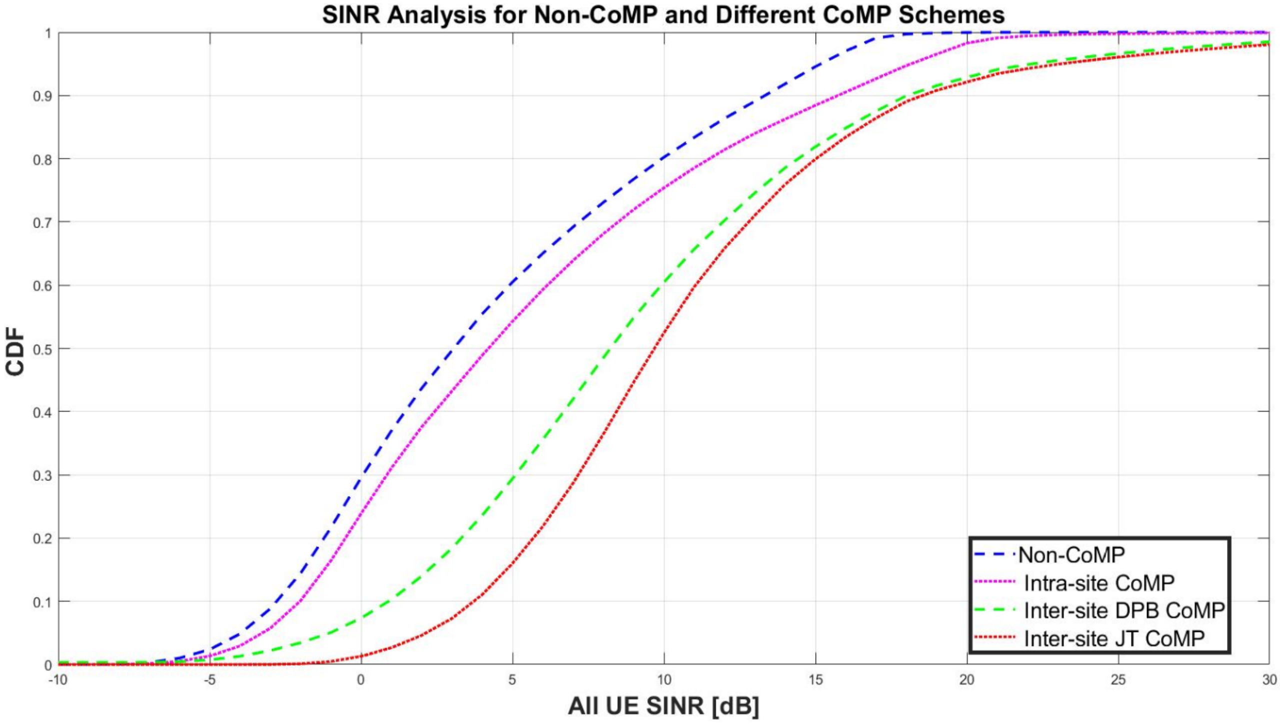


Figure 5.7: UE SINR performance analysis for non-CoMP and different CoMP schemes

The CDF UE SINR for non-CoMP, intra-cell CoMP, and inter-cell CoMP is shown in the figure. This figure clearly shows the SINR behavior in the real network system model by distributing 810 UEs. It can be observed that the proposed scheme's (CoMP) performance is better than the conventional network (non-CoMP) system. In addition, the inter-site CoMP system has better performance than the intra-site CoMP. The collaborating cells are in different geographical locations and have higher overlapping areas, so the inter-site CoMP has an effect on more users' SINR performance. While for the intra-site CoMP, the cooperating cells are sectors of the same BSs, and the overlapping area is limited due to orthogonality. For instance, the probability of UE positions in our system model having SINR above 5dB is around 84% in JT CoMP and 70% in DPB CoMP, while it is 47% in intra-site CoMP and 40% in non-CoMP systems. JT CoMP is better than the other CoMP techniques and almost doubled as compared to non-CoMP systems because a relatively high level of interference is turned into a useful signal. This is to make it more interference reduction, as well as the desired signals are extremely high. In addition, almost all user positions have SINR above 0dB in inter-site JT CoMP due to efficient resource allocation and getting high signal strength, while in non-CoMP, 30% of user positions have SINR below 0dB.

Evidently, SINR improvement appears between coordination and no-coordination techniques. These enhancements reflect the fact that each UE operates the received power from three different cell coordinators, which greatly reduces interference. The reason for this issue is that there are more available desired signals for the user when the number of interferences is lower. On the other hand, users are getting comparatively higher RBs when the number of cells coordinated increases as part of the CoMP system's deployment. Moreover, the proposed method implements a JT CoMP to satisfy more user requirements than other methods, due to turning the interference signal into a useful signal power leads to better SINR. Therefore, in order to perceive SINR gain, the cell edge, cell average, and cell center performance with respect to non-CoMP as a baseline is shown in Figure 5.8.

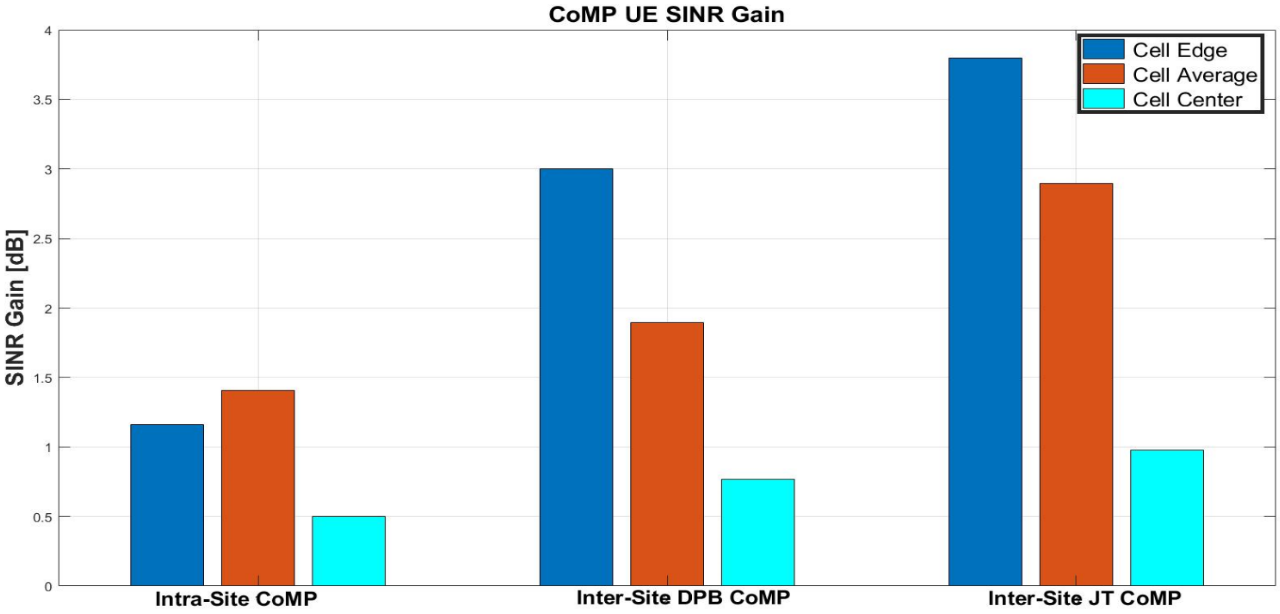


Figure 5.8: SINR gain for all UEs under the CoMP scheme selection criterion

The SINR gain of cell coverage users for the different CoMP schemes is shown in the figure. To check the SINR gain of the selected power threshold values for the overall system, the whole user position SINR is used. Apparently, the SINR gain obtained by the network with the inter-site JT CoMP scheme for the system average and cell edge improved significantly. The performance gain between JT CoMP systems and those in non-CoMP systems is 3.7dB for cell edge and 2.8dB for cell average. Furthermore, DPB CoMP users get 3dB for cell edge and 1.9dB for cell average. However, the SINR gains for cell edge users are slightly higher. Since the primary goal of CoMP transmission is to increase user data rates at the cell edge. In addition, the average user who already has a good channel condition is slightly lower, and cell center users' gain is very small due to less interference. Therefore, the proposed scheme is more interesting for the cell edge and cell average of the UE position. From this point of view, it can be concluded that the COMP methods provide better system performance gains, which increase the entire SINR.

5.4.2 Spectral Efficiency Performance Analysis

As discussed before, Shannon clearly noticed that spectral efficiency has a linear relationship with throughput and a linear logarithmic relationship with SINR values. Therefore, it can be easily observed that in order to increase the spectral efficiency of a given system, one has to increase its SINR. In this simulation, the CDF spectral efficiency performance comparison of CoMP systems and non-CoMP schemes is given for all UE mapped from the simulated SINR as shown in figure 5.9.

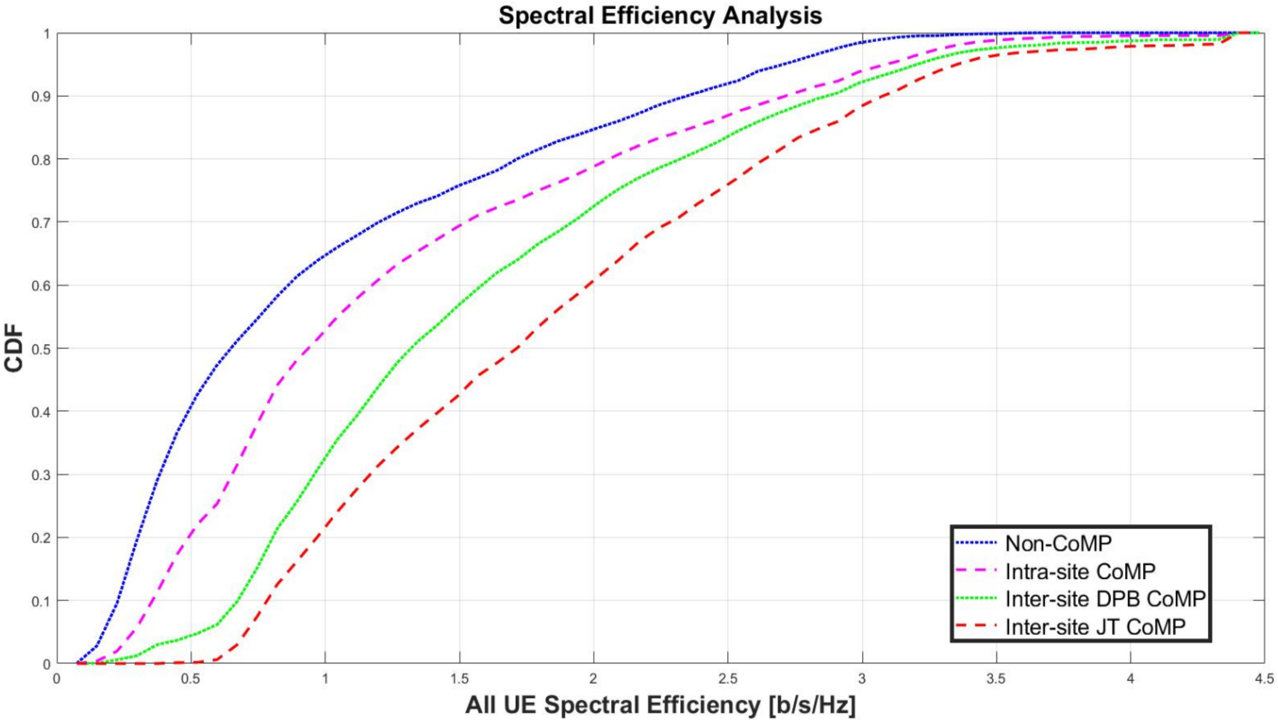


Figure 5.9: Spectral efficiency performance analysis for non-CoMP and CoMP UEs

We can observe that the comparison of spectral efficiency in the figure shows that the proposed method has a higher efficiency in using the frequency spectrum than the baseline of non-CoMP systems. For cell-edge users, the proposed method improves intra-site CoMP by 0.45bps/Hz, 0.75bps/Hz in DPB CoMP, and 0.9bps/Hz in JT CoMP. In addition, cell-edge users can achieve over 2.1, 3.4, and 4.1 times the spectral efficiency for intra-site CoMP, DPB CoMP, and JT CoMP scenarios, respectively. The cell average user spectral efficiency improvements of about 1.8bps/Hz, 2.5bps/Hz, and 3.4bps/Hz can be achieved in intra-site CoMP, DPB CoMP, and JT CoMP schemes respectively, which leads to higher cell throughput. This is because many coordination cells are deployed within the coverage area, which creates more cell boundaries, and the overlay of cells with different transmission powers further increases the interference arena. Therefore, more UEs take advantage of CoMP transmission techniques to reduce the interference and to increase their signal strength. Moreover, JT-CoMP transmission contributes to larger performance gains over the other CoMP systems. This is due to the requirement to share more information among cooperating BSs, which turns the interference signal into a useful signal and leads to better SINR and improved spectral efficiency.

As a result, in order to perceive the spectral efficiency performance gain, it is shown in Figure 5.10. The figure shows the spectral efficiency gain for the cell-edge, average, and center users for the CoMP systems set to a baseline of non-CoMP systems. The actual gain for the cell-edge users shows a 3.2 gain and a 2.4 gain for the inter-site JT CoMP and DPB CoMP respectively, and a gain of 1.4 for intra-site CoMP. For the average user, there is a 2.4 gain and 1.6 gain for the inter-site JT CoMP and DPB CoMP respectively, and a 0.8 gain for the intra-site CoMP systems. Therefore, all CoMP scheme cases provide the highest overall spectral efficiency gains compared with the non-CoMP scenarios.

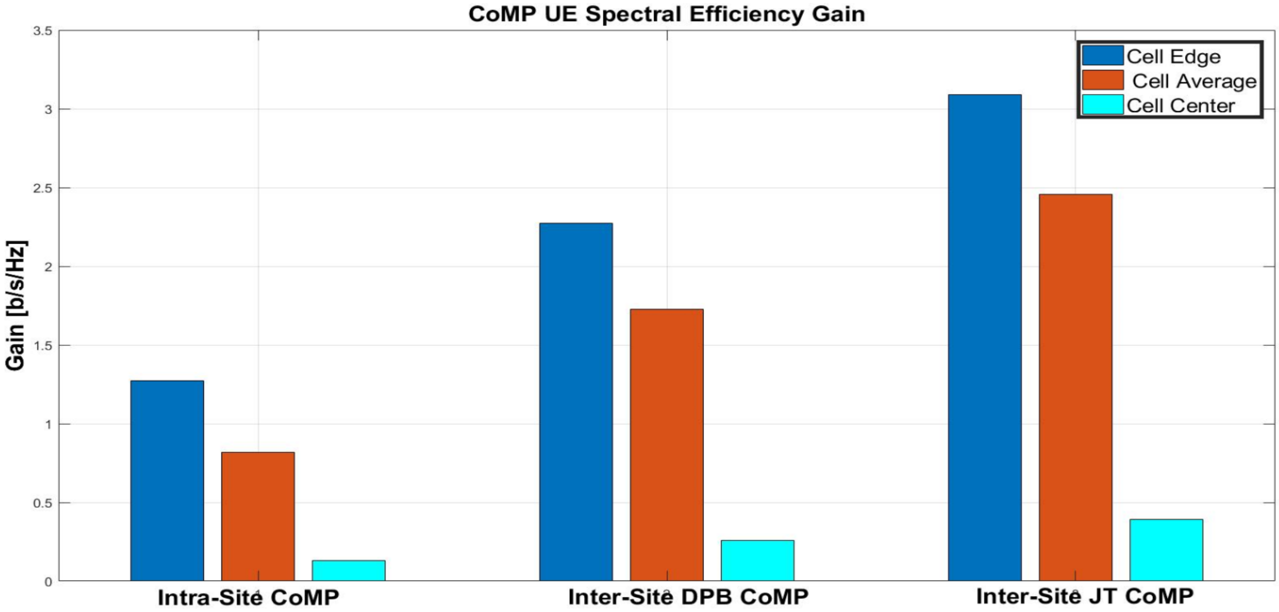


Figure 5.10: Spectral efficiency gain for all UEs under the CoMP schemes

5.4.3 Throughput Performance Analysis

We compared the throughput performance of the proposed algorithm (CoMP schemes) with the outcomes of the existing baseline approach (non-CoMP). Average cell throughput refers to the sum of all achievable UE average throughput (user capacity) values for all snapshots. The estimated cell throughput for various approaches is compared in Figure 5.11. The figure shows the user throughput (bps) for different CDF values under the proposed scheme and the existing system with a non-uniform distribution of users. It is observed that, from the range of CDF plots, the improvement in throughput is quite significant relative to the baseline non-CoMP systems. For non-CoMP, intra-site CoMP, DPB CoMP, and JT CoMP, the percentage of UEs with a throughput greater than 2Mbps is 30%, 39%, 57.5%, and 68% respectively. The JT CoMP has an improvement of 38% compared to the non-CoMP network, which is almost more than doubled. This is due to the fact that in JT CoMP, CoMP UEs data is available at many points for the same time-frequency resource, by default at all points to improve the received signal quality and reduce interference. In addition, the throughput gap between non-CoMP users and CoMP users in intra-site, DPB, and JT is around 0.4Mbps, 0.7Mbps, and 1Mbps respectively for cell-edge users. It is 0.7Mbps, 1.9Mbps, and 2.5Mbps, respectively for average users. This result proves that with CoMP, interference is manageable and the throughput of users has higher performance.

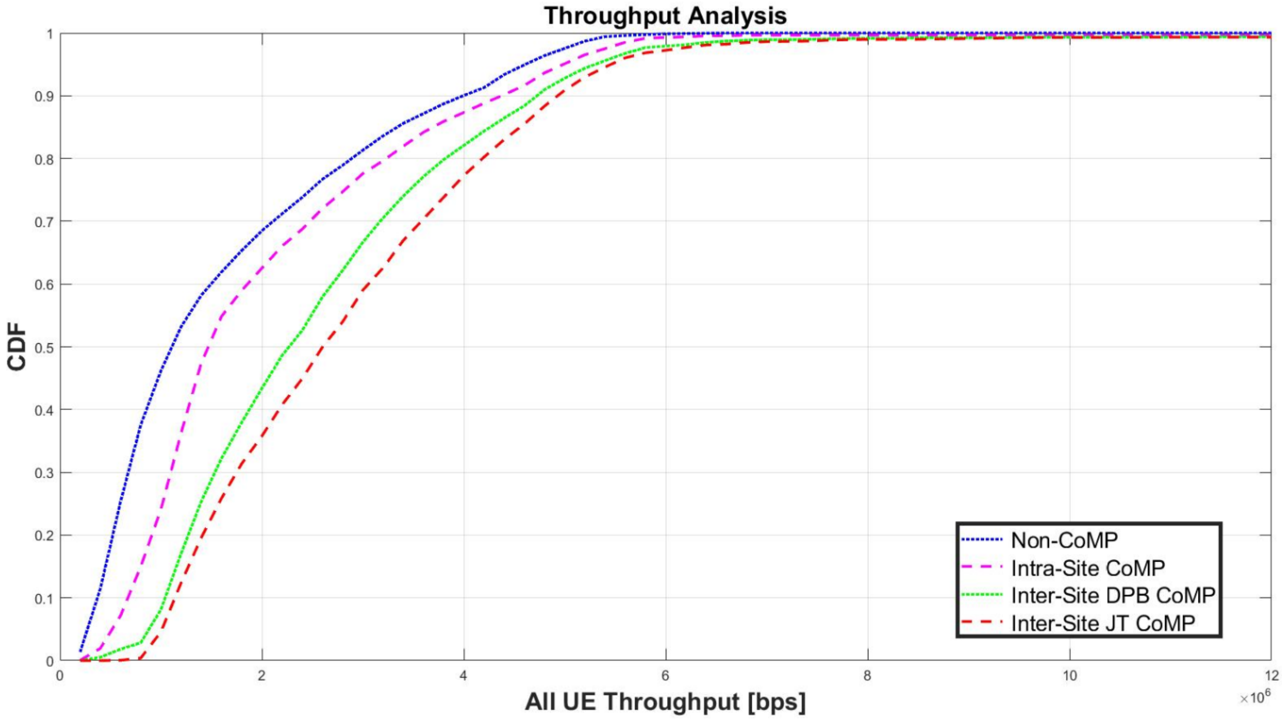


Figure 5.11: UE throughput performance analysis for non-CoMP and different CoMP schemes

In order to perceive the cell edge, cell average, and cell center throughput performance gain with respect to non-CoMP as a baseline are shown in Figure 5.12. The figure shows that it is clear that all CoMP systems can achieve a throughput improvement compared to the baseline non-CoMP systems. Taking the performance of the non-CoMP system as a reference, the cell edge throughput gain can be achieved at over 97% for JT CoMP, 68% for DPB CoMP, and 33% for inter-site CoMP. Moreover, the cell average user throughput gain was achieved at over 70% for JT CoMP, 45% for DPB CoMP, and 15% for the intra-site CoMP. The JT CoMP is the most interesting one in terms of applying a mechanism to mitigate the strongest interference, as it is the one providing the largest throughput values. This confirms that it helps to obtain more significant cell-edge throughput gains. However, it requires sharing more information among cooperating BSs, which unfortunately has a huge signaling impact on the backhaul network.

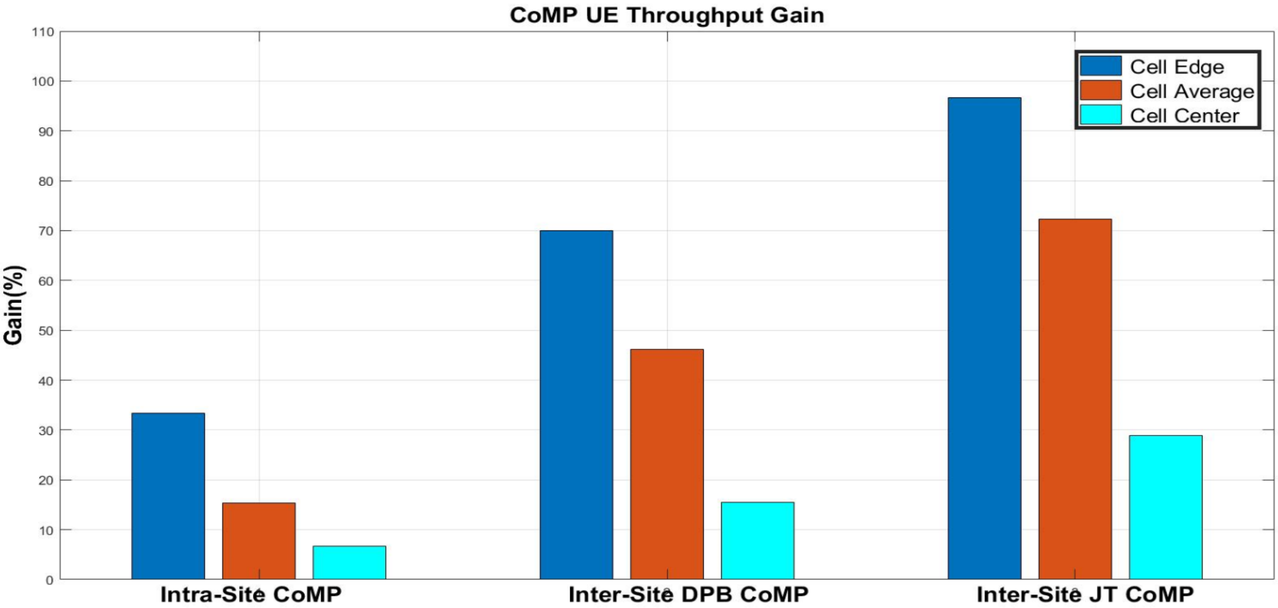


Figure 5.12: UE throughput gain under the CoMP scheme selection criteria

The foregoing findings show that CoMP approaches are a potential technology for LTE-A networks, particularly where cellular deployment is not very regular and uniform and cellular boundaries are complex, with changing user distributions. CoMP will thereby contribute to providing the end-user with a more uniform experience of mobile broadband across the network coverage. From the above results, we can conclude that all three CoMP techniques with a 10dB received power threshold can provide LTE-A network performance gain. It also demonstrates that the performance of JT CoMP is clearly superior to traditional approaches in all parameters examined. The simulation result shows that having to mitigate interference is necessary to maintain good service. In particular, the LTE-A network for the selected area, CoMP systems can efficiently mitigate the ICI and improve the coverage and throughput. Therefore, it is obvious that the CoMP technique is one of the important capacity enhancement methods that are being implemented.

Chapter 6

Conclusion and Future Work

The main goal of this thesis is to study CoMP as a technique for the management of interference to improve network performance. The thesis mainly focused on studying the effects of CoMP on improving UE performance and comparing the performance of real practical networks. This illustrates the deployment value of CoMP under intra-site and inter-site scenarios were simulated and analyzed. An initial analysis of the current LTE-A network in Addis Ababa was done in a static scenario to observe CoMPs' possible gains. With this assumption, one intends to calculate the gain between systems with CoMP and those without CoMP.

The results of the CoMP system simulation on the selected area show a significant improvement in SINR, spectral efficiency, and throughput. The simulation results show that CoMP brings major gains in both the cell edge and average UE of the CoMP systems. The inter-site CoMP always has a better performance gain than the intra-site CoMP systems. The SINR improves by approximately 1.5dB - 7dB when CoMP techniques are employed. When JT CoMP is used, the SINR performance is better as compared to other CoMP techniques. The throughput gain for inter-site JT CoMP can improve by 97% and DPB can improve by 68%, while for intra-site CoMP it can improve by 25% on cell edge UEs. These results show a large enhancement. Therefore, in the Addis Ababa LTE-A network for the selected area, CoMP will enhance the received signal quality as well as reduce interference, improve spectrum efficiency and enhance the effective coverage area and network performance. This is possible because the proposed algorithm attempts to find all possible cooperating base stations. From the results, it is apparent that JT CoMP is worthy of deployment on the LTE-A network in Addis Ababa.

Future research directions could include studying the effect of the backhaul on the CoMP system. As backhaul is the limiting factor in the performance of CoMP and in the current simulation, an ideal backhaul was assumed. In the future, simulations with a non-ideal backhaul will be studied. In addition, the uplink LTE-A network CoMP technique will be studied for interference mitigation. The CoMP resource scheduling technique is another important future work for CoMP deployment.

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