ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

TELECOMMUNICATION ENGINEERING GRADUATE PROGRAM

Performance Evaluation of CoMP in C-RAN-based LTE Advanced Networks: The Case of Addis Ababa, Ethiopia

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

November , 2021

Addis Ababa, Ethiopia

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Declaration

I, the undersigned, declare that the thesis comprises my work in compliance with internationally accepted practices. I have fully acknowledged and referred to all materials used in this thesis work.

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Abstract

The current Addis Ababa Long Term Evolution Advanced (LTE-A) network is being used to improve customer data service. Inter-Cell Interference (ICI), which is caused by a short inter-site distance paired with the use of frequency reuse factor one, has a major impact on mobile data network performance, particularly for users at cell edges. In order to mitigate ICI, the effect of Coordinated Multi Point (CoMP) on Cloud Radio Access Network (C-RAN) is investigated in this thesis. The concept behind C-RAN is to move traditional cell site digital baseband processing units and radio remote heads to the Base Band Unit (BBU) pool for centralized signal processing and management. C-RAN improves inter-cell interference with support of the CoMP technique in mobile networks, allowing for higher throughput. This is especially important as more additional base stations are deployed to increase mobile network capacity, allowing for effective interference management to improve performance.To evaluate the proposed solution, the present Addis Ababa LTE performance is simulated while considering CoMP joint transmission with the C-RAN architecture. The network performance is evaluated for a specified test case area in Addis Ababa, taking into account actual base station locations and city terrain data.

The paper focused on ICI mitigation in the Addis Ababa LTE-A network. The Signal to Interference plus Noise Ratio (SINR), spectral efficiency, and system throughput performance metrics were used to compare and evaluate CoMP coordination and non-CoMP systems of various sizes. The simulation is implemented in MatLab, and network radio propagation is computed in WinProp. The simulation findings show that utilizing CoMP on C-RAN improves the signal to interference plus noise ratio and throughput for both average and cell-edge users significantly in comparison to traditional CoMP. In terms of employing a method to reduce the strongest interference, large-scale CoMP coordination is the most interesting. This confirms that it results in an improved cell average and cell edge of up to 193.5% throughput performance. As a result, it has been demonstrated that the proposed interference mitigation solutions significantly improve network performance and are suitable for deployment on existing Addis Ababa networks.

Key words: C-RAN, CoMP, Inter-Cell Interference, Throughput, BBU pool, LTE-A networks, SINR

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List of Acronyms

3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
ADC	Analog-to-Digital Converter
BBU	Base Band Units
BS	Base Station
BW	Bandwidth
CA	Carrier Aggregation
CAPEX	Capital Expenditures
CB	Coordinated Beamforming
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CS	Coordinated Scheduling
CSI	Channel Status Information
C-RAN	Cloud RAN
CoMP	Coordinated Multi Point
CoMP-JR	CoMP Joint Reception
CPRI	Common Public Radio Interface
CQIs	Channel Quality Indicators
DAC	Digital-to-Analog Converter
DL	Downlink
EE	Energy Efficiency
ET	Ethio Telecom
eICIC	Enhanced Inter Cell Interference Coordination
eNB	Evolved NodeB
EPC	Evolved Packet Core
E-UTRAN	Evolved Universal Terrestrial Access Network
FDD	Frequency Division Duplex

GSM	Global System for Mobile Communications
HetNet	Heterogeneous Network
HSS	Home Subscriber Service
ICI	Inter-Cell Interference
ICIC	Inter-Cell Interference Coordination
JP	Joint Processing
JT	Joint Transmission
JT-CoMP	Joint Transmistion CoMP
LSCP	Large Scale Collaborative Processing
LSC	Large Scale Coordination
LTE	Long-Term Evolution
LTE-A	Long Term Evolution Advanced
MAC	Media Access Control
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
NCJT	Non-coherent Joint Transmission
OPEX	Operational Expense
OTN	Optical Transport Network
OFDMA	Orthogonal Frequency-Division Multiple Access
PDN	Packet Data Network
PDNGW	Packet Data Network Gateway
PHY	Physical Layer
PRB	Physical Resource Block
RB	Resource Block
RF	Radio Frequency
QoS	Quality of Service
RAN	Radio Access Network
RRH/U	Remote Radio Heads/ Unit
SDN	Software-Defined Networking
SE	Spectral Efficiency
S-GW	Serving Gateway

SINR	Signal-to Interference -plus Noise Ratio
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
UL	Uplink
ZFBF	Zero-Forcing Beamforming

Chapter 1

1. Introduction

1.1 Introduction

Mobile broadband traffic has been rapidly increasing over the last few years. Because mobile services are becoming increasingly vital in our daily lives. This implies that consumers increasingly demand their cell phones to perform dependably at any time and from any location, whether at home, at work, or on the go [1]. Furthermore, smartphone usage is on the rise, and tablet usage, as well as the bandwidth-intensive usage trends they encourage, such as video streaming, live video applications, social networking, online gaming, and autonomous driving, has increased demand for data traffic on cellular networks [1]. The total number of people that use mobile broadband is growing in line with the mobile network's data traffic. Mobile users are dissatisfied with the quality of service as the number of subscribers grows due to resource sharing and increased interference. Network optimization and expansion projects have been ongoing to increase service quality. Such an expansion would require the deployment of an increasing number of base stations (BS) to fulfill the needs of users, which would be extremely costly to deploy and run [2]. To maximize network capacity, the network is becoming increasingly heterogeneous due to the deployment of various types of BSs, and interference is becoming more difficult in such a network.

Because data traffic is expanding at an exponential rate, it is becoming increasingly difficult for telecom operators to upgrade their Radio Access Networks (RAN) because income is not growing at the same rate [2,3]. This exponential rise in cellular data traffic over time creates a difficult issue for future generations of cellular networks.Traditional RAN infrastructure, on the other hand, has several shortcomings, including limited system capacity, low system utilization, and high operational costs [4,5].

Ethio Telecom (ET) has installed a Long Term Evolution Advanced (LTE-A) network in Addis Ababa to meet the growing demand for mobile data traffic. Even though ET has made significant efforts to extend the cellular network infrastructure to attain more capacity and coverage throughout the nation. While trying to expand, it is critical to optimize the existing Addis Ababa LTE network to enhance its coverage, capacity, and quality.

Operators must discover ways to save costs while also providing better services to their clients to sustain profitability and growth. The Cloud Radio Access Network (C-RAN) design was recently proposed in this area [3,5]. The C-RAN is a new cellular architecture that is intended to effectively meet this issue. The primary difference between the C-RAN and traditional cellular architectures is that the Base Band Units (BBUs) are aggregated into a centralized BBU pool, allowing statistical multiplexing benefits [5].

The rapid advancement of mobile communication technology has greatly enhanced the speed and quality of wireless transmission. C-RAN offers the ability to lower network deployment and operation costs while also improving the system, mobility, coverage, and Energy Efficiency (EE). C-RANs, particularly for dense networks, can achieve low energy consumption, low interference, and low implementation costs.

To manage inter-cell interference, advanced techniques such as Coordinated Multiple-point (CoMP) work better, but they require close coordination between multiple cells, which the present RAN cannot provide. Furthermore, the existing RAN confronts many main challenges. However, because the centralized BBU pool controls multiple RRHs in the C-RAN architecture, synchronization is no longer a significant concern. As a result, synchronization is possible. CoMP is a good solution for increasing cell-edge data rate and system spectrum efficiency, allowing LTE-A to meet the high data rate demands of 4G mobile networks [5,6].

CoMP is expected to play a significant role in 5G systems and beyond. CoMP implementation, in which numerous RRHs are provided to edge users who typically experience high interference. It permits a user to be serviced by multiple BSs (RRHs in our case) using the same frequency block at the same time. As a result, It converts the interference signal into a useful signal. This contributes to a large improvement in Quality of Service (QoS), particularly for network edge users. As a result, using CoMP can significantly improve network performance. CoMP is difficult to implement in ordinary cellular systems because high synchronization between serving BSs is required.

The C-RAN has recently been presented as a promising architecture to address the fifth-generation (5G) wireless system's explosively expanding data demand. When ultra-dense Radio Units (RUs) are used in C-RAN, cell-edge users are necessarily subjected to significant inter-cell interference,

which reduces cell-edge coverage probability and throughput. CoMP can be used as a viable solution in C-RAN to reduce Inter Cell Interference (ICI) while also improving Spectral Efficiency (SE) [7].

1.2 Problem Statement

In Addis Ababa, LTE-A has been installed and is currently operational. However, because of the frequency reuse factor , one, large Signal to Interference plus Noise Ratio (SINR) zones are limited to the cell center. The signals from the serving cell and alternative neighboring cells for a user during a coverage area have small power variations, leading to a strong interference signal for the user. This results in a low SINR and, as a result, reduced user throughput. For users at the cell edge, the large interference signal is especially noticeable.Furthermore, when the number of users in a real network is small, the effect of ICI can be regulated by scheduling separate radio resources in each cell. However, as the number of users in each cell grows, all available resources are used up, making the ICI more difficult to operate.This condition leads to slower data rates for services like live video streaming, particularly for users in cell-edge areas.

The ET used a drive test measurement to determine the total Down Link (DL) interference level within a specific cell of the LTE-A system to address the DL LTE-A network interference problem. One sample site's data was extracted and analyzed using a four-month Addis Ababa LTE-A network log file. The SINR was too low, falling below 5 dB, as shown in Figure 1.1, according to the log file analysis report.

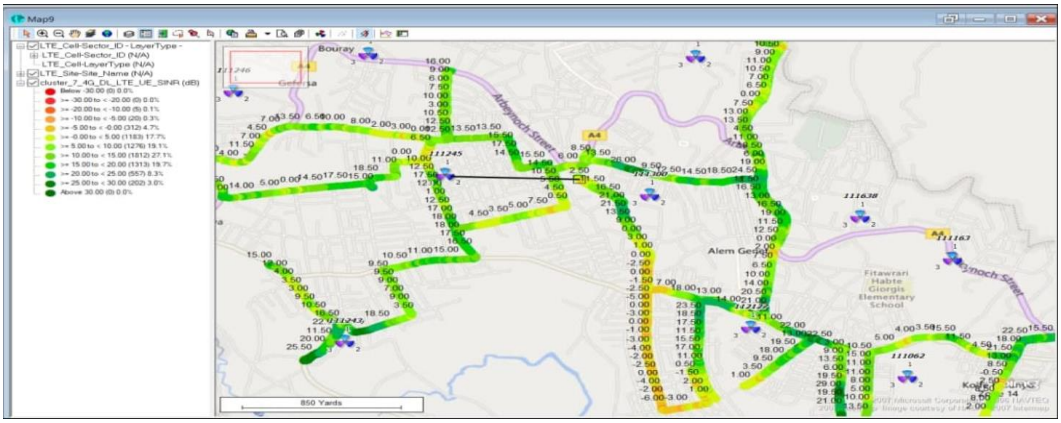

Figure 1.1 Downlink LTE-A network interference drive test analysis

The figure shows a lot of interference due to the low SINR. This indicates that interference has become a significant bottleneck for LTE-A network performance in some areas. ICI, in particular, is one of the most significant potential barriers, as it has a major impact on system and network performance. ET must deal with the interference by employing interference management to effectively manage the network for maximum efficiency.

1.3 Objective

1.3.1 General Objective

The general objective of this paper is to study the performance evaluation of CoMP coordination in the DL LTE-A network in a C-RAN-based architecture in the case of Addis Ababa, Ethiopia.

1.3.2 Specific Objectives

The following are the specific objectives of this paper work that will be achieved:

- ✓ Conduct a literature review on the topic of intereference management.
- ✓ Examining the impact of interference on the ET LTE-A network's performance.
- ✓ Examine the architecture of C-RAN in order to reduce interference.
- ✓ Compare the performance evaluation of cell edge and cell average users using CoMP with different cell coordination.
- ✓ Examine the findings and make recommendations regarding ET's LTE-A network architecture.

1.4 Scope and Limitations

1.4.1 Scope of the Study

The scope of this thesis work is to analyze the C-RAN-based architecture with the CoMP approaches in order to improve overall DL performance in the LTE-A network. Evaluate its performance with selected simulation tools by considering a similar ET network scenario and simulation

parameters. The network performance evaluation and optimization are also carried out for the Addis Ababa LTE-A network, which consists of three-sectioned 24 evolved NodeBs (eNBs), i.e., 72 cells in the Legehar area.

1.4.2 Limitations of the Study

The study is limited only to CoMP cell coordination in the C-RAN network. Due to time constraints, the study is limited to LTE-A networks. This study is limited only to internal interference in the Addis Ababa area. Hence, the outcomes of the study do not consider regional ET cellular networks. The datasets are limited to the LTE-A network's DL data service, and propagation is based on an outdated digital map of Addis Ababa, making it difficult to obtain a complete picture of the topography.

1.5 Methodology of Research

The approach that was used in this study is grouped into three main sections, as shown in Figure 1.1. Firstly, the survey part will identify the interference problem and assess ET interference management procedures through interviews with the ET engineering team and review of relevant documentation, as well as assessments of articles related to interference management and network architecture. Second, the study and investigation part includes literature assessments on interference mitigation techniques and related new technology to address this challenge. Journals, articles, conference papers, white papers, and other works of literature are included in this section. Following a review of the literature, the problem is aligned with state-of-the-art recognized problems and solutions. Then, gather the necessary data from the ET network management system, and evaluate the present ET RAN architecture and interference management technique. Finally, the implementation part, WinProp network simulation, is carried out. Matlab is also used for simulation and performance evaluation through the plotting of figures and the reporting of results. Based on the output, it concludes and makes recommendations. Figure 1.2 depicts the overall technique.

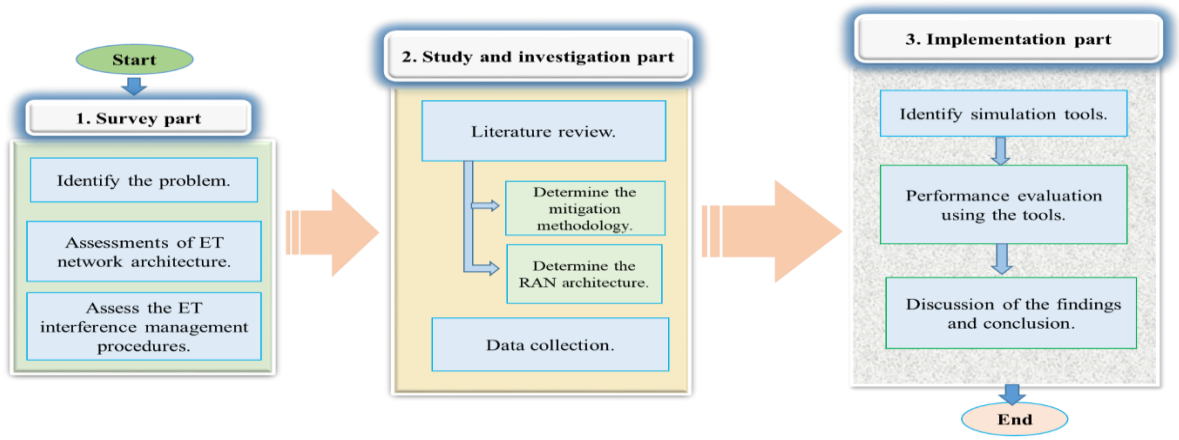

Figure 1.2 Research methodology

1.6 Contribution of the Study

The finding contributes to the ICI management techniques that can be achieved in LTE-A networks through large-scale cell coordination in the CoMP technique. These methods can help to improve the coverage and performance of DL networks in terms of users and cell throughput. The research also examines how ET interference is currently handled and how it affects overall network performance.

1.7 Related Work

Many researchers have already undertaken research on the optimization of RANs based on CoMP in the C-RAN architecture. A brief review of the literature on selected papers is provided below.

In [7], they present a tractable framework for analyzing the performance of two common CoMP techniques, namely Zero-Forcing Beam Forming (ZFBF) and Non-Coherent Joint Transmission (NCJT). The researchers analyze the SINR distribution for a typical Down Link (DL) user using a stochastic geometry-based technique. Furthermore, they analyze the impact of poor Channel State Information (CSI) on the typical user's coverage probability from a practical design standpoint. It has been discovered that ZFBF outperforms NCJT only when there is enough overhead to express the quantized CSI. In conclusion, this work provides a suitable starting point for comparing the effects of CoMP approaches in C-RAN. As a result, in a C-RAN, CoMP is an effective strategy for increasing cell-edge coverage probability and throughput. In [8], this paper shows that the C-

RAN has given excellent spectrum efficiency and EE as a promising paradigm for reducing both capital and operating expenditures. This study also discusses system architectures with various functional splits and the accompanying properties. The state-of-the-art key approaches in C-RANs are fronthaul compression, large-scale collaborative processing, and channel estimation at the Physical Layer (PHY), and radio resource allocation and optimization in the upper layer.

In [9] , To reduce inter-cell interference, the CoMP in LTE-A networks and large-scale coordination in C-RANs are shown. They look at the effects of network density and imperfect channel state information in particular. Despite the network density, modeling studies demonstrate that the LTE-A CoMP approach achieves nearly the same performance improvement as the non-CoMP scheme. Fortunately, the C-RAN can take advantage of dense access point deployment, increasing average and edge throughput by several times. The C-RAN, on the other hand, is more sensitive to channel accuracy, necessitating a strong optimizing architecture. As a result, the findings might be used to advise operators on how to improve network performance in congested hotspot scenarios by carefully deploying C-RANs.

In [10] and [11], simulations are used to investigate the performance of Joint Transmission CoMP (JT-CoMP) over LTE- A HetNets. [10] focuses on the impact of backhaul dependability (X2 interface, no C-RAN present) on JT-CoMP performance in terms of CoMP set throughput in terms of Link Failure Probability (LFP). [11] employs a C-RAN architecture for the LTE-A HetNet and investigates the impact of grouping eNBs into fewer but larger CoMP sets on spectral efficiency, resulting in a well-known SE increase for users at the cell edge as the CoMP set grows.

[12] and [13] use simulations to investigate the performance of CoMP Joint Reception (CoMP-JR) in LTE -A networks. [12] investigates heterogeneous and homogeneous networks with different receiver algorithms, channel estimations, and CoMP techniques, both deployed on a C-RAN architecture. The effect of these parameters on CoMP-JR is evaluated. The effect of CoMP set size on CoMP-JR is investigated in [13]. [14], [15], and [16] describe the CoMP-joint processing field trials, all of which were conducted outdoors and on various testbeds. [14] examines the performance of JT-CoMP over an LTE-A network using the X2 interface to transfer information between eNBs. User Equipment (UE) throughput rises when JT-CoMP is used between two serving eNBs in an urban area. [15] evaluates the CoMP-performance Joint Reception in terms of throughput at the user end when deployed on a C-RAN testbed, including intra-site and inter-site findings.

In [17], field trials are being used to test DL CoMP transmission on a mobile radio network. They evaluated both intra-site and inter-site CoMPs. According to the study's findings, cell throughput improvement spans between 27 and 78 percent for the DL CoMP. Although the study found a throughput improvement, the experiment was conducted with only two isolated cells, without taking into account interference from non-cooperating BSs in the surrounding area. This study explored the C-RAN architecture's important components, key techniques, and challenges in the context of upcoming 5G wireless communication systems[18]. The researcher examined important C-RAN components, the functional split between the BBU and RRH, and signal processing algorithms for uplink and DL transmission. Compression and quantization approaches for C-RAN uplink and DL transmission were also investigated to properly utilize the limited capacity of fronthaul links. In addition, in order to meet the requirements of green communications, resource management systems for energy savings were discussed. To maximize possible performance advantages, Software-Defined Networking (SDN), HetNets, mmWave, and full-duplex communications can be integrated with C-RAN to improve network capacity, SE, EE, network throughput, and operational flexibility [18].

Overall, the findings of the above literature studies indicate that when network deployment, receiver algorithm, channel estimate accuracy, and reference signal orthogonality are considered, CoMP increases network performance. C-RAN can be integrated with SDN, HetNets, mmWave, and full-duplex communications to boost capacity, SE, EE, network throughput, and operational flexibility.

1.8 Research Organization

The following is how this thesis work is organized. The second chapter introduces the LTE network and discusses interference control. C-RAN is explained in Chapter three and includes the C-RAN architecture, deployment, benefits, and challenges. The fourth chapter provides an overview of the Addis Ababa LTE network and network modeling and simulation assumptions that will be studied. This chapter also introduces the propagation modeling software WinProp. The simulation results and performance Comparison discussion are carried out in Chapter five. Finally, Chapter six concludes and gives insight into future work.

Chapter 2

2. LTE Network and Interference Mitigation

2.1 Overview of LTE Network

Long term evolution (LTE), also known as 4G LTE, is a set of third generation partnership project (3GPP) standards in which the DL radio interface is based on Orthogonal Frequency Division Multiple Access (OFDMA) and the Up Link (UL) radio interface is based on Single Carrier-Frequency Division Multiple Access (SC-FDMA). LTE was created primarily for packet data communications, with great spectrum efficiency, high peak data rates, low latency, and frequency flexibility as its main goals. The predecessors of LTE are the Global System for Mobile Communications (GSM) and the Universal Mobile Telecommunication System (UMTS), which are referred to as Second-Generation (2G) and Third-Generation (3G), respectively. GSM is a circuit-switched network in which radio services are set up and resources are allocated at the user's request until the network controller terminates the network. GSM was later modified with packet switching capacity to enable low data rate services, although data rates were limited by GSM's air interface and time division multiple access. Because the channel spacing is just 200 kHz, each user in time division multiple access is assigned to a specific channel (frequency band) and time slot, which serves to limit capacity [19,20].

The air interface for UMTS is a Code Division Multiple Access (CDMA). Active users broadcast over the assigned BW at the same time, which is typically 5 MHz in CDMA. For voice calls and data connections, UMTS enables both circuit and packet-switched services. UMTS can offer faster data rates than GSM due to its wider BW and spectral efficiency. Unlike GSM and UMTS, LTE is a packet-switched network that uses the Internet Protocol (IP) to carry data services. LTE employs OFDMA, which divides the spectrum into resource blocks made up of twelve 15 kHz subcarriers [19].

A transmission based on Orthogonal Frequency Modulation (OFM) is used for DL communication. The idea behind this modulation is to employ numerous subcarriers and split the overall data rate of the system among them. It is feasible to eliminate the conventional guard bands and increase

the channel SE using the idea of orthogonality between subcarriers. The multiple access technique is OFDMA, which is a multiple access variant of Orthogonal Frequency Division Multiplexing (OFDM). The aim is to allow different users to utilize various sets of subcarriers to transmit their information. The constant frequency gap between subcarriers has been set at 15 kHz. To prevent inter-symbol interference (ISI), each symbol has a Cyclic Prefix (CP) [19].

Higher-order modulation techniques up to 64-QAM are supported by LTE, with BW share ranging from 1.4 MHz to 20 MHz. Furthermore, LTE employs Multiple Input Multiple Output (MIMO) technology to deliver theoretically very high data rates (75 Mbps in the uplink and 300 Mbps in the DL for Release 8 [19]. Only shared resources are used by LTE. All resource allocations and assignments are handled by a scheduler at the BS (known as eNB in LTE).

The radio access technique based on OFDMA is a major aspect of LTE. The main concept of OFDMA is to use a large number of orthogonally spaced, densely spaced carriers. Both in the frequency and temporal domains, resources can be dynamically assigned. This allows for very flexible use of available resources. In most LTE systems, the frequency reuse factor is one, which means that all cells operate at the same frequency. As a result, inter-cell interference is very significant in these systems. A relatively high ratio (up to a factor of 10) between peak throughput and cell edge throughput is seen [21].

2.2 Network Architecture

LTE was designed to enable only Packet-Switched (PS) services, as opposed to prior networks' circuit-switched approach. The purpose was to offer continuous connectivity via the Internet Protocol (IP) between the UE and the Packet Data Network (PDN). The LTE Evolved Universal Terrestrial Radio Access (E-UTRAN) network is the evolution of the UMTS radio access, and it is complemented by the enhancement of other network elements, such as the Evolved Packet Core (EPC) network, known as the System Architecture Evolution (SAE). LTE and SAE are the two key components of 3GPP's Evolved Packet System (EPS) [19].

The Figure 2.1 illustrates the entire network architecture, including the core components and their interfaces. A dashed line denotes a control-plane connection, while a solid line denotes a user-plane connection. The network is comprised of four main domains that are identical to those seen in prior systems: services, EPC, E-UTRAN, and UE. The most significant advances in LTE were

made in the E-UTRAN and EPC. E-UTRAN is made up of only one node in a flat architecture known as eNB. eNodeBs are typically dispersed throughout the coverage area, controlling one or more cells and handling all radio communications between the UE and the EPC. Unlike earlier technologies, the X2 interface connects several eNodeBs and is primarily utilized to provide UE mobility and multi-cell capabilities, such as Inter Cell Interference Coordination (ICIC), creating a distributed control system [19].

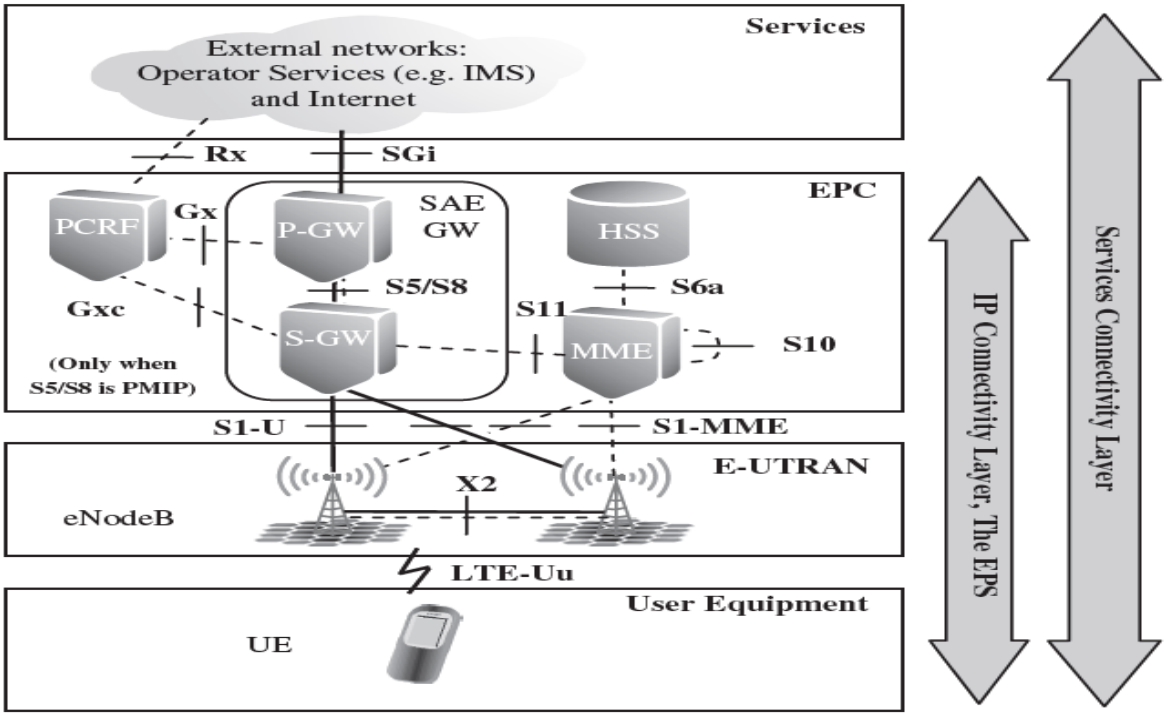

Figure 2.1 Overall EPS architecture of an LTE System [22]

The EPC from Figure 2.1 has five functional elements [22]. These are

Home Subscriber Service (HSS): Users' data, such as the subscribed QoS profile and roaming limitations, are stored in HSS. It also maintains a record of the permitted PDN connections and the user's location at the level of the visited network control element, such as Mobility Management Entity. It may contain the Authentication Center.

The Serving Gateway (S-GW): This is the component responsible for routing and sending user data. It also maintains user mobility handovers between eNodeBs and between LTE and other 3GPP technologies. Furthermore, the S-GW organizes and saves UE data.

The Mobility Management Entity (MME): is the access control node for the LTE network, and it's in responsible of tracking and paging the UE while it's in standby mode. MME also chooses the S-GW for a UE during initial connection and handover, including a change in a core network node. When authenticating a user, the MME communicates with the HSS, which is a master user database that supports IP Multimedia Subsystem and stores subscriber information.

The Packet Data Network Gateway (P-GW): connects the UE to external packet data networks. Furthermore, the PDN GW facilitates 3GPP and non-3GPP technologies such as WiMAX, CDMA 1X, and Ev-DO provide user mobility.

The Policy and Charging Rules Function (PCRF): is in charge of managing the service policy and sending information about QoS settings and accounting rules for each user session.

The eNBs are linked together via the X2 interface, and they are additionally linked to the MME and S-GW via the S1 interface. Radio resource management, admission control, scheduling, and compression/decompression of user plane packet headers are all functions of the eNB [23].

2.3 Base Station Architecture Evolution

Users communicate with a BS that services the cell under which they are located in traditional cellular networks. Baseband processing and radio functionalities are the two major capabilities of a BS. Figure 2.2 shows the key sub-functions of the baseband processing module on the left side. Coding, modulation, and the Fast Fourier Transform (FFT) are just a few examples. Digital processing, frequency filtering, and power amplification are all handled by the radio module. The figure depicts the interconnection and function split between BBU and RRH. This architecture was developed during the deployment of 3G networks, and it is currently used by the majority of BSs [21].

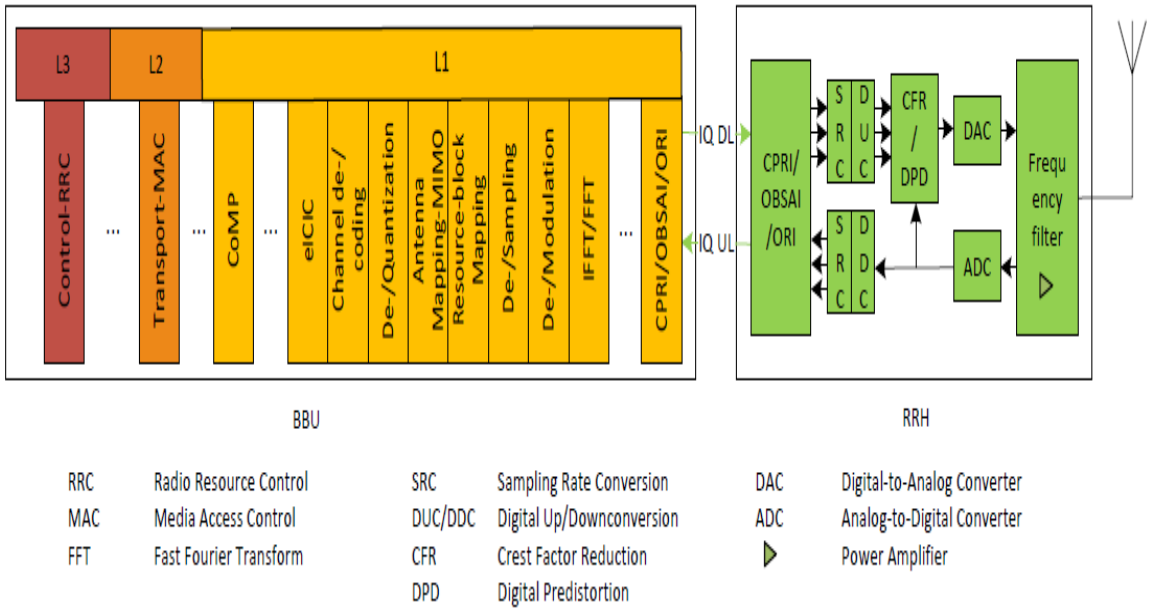

Figure 2.2 Base station functionalities [21]

2.3.1 Traditional Architecture

Radio and baseband processing functionality is contained inside a BS in the traditional architecture. Because the coaxial cables used to connect them have high losses, the antenna module is usually placed close to the radio module (a few meters away), as shown in Figure 2.3a. The X2 interface connects BSs, while the S1 interface connects a BS to the mobile core network. This architecture was widely used in the deployment of First Generation (1G) and Second Generation (2G) mobile networks [8,21].

2.3.2 Base Station with Remote Radio Heads

As illustrated in Figure 2.3, a BS with RRH architecture is divided into a radio unit and a signal processing unit. The radio is known as an RRH or Remote Radio Unit (RRU). RRH handles digital processing, digital to analog conversion, analog to digital conversion, power amplification, and filtering as well as providing the fiber interface. A BBU, or Data Unit (DU), is the portion that processes baseband signals. A BS is separated into an RRH and a BBU in 3G and 4G cellular networks. The BBU can be located far from the RRH in this BS architecture for reduced site rental

and maintenance convenience. A BBU is transferred into a BBU pool that is virtualized and shared by different cell sites in the 4G beyond, and RRHs are connected to the BBU pool via fronthaul links, resulting in a general C-RAN architecture [8,21].

The maximum separation distance between BBU and RRH in C-RAN is restricted to fifty seconds of delay and is set by the network's range of nodes. This range of network nodes restricts the greatest separation distance between BBU and RRH; because the range of nodes will increase, the link length will decrease. In C-RAN, however, the largest separation distance between BBU and RRH is 25 kilometers [24].The distance can be extended up to 40 km [21], with processing and propagation delay being the limiting factors. Microwave and optical fiber connections are both good alternatives. When compared to traditional RAN architecture, where a BBU must be placed close to the antenna, this architecture allows the BBU equipment to be placed in a more convenient, easily accessible location, resulting in cost savings on-site rental and maintenance. RRHs can be mounted on poles or rooftops, allowing for more efficient cooling and lower air conditioning costs in BBU housing. RRHs, like conventional RANs, are statically assigned to BBUs [21].

2.3.3 Centralized Base Station Architecture C-RAN

In C-RAN, BBUs are centralized into a single entity termed a BBU/DU Pool/Hotel to optimize BBU utilization between heavily and weakly loaded BSs. As shown in Figure 2.3c, a BBU pool is shared between cell sites and virtualized. A BBU Pool is a virtualized cluster that performs base-band (Physical (PHY) or Media Access Control (MAC) Layer) processing using general-purpose processors. Inter-cluster communication is organized using the X2 interface in a new form known as X2. From the RRHs to the BBU Pool, the network's fronthaul section runs. The BBU Pool is connected to the mobile core network via backhaul. RRHs are co-located with antennas at remote sites. Low-latency, high-BW optical transport links connect RRHs to the BBU Pool's high-performance processors. Digital baseband, or Inphase/Quadrature (IQ) samples, are sent between an RRH and a BBU [21].

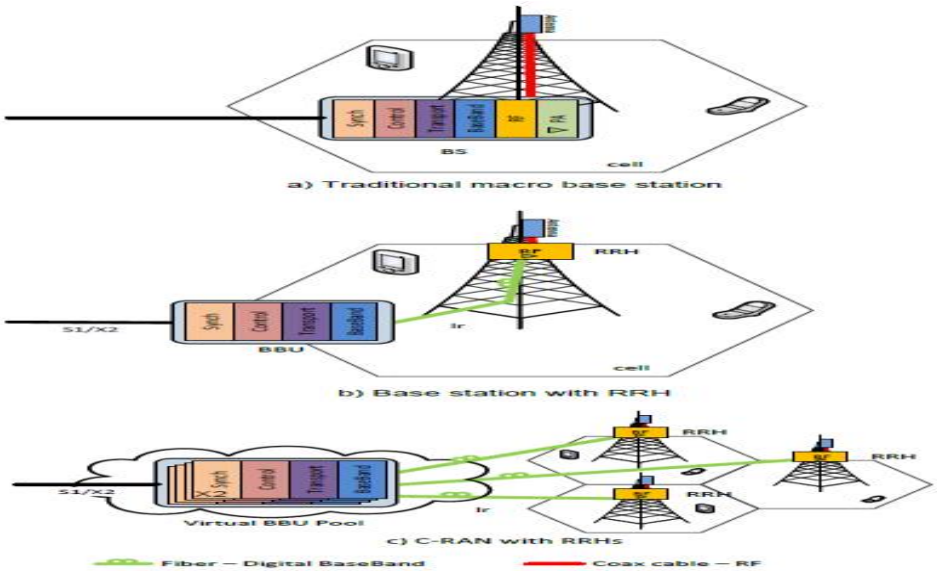

Figure 2.3 Base station architecture evolution [21]

2.4 Inter-cell Interference and Coordinated Interference Management

ICI is a significant issue that has an impact on the data rates of users near the cell edge as well as the cell's average spectral efficiency. Increase the frequency reuse factor, which defines the minimum distance between cells operating in the same frequency band, to reduce overall inter-cell interference. Network coordination requires selecting antennas from various BSs in such a way that signal power is maximized while inter-cell interference is reduced. The use of network coordination at high SINR ratios can also result in a significant gain in spectral efficiency. By communicating cell information among several BSs, BS coordination improves the user experience at the cell edge [25].

Because of the extensive deployment of RRHs, which considerably reduces SE and EE of C-RANs, interference should be severe without enhanced interference coordination solutions in C-RANs. The centralized Large-Scale Collaborative Processing (LSCP) procedures should be used in the BBU pool to reduce interference and hence improve SE and EE [8].

[26] To demonstrate this to decrease interference in HetNets, 3GPP LTE Release 10 Enhanced Inter Cell Interference Coordination (eICIC) approaches have been developed, which are classified into three key categories: time-domain techniques, frequency-domain techniques, and power control techniques. However, interference management techniques can be classified into the following groups depending on network deployment and consideration of various characteristics of interference:

Decentralized Interference Management: There is no coordination between cells in approaches like fractional frequency reuse, advanced receivers, distributed power control, and static resource partition.

Coordinated Interference Management: eICIC, joint power control, and CoMP communications are examples of approaches in which neighboring cells interact with each other using overhead messaging to manage network interference jointly. In our case, this coordination method is used.

Resource Management-based Interference Management: The main goal of resource management and radio resource management (RRM) in Heterogeneous Cellular Networks (HCNs) is to allocate resources between macrocells and smallcells, to handle handovers, and to schedule packets.

Hardware-based Interference Management: There are numerous hardware-based interference management approaches, including the directional antenna and a multichannel multi-antenna-based beamforming-codebook-restriction scheme, that allow Femtocell users to choose the channels that are least affected by cross-tier interference.

Multi-Cell Coordination

Multi-cell coordination is intended to increase system throughput and coverage, satisfy traffic demands, optimize radio resource consumption, and improve SE per unit area. It works by reducing inter-cell interference and thereby increasing system capacity. Multi-cell coordination happens

among numerous neighboring cells, which means cooperative cells share scheduling or data information with one another to reduce inter-cell interference or increase the power of received signals at the user end [27]. Figure 2.4 shows multi-cell coordination.

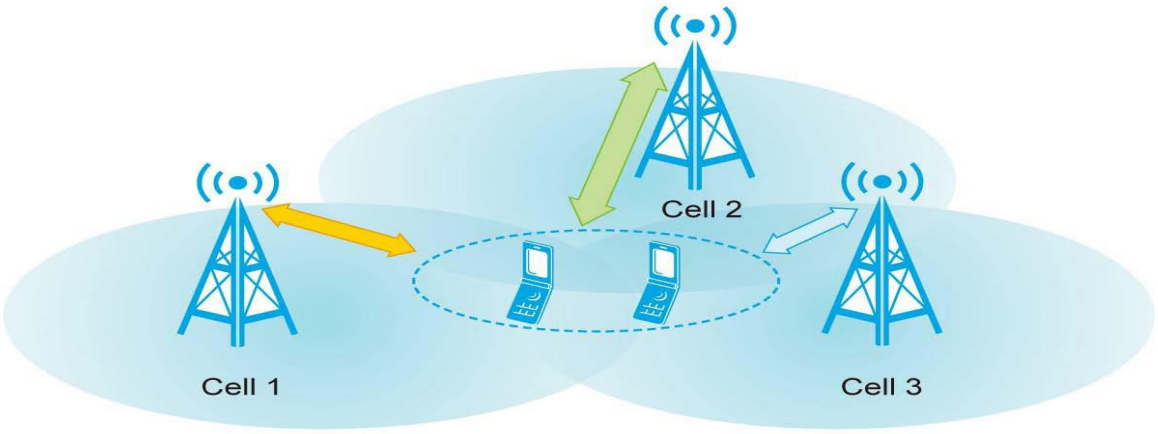

Figure 2.4 Multi-cell coordination [27]

There are now many features in the 3GPP LTE and LTE-A specifications that may be utilized to decrease interference in HetNets with small cells. LTE: ICIC, Carrier aggregation (CA) with cross-carrier scheduling, eICIC, and CoMP, which uses the Channel Status Information (CSI). Some of them are discussed in the below section.

2.4.1 Inter-Cell Interference Coordination

ICIC was launched in Release 8. Under this system, UEs can notify the eNB if they are experiencing significant interference on specific sub-carriers. The eNB can then coordinate with the adjacent cell (through the X2 interface) to ensure that these sub-carriers are not used for that particular mobile. It's interesting to note that this only applies to cell-edge devices. There is no interference around the cell's center, therefore the entire resource (i.e., frequency band) set can be used. Both UL and DL are supported by the scheme. Relative narrowband transmit power is a bitmap providing information on the transmit power of each Resource Block (RB) that the eNBs can exchange in DL. In the UL, there are reactive approaches that use overload indicators and proactive ways that use HII (High Interference Indicators). This approach is simple and does not necessitate

eNB synchronization; only load and schedule information must be shared. The drawback is that if neighbor cell interference is taken into account, the scheduler in each eNB may make less optimal scheduling decisions. Furthermore, because control channels are sent on fixed resources, they continue to interfere. This approach is slow enough to work in networks with a distributed BS architecture without causing problems [21].

2.4.2 Enhanced Inter-Cell Interference Coordination

eICIC approaches have been developed for 3GPP LTE Release 10, which are classified into three primary groups [28]: Time-domain techniques [29], Frequency-domain techniques, and power management techniques, to reduce interfering in HetNets [26]. eICIC was first launched in Release 10. eICIC utilizes the time domain by providing almost blank sub-frames, which mutes specific sub-frames (in reality, they aren't fully muted). Some signals, such as the common reference signal, are still delivered to make them backward compatible with Release 8, hence the term "almost blank." There will be (nearly) no interference if one transmission is muted, and this interference-free time interval can now be used to communicate vital information, like signaling and reference signals. The X2 interface is used to coordinate the actual muting pattern to be used between the eNBs. Interference issues can also be solved by utilizing the power domain. In HetNet scenarios, these approaches are most useful in the UL direction. The idea is to manage interference between the pico and macro layers by dynamically controlling the transmit power of the mobile station [21].

2.4.3 Coordinated Multi-Point

CoMP is a 3GPP Release 11 feature that can improve a UE's signal in areas where there is a lot of interference. It manages the ICI to help UEs, particularly those with weak QoS, improve their performance. The essential concept behind CoMP is that many BSs serve a UE at the same time, either by sending/receiving the same data or by scheduling UEs in each BS to prevent the ICI. As a result, the desired power received will grow, while interference power will decrease.

CoMP's main idea is that multiple BSs in a cooperating set serve the same UE at the same time, either by sending/receiving the same data or by scheduling UEs in coordination to avoid unneces-

sary interference. The coordinated transmission increases the power of desired signals while reducing interference power. The most advanced method of dealing with inter cell interference is CoMP, and it is based on the principle of changing interference into a useful signal. This enhances the mobile's SINR, resulting in greater achievable data rates. Release 11 of the specifications includes it. Using CoMP, several cells, organized into a so called CoMP set, work together to serve one or more users based on feedback from the mobile devices. This needs precise synchronization and cooperation among the BSs in a CoMP system, especially in DL. CoMP allows for intra-site or inter-site cooperation. The two types of CoMP systems are depicted in Figure 2.5 [21,25,27].

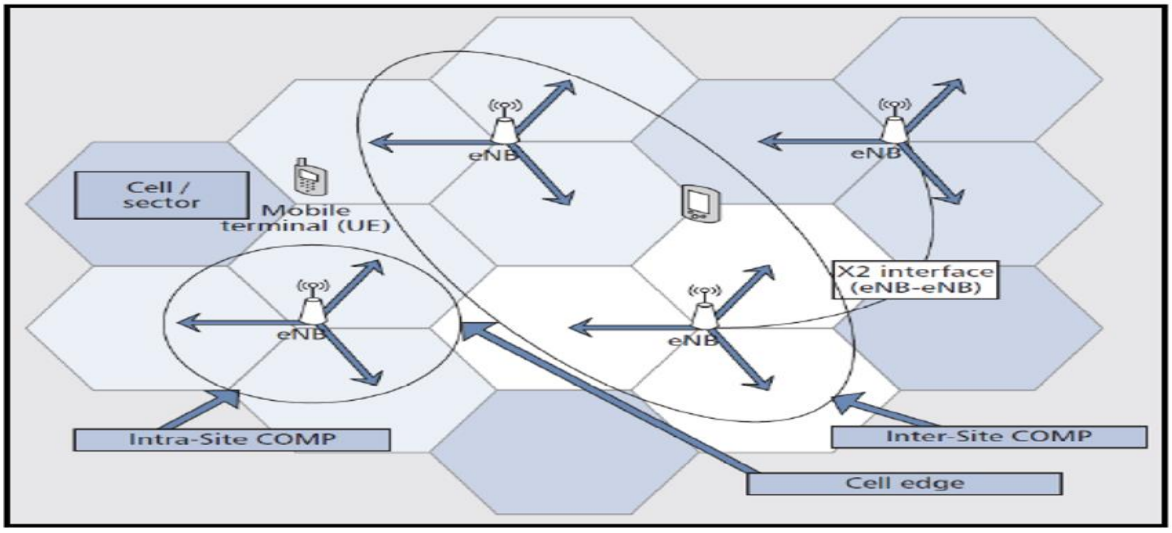

Figure 2.5 Base station Cooperation: Inter-site and Intra-Site CoMP [27]

Coordination between eNBs is a viable strategy for reducing network inter-cell interference in both the DL and uplink. In the DL, CoMP is used to reduce interference by performing a coordinated transmission from the BS, but in the uplink, interference can be reduced by performing a coordinated reception in eNBs. The majority of CoMP approaches have the same requirement of requiring some scheduling information about the users at the various BSs to be exchanged among them. This requires the use of links with low latency so that information may be transmitted across coordinated nodes in milliseconds [25].

The UE transmission power is pooled once it is received from several cells. More significantly, harmful interference can be converted into a useful signal by merging channel information from surrounding cells, which will enhance the performance. CoMP has the potential to significantly

improve coverage and capacity. Many factors can influence CoMP gain. From the standpoint of implementation, it is dependent on network deployment, receiver algorithm, and channel estimation accuracy. CoMP performance is dependent on accurate channel estimation, which means the accuracy of the channel estimate decreases, resulting in a lower CoMP gain. In a dense network, CoMP performs better. Furthermore, increasing the size of the CoMP region improves the gain. In the downlink, the CoMP scheme is divided into two types: Joint Processing (JP) and Coordinated Scheduling/Beam Forming (CS/CB). Many BSs give the same data to the UE in JP to promote spatial variety and minimize dominating inter-cell interference. In downlink CoMP, various techniques such as Joint Transmission (JT) and dynamic point selection can be employed to achieve JP. At the same time, JT distributes data to all UEs at the same time, whereas DPS uses a rapid point selection approach, with only the best channel condition delivering data in a single subframe. The two types are discussed below [6, 27]:

Joint processing

Multiple BSs provide the same data to the UE in JP to increase spatial variety and reduce dominating ICI. In fact, in downlink CoMP, JP can be implemented using a variety of techniques, like joint transmission and dynamic point selection. The main difference between these two techniques is that JT sends data to UE simultaneously, whereas DPS employs a fast point selection approach, with only the optimal channel condition transmitting data in a single subframe. The two approaches are discussed below.

1. Joint Transmission

Using this technique, data to a single UE is broadcast coherently or incoherently from multiple transmission points in the same resource block. Interfering signals from nearby cells are converted into useful signals, lowering interference levels while increasing the power of the desired signal. As a result, the SINR of the cell edge user, who is more likely to have poor signal and high interference, can be significantly increased. Furthermore, when implementing JT, using a fixed set or all of the transmission points wastes network resources. As a result, dynamically determining the serving set of eNBs that will form a CoMP cluster is extremely important. A semi-static or static setup for a CoMP cluster of transmission points is possible. Later, as more CQI, or CSI data is

collected from UEs, the serving points in the corresponding CoMP set can be changed based on service quality and traffic load. Points with poor service quality are removed from the set, and their resource utilization is improved by serving other UEs. JT is the most advanced CoMP scenario. The data to be sent is also available to all cells in the CoMP set in JT, but in this situation, numerous cells transmit to one user jointly and coherently. It relies on highly timely and precise feedback from the terminal on the combined channel's property from several BSs. To accomplish this, a new set of CSI reference signals were created and integrated into the system [21, 27].

2. Dynamic Points Selection

Another joint processing approach is dynamic point selection, which ensures that the signal to a specific UE in a CoMP cluster is always sent from a single transmitted point at a time. The corresponding CSI is frequently reported by UE to all points engaged in the serving set of eNBs. As a result of the CSI feedback and realistic resource utilization to serve the UE, a conclusion has been reached. If there is a possible point that can provide better service, that point will automatically take the place of the previous one in sending the signal to the UE in the next subframe. However, from the standpoint of UE, the method for switching between various sites in the CoMP cluster is transparent.

Coordinated scheduling/beamforming

Unlike JP, CS/CB only has one transmission point from which user data can be accessed and transmitted. However, information on the UE's channel state for each transmission point in the CoMP cluster should be shared. To deploy a basic CS/CB strategy, BSs in the CoMP cluster ask the UE to send back channel information, which comprises the downlink channel state of all available serving BSs. Each BS is locally precoded and the UE is scheduled in the subframe with the best resources and channel quality based on reports. Following that, each cell must maintain an update status on the coordination status for each UE. The premise is that each scheduling decision should take into account the utility of both the planned UE and the victim UE scheduled by other cells. Any modification to a scheduled beam in the next subframe in a specific cell is likely to have an impact on all other scheduling decisions in that cell.

Chapter 3

3. Cloud Radio Access Network

3.1 Introduction

C-RAN was first introduced by China Mobile in 2009 to accommodate such a rapid growth in mobile networking. It is a new mobile architecture that, via the use of virtualization, can manage as many BSs as the network requires. In a centralized baseband pool, C-RAN virtualizes and shares baseband and channel processing among operators.Such centralization and sharing allows for more dynamic traffic handling and better utilization of resources, including BS deployments. Such an architecture would have the potential to decrease the cost as BSs are virtualized instead of physically deployed in different areas [2].

LTE-A is the most recent mobile network standard developed by the 3GPP in Releases 10 and 12. In a C-RAN architecture, any mobile network standard might be implemented. LTE and LTE-A are the most common standards to be installed as C-RANs because LTE is currently deployed all over the world. C-RAN is an innovative architecture that can reduce RAN operating costs, increase system scalability, lower costs, lower power consumption, improve wireless transmission performance, and maximize resource utilization [2,4,21,29].

The requirement for a very low degree of latency is one of the fundamental requirements for LTE-Advanced. Information sharing across sites and coordinated processing from many nodes could cause substantial delays. To address this issue, C-RAN is expected, with multiple locations potentially connected [6]. The primary idea behind C-RAN is to separate traditional cell site digital BBUs from RRHs and relocate them to the cloud (BBU pool) for centralized signal processing and management [3,30].

Based on the centralized cloud principle of sharing storage and computing resources via virtualization, the C-RAN is a breakthrough combination of emerging technologies from both the wireless network and information technology industries that has the potential to improve SE and EE. The virtualized BBU pool provides LSCP, cooperative radio resource allocation, and intelligent networking, while RRHs with radiofrequency functions support high capacity in hot spots. The BBU pool connects with RRHs via the Common Public Radio Interface (CPRI) protocol, which

comprises control plane and data plane requirements and supports a constant bit rate and bidirectional digitized In-Phase and Quadrature (I/Q) transmission [8]. In comparison to traditional LTE networks, a quantitative cost analysis of C-RANs was presented, and it was proven that C-RANs could result in a capital expenditure (CAPEX) decrease of 10% to 15% per kilometer (km). Meanwhile, C-RANs allow for the flexible deployment of scarce radio and computing resources across all RRHs that are centrally processed by the same BBU pool, resulting in statistical multiplexing advantages due to the load balance of nearby RRHs for traffic distribution that is not uniform [30].

C-RAN stands for Centralized/Cloud/Clean/Collaborative RAN, and it is envisioned as such a redefinition. The core idea behind this concept is to pool baseband signal processing from several BSs into a single physical location, which is referred to as a BBU pool. As a result, BSs are split into two parts: the Remote Radio Head or Remote Radio Unit, which only comprises Radio Frequency (RF) circuits, Digital-to-Analog Converters (DACs), and Analog-to-Digital Converters (ADC), and the BBU, which is instantiated at the BBU pool utilizing a cloud platform. The BBU pool reduces the deployment and maintenance costs of BSs by combining the baseband signal computation of numerous BSs. It also allows for more efficient resource allocation by avoiding the underutilization of baseband computation given to idle BSs due to non-uniform traffic behavior. The BBU pool's computational capacity can be quickly adjusted because it is virtualized over simple hardware modules that may be simply added and deleted, resulting in high scalability [9, 24].

Baseband processing is aggregated and shared across sites in a virtualized BBU pool using C-RAN. This implies it can adjust to non-uniform traffic and make better use of its resources, like BSs. Because C-RAN requires fewer BBUs than conventional RAN architecture, it has the potential to lower network operational costs by reducing power and energy usage. New BBUs may be readily added and upgraded, increasing scalability and simplifying network management [21].

3.2 C-RAN System Structure

[2] demonstrates that, according to BBU and RRU functionalities, a C-RAN system structure can be divided into three categories: fully centralized, partially centralized, and hybrid. The basic division here depends on where the PHY, MAC layer, and network layer functions are handled. PHY

functions include baseband processing, i.e., radio functions, while MAC is an access control mechanism and the network layer is a routing mechanism. In the following, we will discuss each of these structures in brief.

3.2.1 Fully Centralized

A fully centralized structure would move all physical, MAC, and network layer functionalities to the BBU pool. Because BBUs handle all of the functions of managing and processing resources, such a structure can benefit greatly from ease of operation and maintenance. However, communication overhead between BBUs and RRUs places a significant burden on such structures, limiting their performance to fronthaul capabilities. The fundamental advantage of the fully centralized architecture is that RRHs require essentially no digital processing units, possibly making them small and inexpensive, whereas the required data rate of fronthaul links for I/Q forwarding is very high [2,8].

The BBU Pool, as shown in Figure 3.1a, contains the L1, L2, and L3 capabilities in the fully centralized approach. This architecture has the advantages of easy upgrading and network capacity expansion; it also has a better capability for supporting multistandard operation, maximum resource sharing, and is more convenient for multi-cell collaborative signal processing. The large BW required between the BBU and the baseband I/Q signal is its main drawback [21,29]. A Time Division LTE (TDLTE) 8 antenna with a 20MHz BW will require a transmission rate of 10 Gbps in the worst-case scenario [29].

3.2.2 Partially Centralized

In partially centralized structures, the PHY functions are done at RRUs while MAC and network layer functions are performed at the BBUs. This can greatly reduce the overhead of RRUs-BBUs communication as the PHY takes on the major computation burden of C-RANs. However, these structures come with complex physical and MAC communication and do not support PHY resource sharing between different RRUs. By isolating the baseband processing from BBU and integrating it into RRH, the "partial centralized" C-RAN architecture has the benefit of requiring considerably reduced transmission BW between BBU and RRH. It does, however, have flaws of

its own. Because the baseband processing is built into the RRH, it has limited upgradeability and is inconvenient for multi-cell collaborative signal processing [2, 29].

In the partially centralized system depicted in Figure 3.1b, L1 processing is co-located with the RRH in the partially centralized system, decreasing the BW load on the optical transport links because the demodulated signal occupies 20 to 50 times less BW than the modulated one. However, this technique is less ideal because resource sharing is severely limited, and advanced features such as CoMP cannot be supported effectively. CoMP benefits from processing the signal on L1, L2, and L3 in a single BBU pool rather than in multiple BSs [8, 21].

In a partially-centralized architecture, PHY functions are integrated into RRHs, with other upper-layer functions incorporated into the BBU pool. Although the partially-centralized architecture alleviates the heavy burden on fronthaul connections, LSCP cannot be efficiently supported because PHY functions remain in the individual RRH, and only the usual distributed CoMP benefit can be realized. When the functional split is transferred to the MAC layer, the necessary fronthaul capacity and signal processing capability in the BBU pool are reduced dramatically [8].

3.2.3 Hybrid Centralized

In a hybrid centralized structure, part of the PHY functions are done in RRUs while others are done in BBU. RRU takes the responsibility of users or cell-specific functions that are mainly concerned with signal processing. Such a structure can be the most flexible one in resource sharing, besides having the potential to reduce energy consumption and communication overhead in BBUs [2].

Mobile operators may easily install and update their networks using any of these C-RAN architectures. To increase network coverage or boost capacity, the operator just needs to install more RRHs and link them to the BBU pool. If the network demand increases, the operator just needs to update the hardware of the BBU pool to handle the additional processing capacity. Furthermore, the "fully centralized solution," when combined with an open platform and general-purpose processors, will make it simple to develop and deploy Software-Defined Radio (SDR), which allows for software only upgrades to air interface standards and makes it easier to upgrade RAN and support multi-

standard operations. As a result, a fully centralized solution is preferable. Other alternatives, in between the two mentioned above, have been offered, in which only some specific tasks of L1 processing, such as L1 preprocessing of cell/sector-specific functions, are colocated with the RRH, while the majority of L1 is left in the BBU. Figure 3.1 shows the C-RAN System Structure [29].

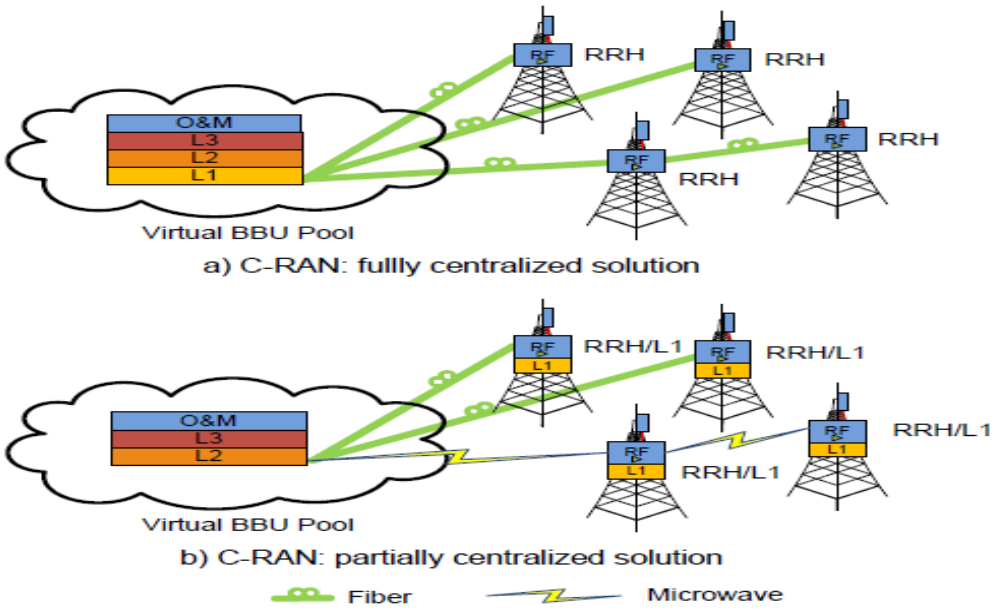

Figure 3.1 C-RAN System Structure [21]

3.3 C-RAN Architecture and Components

3.3.1 C-RAN Architecture

The BBUs are on the cloud server, and the RRHs are geographically separated from the BBUs, according to the C-RAN architecture. In addition, BBU and RRH are connected via a fronthaul link, while BBU and the core network are connected via a backhaul link [18]. This innovative C-RAN architecture has various benefits to operators, including cost control, energy savings, greater SE and resource efficiency, increased network flexibility, and service on edge facilitation [24]. Below, Figure 3.2 shows the C-RAN architecture.

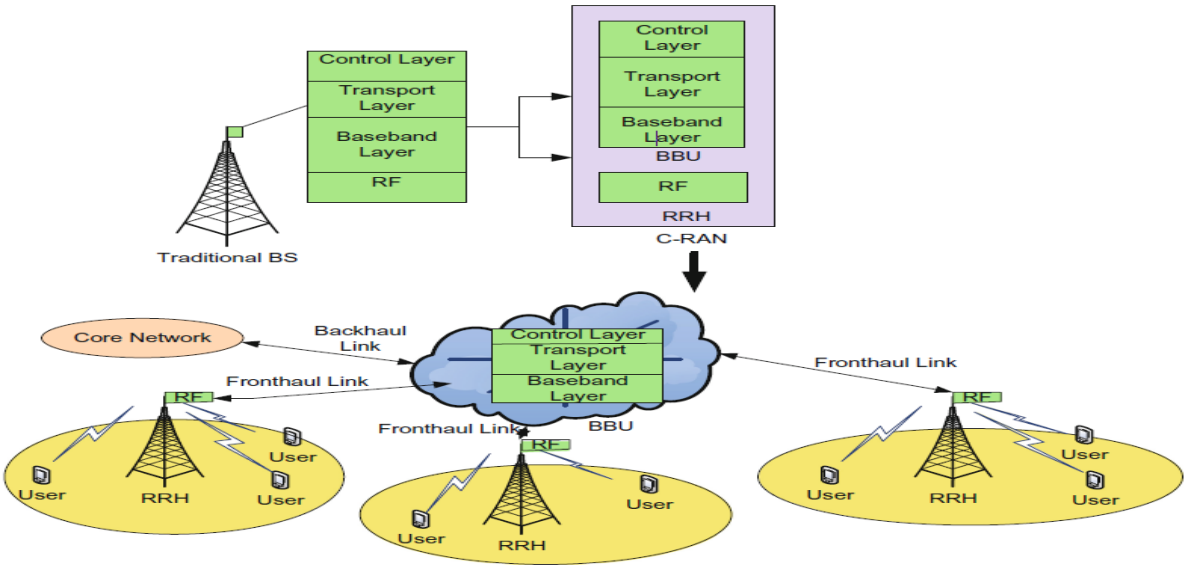

Figure 3.2 C-RAN architecture [18]

3.3.2 C-RAN Components

The C-RAN architecture is made up of three primary components: 1) BBUs with real-time cloud infrastructure, 2) high-speed optical fiber transmission networks, and 3) distributed RRUs (Remote Radio Unit). RRU converts RF analog signals to baseband digital signals and sends them to BBU via an optical fiber transmission network. BBU is developed on the General Purpose Processing (GPP) platform rather than the traditional hardware platform based on DSPs to be more scalable and adaptable. Several BSs can be combined into central processing pools by using virtualization technologies [2,4,24,31]. Figure.3.2 above shows the overview of the C-RAN architecture, while the following summarizes the main functions of each component [2]:

3.3.2.1 Base Band Unit Pool

The BBU pool is stored centrally, such as in a cloud or data center. It's made up of a bunch of BBU nodes with a lot of processing and storage power. These BBUs are in charge of processing resources and allocating them to RRUs dynamically based on network requirements.The BBU pool

handles PHY, medium access control layer, and network layer functions, whereas distributed access points handle fundamental RF duties. Traditional CoMP can be easily included and extended to the LSC in C-RANs since the entire baseband processing resources are consolidated into the BBU pool. In comparison to LTE-A networks, C-RANs can achieve low energy consumption, low deployment costs, and low interference, especially in dense networks [2, 32].

The C-RAN BSs must be configured in such a way that the number of active RRUs/BBU units within the BBU pool is maximized to provide the best throughput and energy savings. There are numerous active research projects aimed at developing efficient resource-sharing algorithms. Furthermore, numerous publications propose that achieving optimal C-RAN performance necessitates collaboration between resource sharing and BBU clustering techniques [33]. For example, the authors of [34] suggest a C-RAN mapping system that may dynamically change BBU and RRU connections in response to traffic demand.The authors of [35] offer several semi-static and adaptive BBU-RRU switching algorithms for C-RAN and show that, as compared to static assignment, the number of BBUs may be greatly reduced.

The BBU is enabled by cloud computing, which achieves flexible spectrum management and advanced network coordination. Moreover, BBU can handle a significant part of the baseband signal processing of the whole network; it also controls the signaling to RRHs. Compared to a traditional BS, the joint signal processing across a larger coverage area can be done at the BBU side in a centralized and soft way, which has the potential to mitigate interference and improve performance [18]. Different network operators can share a virtualized BBU pool, allowing them to rent RAN as a cloud service [21].

Baseband processing can be implemented at the BBU pool utilizing software radio technology based on open IT frameworks, allowing systems to be upgraded to other standards without requiring hardware modifications. Mobile operators can easily deploy RRHs using C-RANs to grow and update their cellular networks. To expand network coverage or split the cell to improve SE, mobile operators just need to deploy new RRHs and connect them to the BBU pool [36].

3.3.2.2 Remote Radio Head

RRH entities include a power amplifier, a low-noise amplifier, and an analog-to-digital converter. As previously stated, all processing parts are no longer located on the cell site, which reduces energy consumption and the complexity of these modules, lowering their cost. As a result, it is possible to enhance the density of RRH in locations with significant traffic loads. Different network operators can share a virtualized BBU pool, allowing them to rent RAN as a cloud service [21,24]. The RRH is mainly responsible for the RF function and some simple signal processing. The deployment of RRH can provide seamless connectivity, especially in hot spot areas. Moreover, densely deployed RRHs can offer stronger coverage with a high data rate [18]. RRH/U networks connect wireless devices in the same way as traditional cellular networks connect access points or towers [2, 32].

3.3.2.3 Fronthaul Network

The fronthaul links can use wired or wireless media based on the application scenarios, and they are capacity-limited in general. Within the two-hop C-RAN structure, the limits of fronthaul should be carefully considered for practical system designs [18,24].

Fronthaul, or transport network: The connecting layer between a BBU and a group of RRUs that provides high BW links to handle the demands of many RRUs is known as fronthaul. Different technologies, such as optical fiber communication, cellular communication, or millimeter-wave communication, can be used to implement fronthauls. Optical fiber communication is considered ideal in C-RAN as it provides the highest BW requirement. However, it comes with high costs and lacks flexible implementation. On the other hand, cellular communication, or millimeter-wave communication, is cheaper and easier to deploy. However, it comes with the cost of less BW and more latency than optical fiber [2, 31].

3.4 Functional Split

The centralization of baseband signal processing in the C-RAN architecture enhances network coordination flexibility and enables large cooperative processing advantages. There are tradeoffs between the split option, fronthaul capacity, and signal processing complexity. The first alternative is suggested for the first C-RAN architecture. Almost all PHY layer functions have been migrated

to BBU. Meanwhile, RRH functions as a basic relay equipped with RF, ADC/DAC, and a digital front end. In this option, the CPRI connects BBU and RRH. This centralized PHY architecture can deliver the most cooperative processing benefits. However, transmitting I/Q samples across fronthaul lines necessitates a large amount of transmission capacity. I/Q samples should be compressed at BBU and RRH to reduce fronthaul BW [18].

The second alternative is depicted in Figure 3.3b, in which baseband processing is largely centralized but certain PHY layer processing is still reserved at RRH. This functional split can considerably reduce fronthaul transmission capacity while also achieving great cooperative processing benefits. However, because of the distributed deployment of PHY capabilities, the implementation of cooperative processing becomes complex. The goal of this architecture is to achieve a balance between fronthaul capacity and signal processing complexity. The last alternative is depicted in Figure 3.3c, in which all PHY layer functions are relocated to the RRH. The transmission BW of the fronthaul link is lowered to the maximum MAC layer throughput in this architecture, imposing the smallest fronthaul BW requirement when compared to the previous two alternatives. The cost of this decrease is increased scheduling delays in the fronthaul link, which may affect system performance and network throughput, whereas the advantage of this architecture is lower power consumption at BBU and greater flexibility in radio resource allocation towards users. To summarize, splitting baseband signal processing between BBU and RRH allows for a variety of C-RAN deployment choices with varying fronthaul capacity constraints. However, without appropriate PHY layer signal processing, it is difficult to implement a cost-effective C-RAN deployment [18].

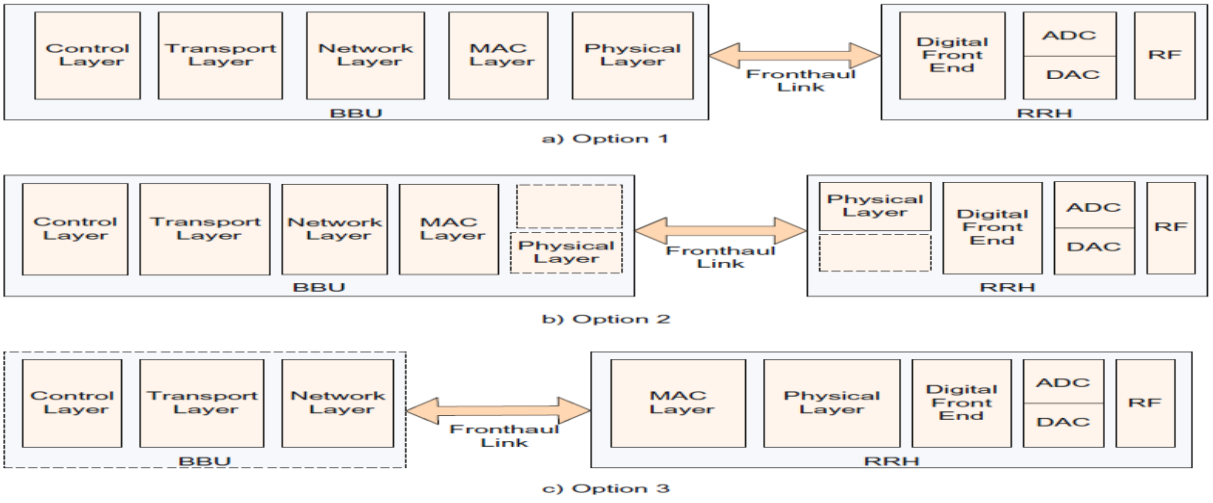

Figure 3.3 Functional Split between BBU and RRH [18]

3.5 Virtualization in C-RAN

Virtualization technology facilitates the logical isolation of resources while the physical resources are shared in a dynamic and scalable way. Those resources include network, computing, or storage resources. Network virtualization is critical in C-RAN and its deployment architectures because of these resources. Network virtualization consists of multiple nodes and links that are deployed on the same physical machine. Thus, such technology enables flexible control mechanisms, efficient resources, low cost, and diverse applications. Network virtualization is done at the BBU pool level in the context of C-RAN. Each BBU is a virtual node, and virtual links are used to communicate between them. The pool runs on a single physical system, with numerous BBUs sharing CPU, memory, and network resources. Figure 3.3 illustrates the resource sharing in a BBU pool where the pool is deployed on a physical machine while the BBUs are on virtual machines. RRUs connect to the BBU pool, which distributes them over the BBUs in its virtual machine. Such technology comes with many advantages, including reducing the cost, minimizing the time required for BBU communication, and most importantly, scalability. Adding or removing BBUs has become easier as those BBUs are virtual machines that are much easier to turn off and up than physical machines [2,9,31].

The C-RAN architecture promotes flexible control, low cost, efficient resource consumption, and diverse applications by deploying virtual networks. Virtualization of the C-RAN can be done at different levels [33]:

Virtualization of wireless networks: Network virtualization is exemplified by the C-RAN concept. The goal of ongoing research in this area is to provide virtualization for various wireless network technologies, such as WiFi and Bluetooth.

Hardware virtualization: In terms of C-RAN, hardware virtualization primarily focuses on virtualizing the underlying hardware most effectively.

Resource virtualization: this term refers to a system that allows numerous virtual operators and/or BSs to share the same resources and spectrum (this type of virtualization is used for this paper).

3.6 Interference Management in C-RAN

Interference occurs in the traditional RAN when users migrate from one cell to another, changing the coverage area of the linked BSs. As a result, the QoS decreases. In the C-RAN design, many RRHs from various cell sites are coupled to BBUs that share the same BBU pool. Customer changes in the coverage area of RRHs do not cause interference, although user dynamics do. This is because BBUs from a vast area, as well as the RRHs that are connected to those BBUs, are all assigned to the same BBU pool.This reduces the amount of interference generated by users moving between cell sites [2, 4].

C-RAN refers to a network architecture in which baseband resources are pooled and shared among BSs. Because BBUs from multiple sites are pooled together, they can communicate with shorter delays. Methods such as eICIC and CoMP, introduced for LTE-A to increase spectrum efficiency and throughput, are greatly facilitated. The implementation of load balancing between the cells is also made easier. Additionally, network performance is enhanced, for example, by minimizing delays during intra-BBU Pool handover [21].

eICIC and CoMP capabilities are considerably helped by the pooling of BBU resources in a C-RAN, as signal processing from multiple cells may be done across one BBU pool, easing implementation and decreasing processing and transmitting delays. In general, there are two techniques to deal with interference: reducing interference and constructively utilizing interference channels. In the time, frequency, and power domains, ICI can be prevented statically or dynamically. Not employing co-channel deployment, i.e., just using different frequencies in nearby cells, is a simple, static option. This is known as "hard frequency reuse," and it has the advantage of almost eliminating X2 signaling. It is also possible to use fractional frequency reuse. However, because lower band frequency resources are limited, it is preferable to adopt other solutions rather than those involving frequency reuse [21].

C-RAN boosts ICIC and CoMP transmission techniques, allowing for better throughput in a mobile network. This is particularly critical as more new cells are deployed to boost mobile network capacity, enabling efficient interference management to achieve the capacity increase. When all of the cells in a CoMP set are served by a single BBU pool, signal processing is handled by a single entity, allowing for closer collaboration between BSs. As a result, interference can be kept to a minimum, allowing throughput to be enhanced. Furthermore, deploying ICIC across a central unit (BBU Pool) allows for the optimization of transmission from a large number of cells to a large

number of BBUs. It has been observed that integrating cell clustering with CoMP allows for more efficient use of radio BW [37].

When all of the cells in a CoMP set are served by a single BBU pool, signal processing can be done by a single entity, allowing for closer communication between BSs. As a result, interference can be kept to a minimum, allowing throughput to be enhanced. Combining cell clustering with CoMP has been shown to make more efficient use of radio BW. Furthermore, ICIC can be used to optimize transmission from numerous cells to multiple BBUs via a central unit called the BBU Pool [21]. The receiver algorithm, reference signals, orthogonality, channel estimation, network density, and network size as they affect the performance of CoMP with LTE-A in C-RAN UL [6].

When the network gets denser, both the average SE and the edge UE SE of the non-CoMP scheme become worse due to higher ICI. The LTE-A CoMP scheme achieves almost a similar performance gain over the non-CoMP scheme despite the network density. And the C-RAN scheme achieves tremendous gain for both average SE and edge UE SE in the denser network, due to its capability to perform LSC. However, when the network density is low enough, the performance of C-RANs descends and becomes even worse than that of the non-CoMP scheme. That is because the coordination among access points will reduce the receiving power of intended signals when the transmit power is equally allocated to UEs.

The C-RAN network shows significant potential in the dense network to enhance the network capacity and improve the experience of edge UEs, compared with the existing CoMP-enabled LTE-A small cell network. The C-RAN is more sensitive to the imperfect CSI than the LTE-A CoMP scheme. When the accuracy of the CSI decreases, the capacity of the C-RAN scheme can be even worse than that of the LTE-A CoMP scheme. This is because, on one hand, the LTE-A CoMP scheme is only applied to a few edge UEs, while the whole UEs in the C-RAN is affected by the imperfect CSI; on the other hand, the performance degradation of coordinated processing is positively correlated with the number of cooperating access points [9]. The C-RANs are affected by the network density. Higher network density leads to faster performance degradation. Therefore, the imperfect CSI issue must be carefully considered for the implementation of C-RANs. The C-RAN network shows significant potential in the dense network to enhance the network capacity and improve the experience of edge UEs, compared with the existing CoMP-enabled LTE-A small cell network. The way to a complete C-RAN deployment can be prepared by completing Phase 1

of C-RAN when baseband resources are pooled. Specialized baseband chips, or DSPs, are used for baseband processing. Phase 2, in which resources are virtualized via GPP, allows the full benefits of C-RAN to be realized [2, 21].

3.7 Benefits of C-RAN

Energy efficient/green infrastructure, cost savings on CAPEX and Operational Expense (OPEX), capacity improvement, scalability and adaptability to non-uniform traffic, smart internet traffic offload, increased throughput, decreased delays, and network upgrade and maintenance ease are advantages of the C-RAN architecture [21, 29, 33, 37]. Joint processing and scheduling will be easier to execute. BBU failover mechanisms have been improved, reducing ICI and increasing SE [33,37]. According to a China Mobile study, energy savings can amount to up to 71%. During moments of low activity, some BBUs in the BBU pool can be turned off to save energy while maintaining full network coverage [37].

A centralized BBU comes with many advantages that include the simplicity with which advanced technologies, resource virtualization, and service deployment can be implemented at the edge. BBUs are located at the network center in a centralized BBU pool, while RRUs are distributed. This enables C-RAN to have several advantages over traditional cellular networks in which BBUs are distributed.The first advantage is the possibility of implementing various advanced technologies that require high processing and cannot be implemented in traditional networks. As BBUs can be located in powerful data centers and have efficient information exchange, they can do extensive computation that cannot be done in current networks. As a result, joint processing and cooperative radio sharing technologies will become possible with the C-RAN architecture. In addition, with multiple BBUs that share a common pool, resource sharing can become feasible, and hence allocation can be more flexible and on-demand, unlike traditional networks. This can improve resource utilization, resulting in less power consumption and more user satisfaction due to the larger pool of resources.

Moreover, with such large and distributed networks, services can be deployed on the network edge instead of the core. As C-RAN servers are powerful and have large computations, the realization of edge service deployment becomes much easier. In this way, services will move closer to the user, resulting in faster responses and better user satisfaction. Furthermore, this can reduce the load

on backhaul networks, making them more flexible and scalable than they are now. As a result, using centralized BBUs in C-RAN can provide numerous benefits, including joint processing and resource sharing capabilities, in addition to service implementation at the edge. This can enhance user satisfaction, improve resource utilization and reduce backbone server pressure [2]. Some of the additional benefits are also described below [21, 33]:

Ease in network upgrades and maintenance: The C-RAN architecture with multiple co-located BBUs simplifies network maintenance: not only can BBU pool automatic reconfiguration absorb C-RAN capacity peaks and failures, reducing the need for human intervention, but human intervention is only required in a few BBU pool locations when hardware failures and upgrades are required. Traditional RAN, on the other hand, may require service at as many cell sites as there are in the network. Because hardware only needs to be put in a few strategic locations, C-RAN with a virtualized BBU Pool allows for a smooth introduction of new standards [21].

Increased capacity and reduced inter-channel interference: The centralized BBU can dynamically and cooperatively share resources among many cells (i.e., RRUs). As a result, the resources can be properly employed by service demand. Because of the combined scheduling and processing, interchannel interference can be reduced.

Improved system throughput: C-RAN can help with dense RRU deployment schemes in areas where high throughput services are required.

Decrease in delays: Delays are decreased because handovers can now be done within the BBU Pool rather than between eNodeBs [21].

3.8 Requirements and Challenges of C-RAN

The requirements of C-RAN systems with a fronthaul network are determined by the separation distance between BBU and RRH. As a result, the amount of latency delivered into the fronthaul network must be carefully examined, as must the real timing performance. As a result, the C-RAN architecture's fronthaul network has highly strict requirements. Furthermore, when a single BBU is shared by multiple RRH, a variety of issues arise. Some challenges include high fronthaul capacities needed, BBU cooperation and clustering, latency, virtualization techniques used,

synchronization, and jitter and security [2, 24]. The fronthaul capacity issue and the difficulties of virtualization approaches are two important challenges in the C-RAN architecture. The practical fronthaul is usually capacity and time-delay constrained, reducing spectral and EE advantages dramatically. Because of the particular characteristics of wireless communication, using virtualization techniques in cellular networks like C-RAN is significantly more challenging. Some of the C-RAN needs and challenges are discussed here [2,24,29].

3.8.1 High Fronthaul Capacities Needed

The fronthaul link between BBUs and RRUs is required to have high BW capability with low delay and cost requirements. The fully centralized approach is the most widely adopted structure in C-RAN and requires a huge communication overhead on the fronthaul link. As a result, the high BW requirement is required at the fronthaul, which cannot be met by wireless communication.

Optical fabric communication can give the high BW required to solve such problems. However, optical fabric comes with the problem of very high cost, which cannot be afforded by most cellular providers.

The aggregation of flows from one or more antennas results in very high bitrate traffic flows in the C-RAN network, often in the range of units to tens of Gbit/s for a cell site. The data rate of the CPRI is determined by the Radio Access Technology (RAT), carrier BW, and MIMO implementation. It has a range of 614.4 Mbit/s to 10.17 Gbit/sec. For example, LTE-A with 4x4 MIMO and a carrier frequency of 20 MHz necessitates a CPRI rate of roughly 4.915 Gbit/s per sector. Similarly, the CPRI rate for a single sector LTE with 20MHz and 2x2 MIMO is 2.457 Gbits/s. When considering the time-varying traffic load condition of a cell, such very high data rates result in fully non-elastic traffic. These aspects are the most difficult for conventional RAN because they are designed to transport much lower bitrates [24].

When a mobile network operator has cost-effective access to a legacy Optical Transport Network (OTN) network that can be exploited for C-RAN, OTN is a recommended optical transport method for IQ transmission between RRH and the BBU pool. OTN provides support for both wavelength

and time-domain multiplexing, which maximizes fiber network BW consumption, and Forward Error Correction allows client signals such as CPRI to be broadcast over longer distances or in noisy situations [37]. Hence, a compromised solution between delay, BW, and cost needs to be taken into account in such systems before they come to reality.

3.8.2 BBU Cooperation

BBUs in the same pool need to cooperate to support sharing users' data, scheduling, and channel feedback collection. Such cooperation is not defined and introduces a challenge in terms of how to deal with user privacy, high BW, and low-latency communication between such BBUs.

3.8.3 Cell Clustering

Optimal clustering of the cells and BBU pool assignability with minimal overhead and maximum gain is still a challenge. One BBU pool should achieve the maximum number of send and receive channels while minimizing the fronthaul delay and overhead. In addition, one BBU should support multiple distributed geographical locations, such as offices in different states, to consolidate them into one BBU. Therefore, such clustering and BBU assignment are still challenges to be resolved in C-RAN systems.

3.8.4 Latency

Fronthaul and CPRI/Open BS Architecture Initiative protocols have highly strict latency requirements, which are frequently the limiting considerations for how far a fronthaul network may extend. Due to the decoupling of traditional BS functions into a centralized BS that would be shared among a large number of RRHs (i.e., fronthaul network), radio access technology standards have placed significant time constraints between the BS and the RRH. One of the main causes of delay is the transit of fronthaul signals over the RAN network, also known as fronthaul latency. The total latency in the BS is affected by significant problems with the BBU-RRH design.

Both BBU and RRH's internal processing delays are determined by the software and hardware configuration. The fronthaul network's latency, on the other hand, has a set upper limit. Latency

can be further subdivided into two parts: 1) latency generated by the adaption of fronthaul signals into RAN infrastructure services, which might be caused by the CPRI and Open BS Architecture Initiative transmission/reception interfaces, as well as additional tasks required by optional layer transport technologies (i.e. multiplexing/demultiplexing, buffering, reframing, and error correction), and 2) latency due to signal propagation along with the RAN. The second contribution establishes a maximum geographical distance between the BBU hostel and the controlled cell sites.

3.8.5 Synchronization

Mismatches in transmitter and receiver clock frequencies, bit mistakes, and clock phase variations are all particularly sensitive to baseband radio signals (jitter). Traditional BS and C-RAN BS have different synchronization techniques. Traditional BS feeds all-in-one BS with a single clock generator, while in C-RAN, the BBU is responsible for both transmitting baseband data and sending the clock signal generated at the BBU to the RRH.

Proper synchronization (keeping the carrier frequency sharp) is required for mobile network functioning to reduce signal overlap from different BS operating at different frequencies and meet the requirements given by radio access technology standards on accuracy and stability of the radio interface. The RRH clock is synchronized to the bit clock of the received CPRI signal for proper Time Division Duplex network functioning. It must adhere to time frames to ensure that DL and uplink frames do not overlap. If the CPRI signal is affected by jitter, the frequency precision can be modified.

In fronthaul, there are two types of synchronization methods: 1) frequency synchronization, which matches the time between two rising edges of the clock, and 2) phase synchronization, which requires the rising edge to occur at the same time. Fronthaul networks, in general, have strict synchronization requirements in terms of the maximum tolerated frequency error contribution, bit error rate, and phase synchronization.

3.8.6 Virtualization Technique

Virtualization techniques promote the distributed processing and sharing of resources between multiple BBUs, which imposes another challenge on C-RAN. Processing needs to be real-time and dynamic to support changing cell loads. Furthermore, the requirements for clouds that BBUs will be implemented on will be different from the known IT cloud requirements. Therefore, cloud infrastructure needs to be adjusted to meet such requirements. Hence, virtualization is another critical challenge that affects the current deployment of C-RAN in practice.

3.8.7 Security

Another significant challenge in C-RAN is the security challenges in terms of user privacy and trusted parties. Because resources are shared among BBUs, it is possible to breach user privacy and gain access to supposed secure data, especially in such a distributed design. In addition, parties are assumed to be trusted in C-RANs, including BBUs and RRUs. Such assumptions might be invalid, especially with the large number of users subscribed to such systems. A compromised user can take advantage of such a large, virtualized system to misbehave and threaten the system. Therefore, in addition to the vulnerabilities that exist in traditional cellular systems, C-RAN would present another security challenge that was not considered or less challenging before [2].

There are also some technical challenges to implementing C-RAN. Those challenges are Radio over Low-Cost Optical Network, Advanced Cooperative Transmission/Reception, Baseband Pool Interconnection, BS Virtualization Technology, and Service on Edge [29]. A high-BW, low-latency, low-jitter, and low-cost transport network is required. BBU cooperation, interconnection, and clustering techniques must be developed, as well as BBU pool virtualization techniques must be proposed [21].

Chapter 4

4. System Modeling and Assumptions

For this thesis, the actual distribution of the BS in the Addis Ababa LTE-A network and the topography of the city are used for the study of the large scale cell coordination in the CoMP system. The Addis Ababa LTE-A network is designed and deployed to provide users with very high data rates of up to 2Mbps at peak hours and improved capacity. And each user in the network is allocated a BS based on the received signal strength. All the signals coming from the BSs other than the serving BS act as interference and significantly affect the user performance. In this study, the large-scale cell coordination scheme CoMP is proposed to overcome the ICI, and using simulation, the performance of the Addis Ababa LTE-A network is studied with the introduction of C-RAN and CoMP. For the study, part of the Addis Ababa LTE-A network was selected as a test case area. In this chapter, an overview of the propagation tools, selected test case areas, assumptions, and performance measurements are given.

4.1. Tools

WinProp is used for antenna pattern, propagation, and network simulation, and Matlab is utilized for performance comparison. These commercial tools have been used by professional researchers and academicians in a variety of research projects [27,38,39]. WinProp is used for propagation modeling of various scenarios (rural, urban, indoor, tunnels, etc.) and network planning of various air interfaces (LTE, 3G, 2G, etc.), utilizing propagation models such as the dominant path model. Depending on the scenario, predictions are made using topography, clutter, urban building, and/or 3D planar objects and walls (vector) databases. It is made up of six parts: ProMan, WallMan, AMan, TuMan, CoMan, and OptMan. For this study, two components of WinProp have been used [40].

ProMan: ProMan uses static and location-dependent simulations to perform wave propagation models, radio network planning, and network simulation. WinProp computes throughput, maximum data rate, and other capacity planning metrics.

WallMan: WallMan is used to define building databases and convert them to ProMan-compatible formats such as building databases, topographic databases, and clutter databases.

In order to develop the simulation, the Matlab simulator tool is used. Matlab has a large number of libraries and toolboxes, especially in the telecommunication field. I started from an available pathloss from a Winprop simulation, according to the propagation model using a dominant path model. The dominant path model is a baseband model for LTE-A networks, and Matlab simulations are used to analyze system performance in non-CoMP, JT- CoMP with three cell and seven cell coordination scenarios.

4.2. Selected Area

The study focuses on the LTE-A network for Addis Ababa's areas. The study considers LTE sites that are located around the Leghar area, which is a hot spot for high traffic data and is also considered an urban area. The area selected includes 24 eNodeBs with three sectors each. Each eNodeB's three sectors is regarded as a cell. Their data traffic over the course of a year is illustrated in Figure 1.1 below.

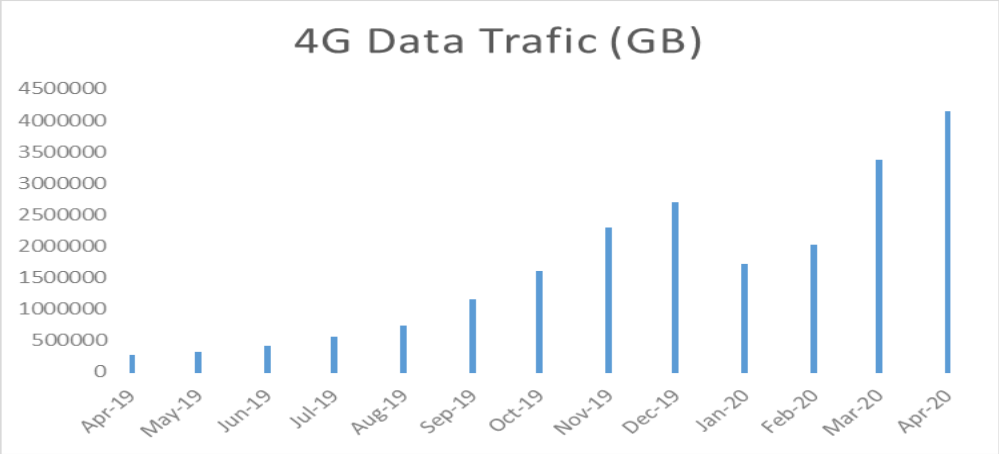

Figure 4.1 Shows the 24 eNodeB data traffic for the year of 2019/ 2020

The antenna for each cell is mounted on a cell tower or a few meters above the rooftop of a building. Figure 4.2 shows the satellite view of the selected area using Google Earth. Although each cell (sector of an eNodeB) is identified with its unique ID in the Addis Ababa network, In addition, in the figure, it can be seen that the distribution of the eNodeBs is non-uniform with different

distances between the eNodeBs. Currently, ET has not deployed the C-RAN. Therefore, for simulation purposes, the selected base stations are assumed to be pooled into three groups. The selected area of the outdoor scenario based on 2.1km x 2.3km in the Legehar area was selected, which consists of hotels and cafeterias, a national stadium, Meskel Square, hospitals, and also populated buildings with business shops and residential areas where potential mobile users are found.

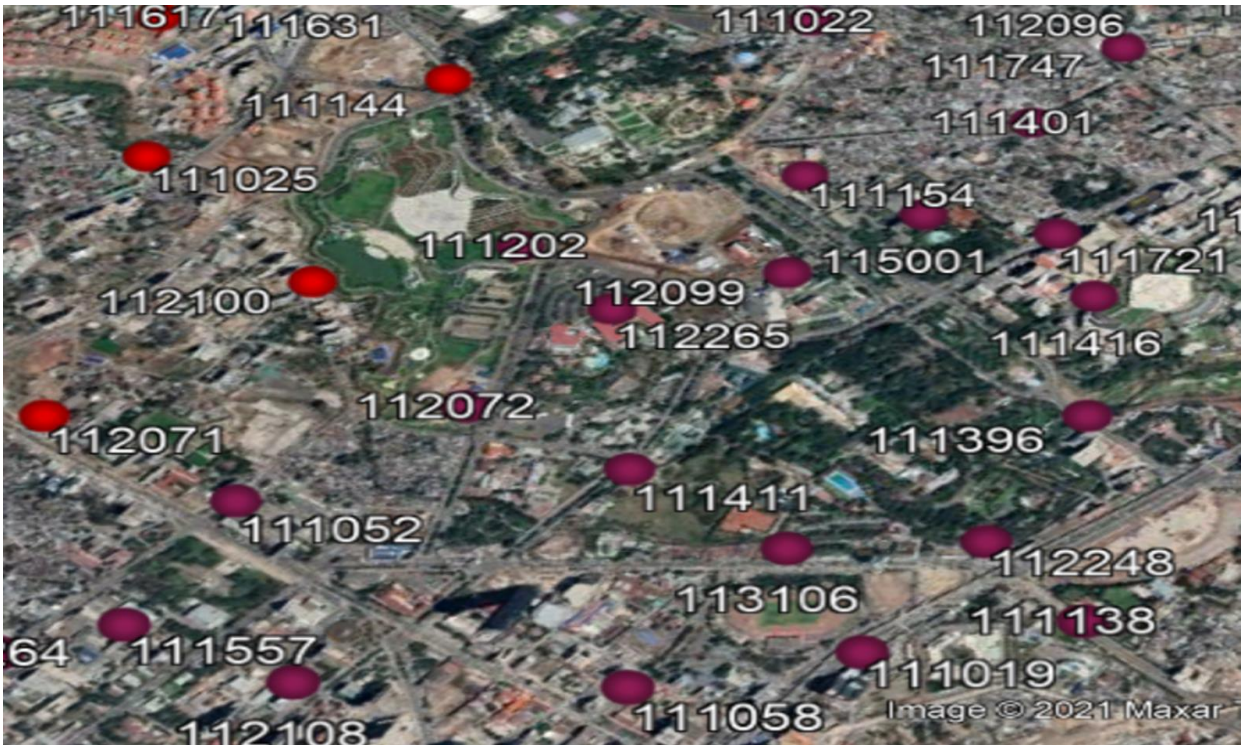

Figure 4.2 Site selection using Google Earth

4.3. Model Overview

The approach is carried out in such a way that the network is simulated while utilizing existing system setup, including LTE-A radio access network base station settings. Figure 4.3 illustrates the general optimization approach.

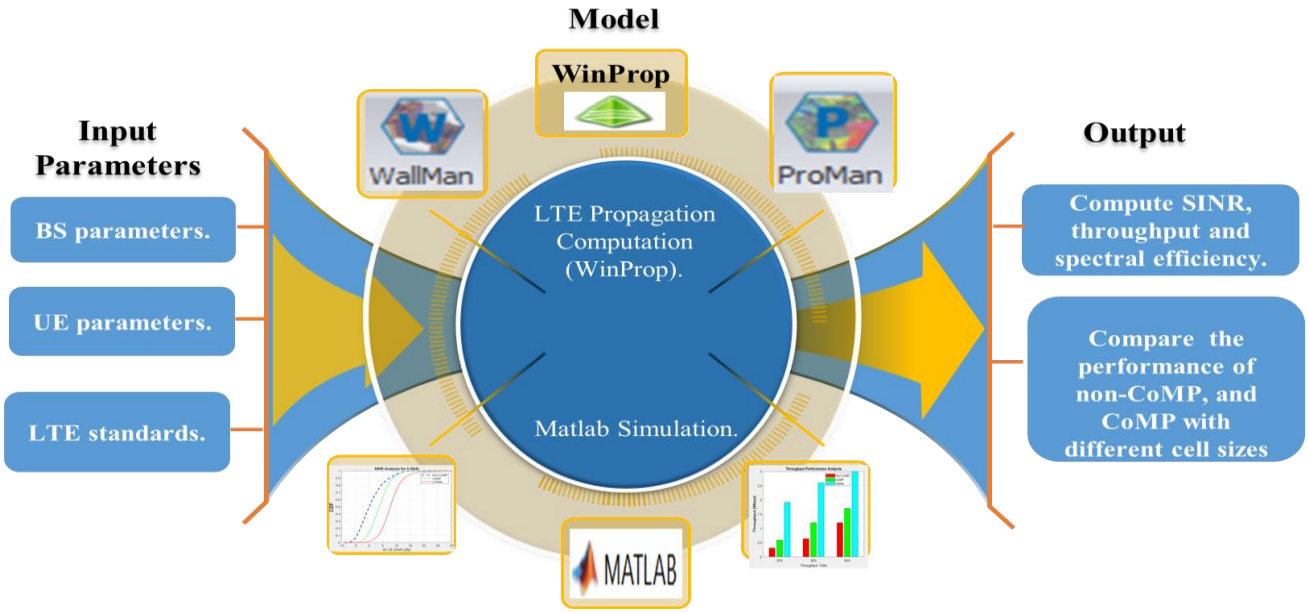

Figure 4.3 Model overview

4.4. Performance Metrics

4.4.1 Signal to Interference Plus Noise Ratio

In LTE-A, the SINR is measured by the UE on a RB basis. On each RB, the UE computes SINR, converts it to a Channel Quality Indicator (CQI), and reports it to the eNodeB, which uses it to select the best modulation and coding scheme for user data transmission in that RB. SINR is defined as the ratio of signal power (PSignal) to the sum of average interference power (PInterference) from other cells plus background noise (PNoise) [6,41].

$$\text{SINR} = \frac{Psignal}{\text{PIntereference} + \text{PNoise}} \quad (4.1)$$

The SINR for user k in the system using typical LTE transmission is [41]:

$$\text{SINR}_K = \frac{P_{ue}\ PL_{k,l}}{P_{ue} \sum_{i=1,i\neq l}^{L} PL_i + N} \quad (4.2)$$

N is the noise power

The following steps are performed to obtain the SINR for all probable UE locations in the selected AA network. In the specified area, for each possible user location k:

1. Choose serving cell l based on the best received signal, where $P_{r(k,l)} = Pue * PL_{k,l}$

2. The received powers $P_{r(k,i\neq l)}$ from the other cells are taken as interference.

3. Compute the SINR for each k=1: K as follows [41]

After getting the SINR values, the throughput for any potential UE in the coverage area may be calculated.

4.4.2 Throughput Calculation

The modified Shannon formula proposed is used to calculate LTE throughput. The modified Shannon capacity formula is intended to account for system bandwidth efficiency as well as LTE SINR efficiency. For user k, the spectral efficiency using the modified Shannon formula is given as [41]:

$$C\,(\mathrm{k})\,(in\ bits/s/Hz) = BWeff * log2\,(1 + SINRk\,/SINReff) \quad (4.3)$$

The bandwidth and SINR implementation efficiency of LTE are represented by BWeff and SINReff, respectively. LTE has an approximate bandwidth efficiency of 0.83, after accounting for pilot overhead, cyclic prefixes, and other control information. Furthermore, the optimal SINReff value for BWeff =0.83 is 1.6dB. We can use the following calculation to calculate the throughput for a given UE with a BWk bandwidth:

$$Throughput\,(bits/s) = BWk \cdot (k) \quad (4.4)$$

C (k) represents the spectral efficiency in bits per second.

4.5. Scheduling

As all macro cells have different cell IDs, each cell is scheduled individually. In the simulation, the scheduling algorithm is used. Therefore, the radio resources of the macro cell are divided between non-CoMP UEs and CoMP UEs. UEs are assigned resource blocks in a round fashion (one

after another) in round-robin scheduling without considering CQI. Giving the best possible fairness is a straightforward procedure. This scheduling achieves fairness by allocating an equal amount of packet transmission time to each user. Cell throughput, on the other hand, was severely reduced since the scheduler did not use the immediate downlink SINR values to determine the number of bits to be transferred.

4.6. Downlink CoMP

4.6.1. CoMP Schemes Selection

In our simulation, CoMP JT schemes are applied to make a comparison with the non-CoMP and CoMP outcomes in a C-RAN implementation. CoMP coordination areas of various sizes were investigated. JT has already been introduced in Chapter 2. In CoMP JT, a victim UE is served by multiple BS depending on the received signal power from the different transmitters. The coordination in CoMP can be intra-site or inter-site.

In intra-site coordination, the transmission points are sectors of the same base station. For the system with three sectors, it means the selection of a transmission point is limited to the three sectors. In addition, because the transmitters reside at the same eNodeB, there is no backhauling issue in this system. Since a site has three sectors, the number of coordinating cells in intra-site CoMP is also three.

In inter-site coordination, the transmission points are sectors of multiple eNodeBs. Since there are multiple received signals at the UEs in the simulation, the transmitters with the highest three received signal powers are assumed to be for the cooperating set. Then, using the cooperating set, the CoMP selection criterion is used to decide if a UE is a CoMP UE. However, this thesis work uses inter-site coordination techniques only for system performance simulation analysis.

4.6.2. CoMP UE Selection Criteria

The received signal power is used to determine whether a UE is CoMP. The system identifies a UE that will use CoMP based on the power difference between the strongest and second-strongest received signals. As a condition for CoMP, a predefined power threshold is employed. Further-

more, the transmission points chosen for collaboration can be extended to the third strongest received signal and more if the power for that BS meets the criterion. The conditions for identifying a user as a CoMP are shown below.

Conditions for CoMP

$|Prx1 - Prx2|<$ Rx Power Threshold and/or $|Prx1 - Prx3|<$ Rx Power Threshold (4.5)

$Prx1$: strongest Rx signal power

$Prx2$ and $Prx3$: are the second and third strongest Rx signal power.

The above condition is the basic CoMP UE selection criterion [27]. It is used to determine whether or not a UE employs CoMP. Based on this condition, a UE is chosen to apply CoMP based on the difference in power between the received signal and the interference signal with the highest power. The received (Rx) power threshold is used as a trigger condition for CoMP. When the power differential at the UE is less than the threshold, the UE is considered a victim UE that must use CoMP. The CoMP method used in our simulation to compare to the non-CoMP system is JT. In Chapter 3, JT was introduced. A victim UE is supplied by multiple BS in JT CoMP, based on the received signal powers from the various transmitters as described in the preceding condition.

To determine the performance gain, an existing interference coordination mechanism in the LTE system is used. The CoMP is a key element of LTE Release 11 that attempts to boost the performance of cell-edge UEs. The serving BSs and the strong interfering BSs cooperatively service the edge UEs in CoMP mode. In CoMP mode, the serving BSs and the strong interfering BSs operate together to support the edge UEs. The number of collaboration BSs is limited because of insufficient backhaul connectivity. In this study, the simulation results of non-CoMP, JT-CoMP 03, and JT-CoMP 07 schemes are discussed.

The physical layer, medium access control layer, and network layer functions are all performed by the BBU pool, while the distributed APs are configured with basic radio frequency functions. Because all baseband processing resources are centralized at the BBU pool, traditional CoMP can be easily incorporated and extended to the LSC in C-RANs. Light interference, low energy consumption, and low deployment cost are all advantages of C-RANs over LTE-A small cell networks, especially for dense networks [9].

Chapter 5

5. Simulation Results and Performance Comparison

This chapter presents the simulation results for the specified Addis Ababa LTE-A system, created with WinProp and Matlab. The first simulation results show how well the network is operating right now. The network is then studied by incorporating JT-CoMP three cell coordination (JT-CoMP 03) into the system, and the JT-CoMP seven cell coordination (JT-CoMP 07), which in our case, is assumed to be implemented in C-RAN), is then assessed. The first simulation of the CoMP system examines the impact of the chosen power threshold on the selection of CoMP UEs and the CoMP system.

5.1. Simulation Approaches, Parameters, and Assumptions

5.1.1. Simulation Approaches

Now that the investigation area and base station serving the area have been defined, and user distributions have been established based on the traffic intensity map, we may input key study area parameters into the simulation environment. In this simulated scenario, base stations are laid out in a hexagonal configuration, and evaluated UEs are positioned at the center. Due to this, the maximum coordination of seven cells is assumed for the simulation case.This research makes use of a Matlab-based LTE system-level simulator. The propagation environment, commonly known as path loss data, is the major input data to the simulator. WinProp is used to calculate the propagation environment (path loss data). Relevant data, such as a digital building map and landscape, must be imported to do so. After that, properly configured macro parameters are configured, as well as building and terrain data, as shown in Figure 5.1. We conduct propagation computation after specifying the settings in WinProp to acquire path loss data in text format. The path loss data obtained from WinProp is not acceptable for use in the LTE simulator. As a result, the path loss data is transformed into a format called ".mat" files that the LTE simulator can understand. For optimization, the translated path loss of each cell is fed into the Matlab LTE simulator's CoMP algorithm.

For each pixel from each site, the LTE system-level simulator gathers path loss, cell location information, and azimuth, transmit power, and antenna height from the converted path loss data. The SINR, throughput, and spectral efficiency are calculated using the method outlined in Chapter 4.

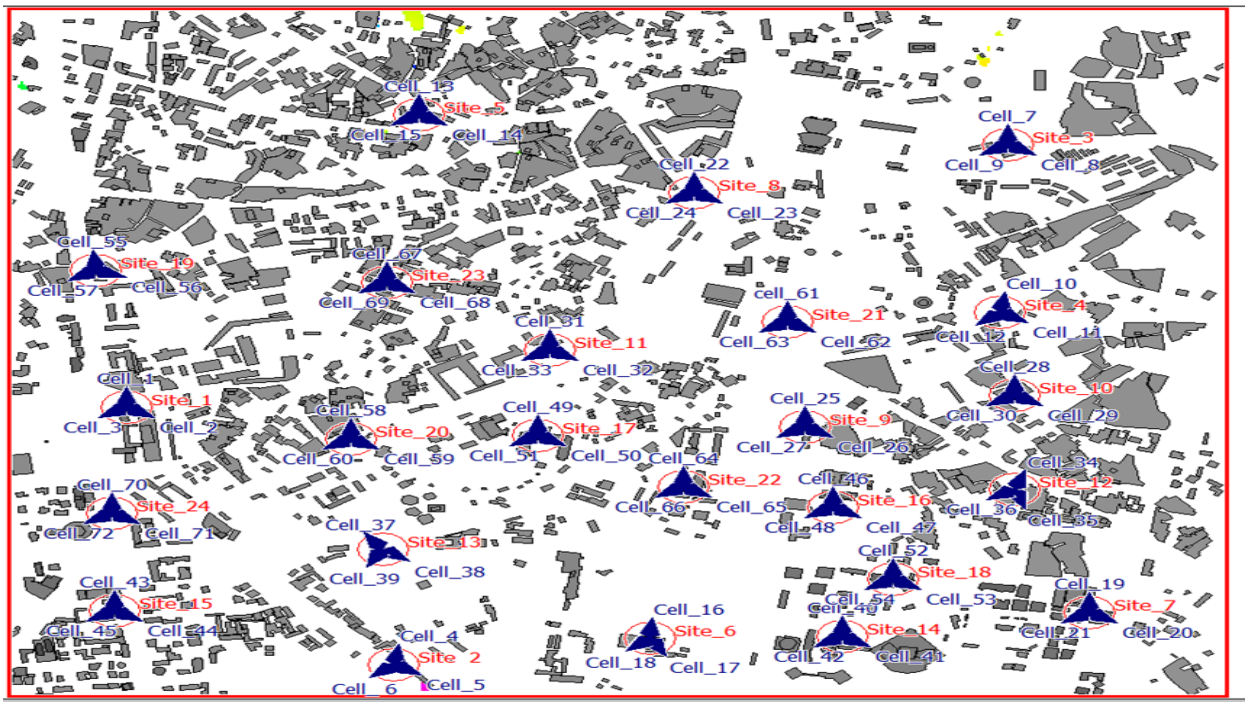

Figure 5.1 Selected sites with Macrocells in WinProp

5.1.2. Simulation Parameters and Assumptions

In Table 1 below, the important simulation parameters related to macro cell configuration and network scenario are summarized.

Table 1 Simulation Parameters and Assumptions

Common Parameters	Values/Assumptions
Deployment Scenario	24 Macro sites/72 cells
Carrier Frequency/ Duplex Mode	2600 MHz / FDD
CoMP threshold	10 dB
Simulations	Radio propagation modeling (WinProp), System level simulator (Matlab)

Resolution of prediction	5 m	
Bandwidth	20MHz	
SINR-throughput mapping	SINRmin (dB)	-10
	Bw_eff	0.62
	SINR_eff	1.8
Macro Cells Parameters		
Tx power	46dBm	
Antenna height/Azimuth/Tilt/Location	Based on ET engineering parameters	
Antenna Pattern	Kathrein 742212	
UE Parameters		
UE number	864	
UE height	1.5m	
Receiver noise figure	9 dB	
Thermal noise density	-174 dBm/Hz	
Shadow Fading and Scheduling Characteristics		
Shadow Fading	Log-normal with standard deviation of 8 dB and decorrelation distance 50 m	
Cell association	Based on RSRP	
Scheduling	Round robin scheduling	

5.2. Cumulative Distribution Function

The Cumulative Distribution Function (CDF) is one of the approaches for plotting the simulation results. The CDF is a suitable mathematical description of a random variable X and is defined as the probability that X will take a value less than or equal to x.

$$F_X(x)=P(X\leq x)$$

Where X is the random variable and x is a variable that takes a value from all of the random variable's possible outcomes. The CDF can be used to identify the probability that a random variable is lower than, higher than, or between two values. The CDF is employed in our simulation, with the SINR, throughput, or spectral efficiency values assumed to be random variables.

5.3. Simulation Results

5.3.1. Simulation Result of Existing Network

The downlink performance is the focus of this simulation study. A coverage analysis of the existing LTE-A network based on SINR was performed for the system-level analysis of the current network. Figure 5.2 below depicts the existing network as a result of the network propagation tool, with a minimum SINR of -8dB and a maximum SINR of 16dB. This result shows that it has a high ICI because the network performance is low, so it needs ICI mitigation techniques to improve this problem.

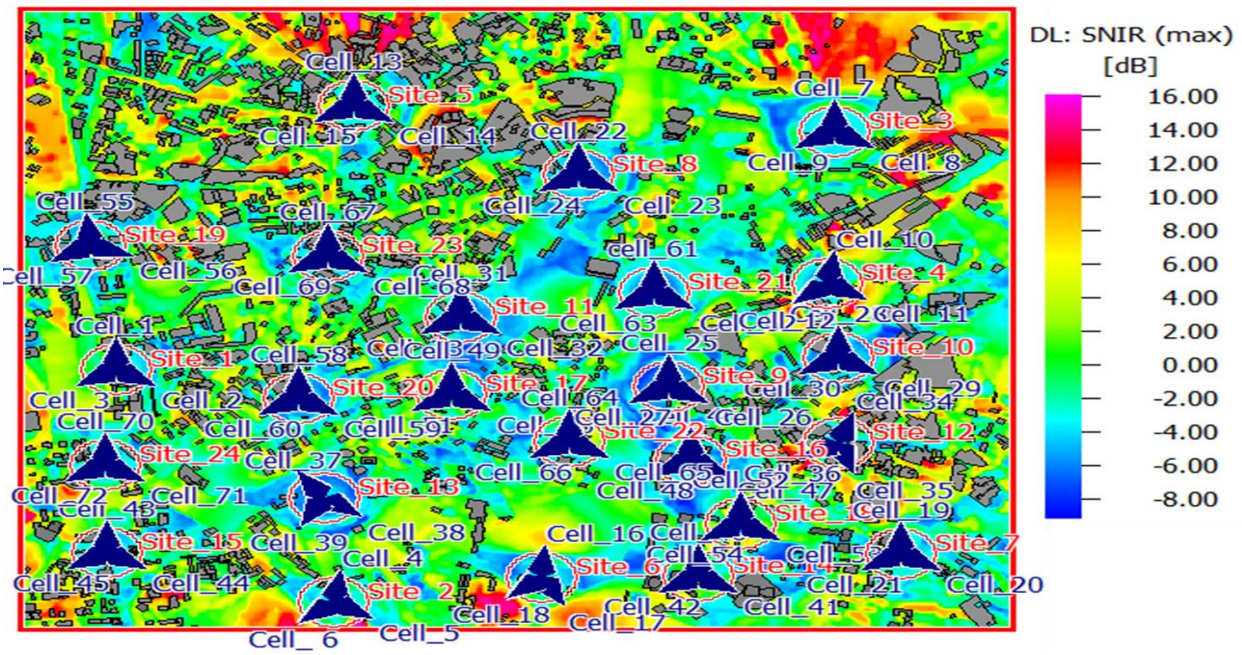

Figure 5.2 SINR of existing networks from WinProp tool

Figure 5.3 shows the SINR in terms of probability (CDF) for each possible UE position in the coverage zone, with each UE position occupying 5m2 of area. Figure 5.3 depicts the existing network, which was generated using the Matlab simulation tool and has a minimum SINR of -8dB and a maximum SINR of 16dB. The path loss data obtained from the propagation tool is used in Matlab for this SINR result.

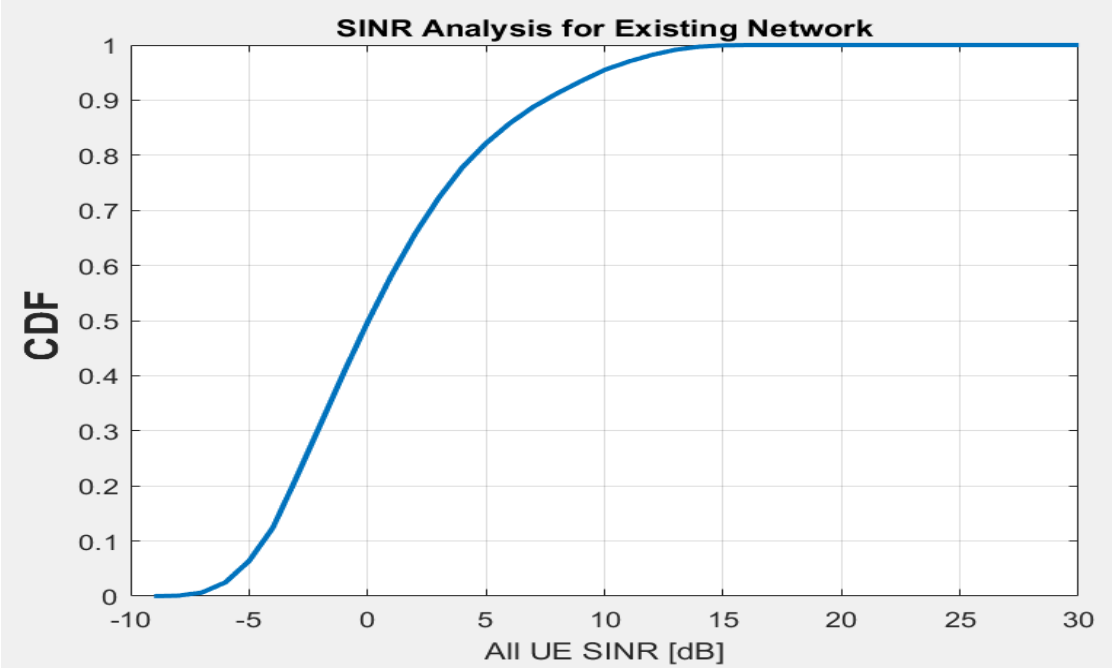

Figure 5.3 SINR result of the Existing networks

Figure 5.3 demonstrates the SINR performance in several random locations. The SINR value at the cell edge (at a CDF of 0.2) can reach -3dB, while the SINR value at the cell average (at a CDF of 0.5) can reach 0dB. This figure shows that the UEs are faced with a high level of interference. As a result, the low SINR performance indicates that the closest macrocell strongly interfered with the services given by another macrocell. CoMP can be deployed between macrocells to address these difficulties, resulting in improved performance.

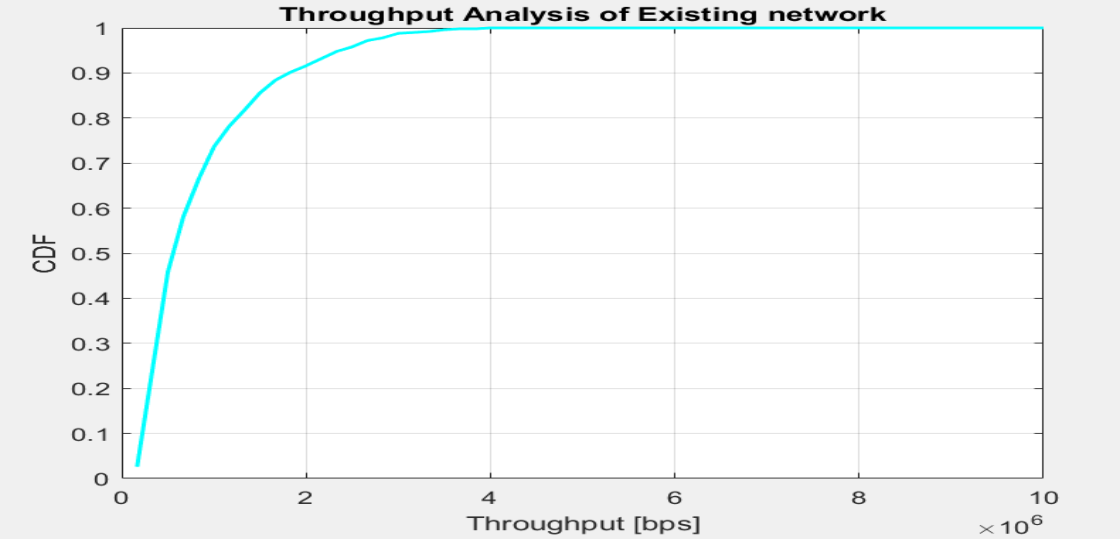

Figure 5.4 Existing networks throughput analysis

The existing network configuration of the throughput result shows that approximately 75% of the UEs have a throughput of less than 1 Mbps (as shown in Figure 5.4). The cell edge and cell average throughput values are 0.31Mbps and 0.59Mbps, respectively.

See below Figure 5.5, which shows the spectral efficiency.When all feasible UE locations are taken into account, the coverage results are shown in the simulation below. To see the findings in a system that was similar to the real situation, a simulation was developed with randomly distributed users in each cell of the coverage area. The simulation result is depicted in Figure 5.5 below. The spectral efficiency values for the cell edge and cell average are 0.2 b/s/HZ and 0.4 b/s/HZ, respectively.

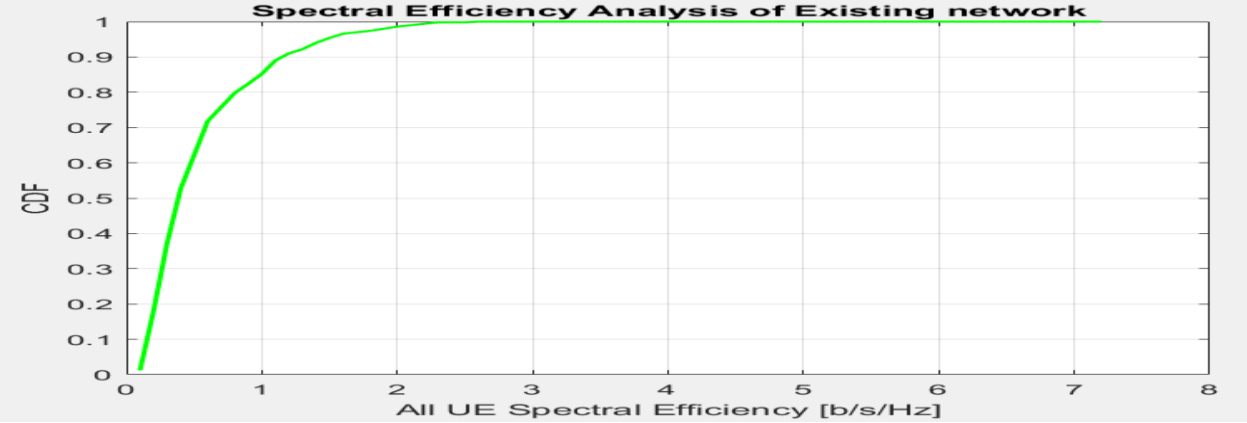

Figure 5.5 Existing network Spectral Efficiency

5.3.2. Simulation Result using CoMP

The comparison between the non-CoMP and the JT CoMP three coordination area (JT CoMP-03) systems is discussed below. Figure 5.6 depicts the SINR graph for both the existing network configuration and the CoMP system. As illustrated here, UEs at the cell edge reach a maximum SINR of 3.94dB, UEs at the cell average achieve a maximum of 3.69dB, and UEs at the cell center achieve a maximum of 1.3dB (at a CDF of 0.9). As a result, CoMP has improved its cell edge and cell average.

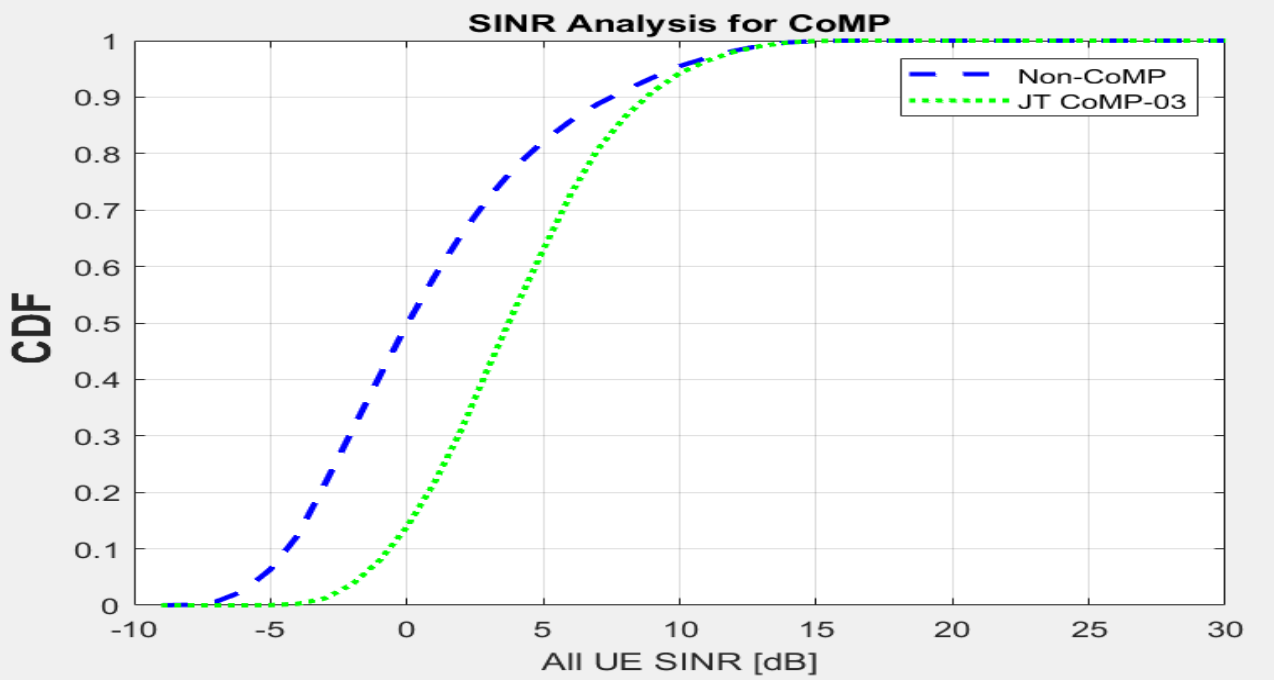

Figure 5.6 SINR analysis Non-CoMP and JT CoMP-03

Figure 5.7 illustrates a throughput performance plot that compares the performance of the existing network setup with the performance after the CoMP approach was modified. In the figure below, UEs at the cell edge achieve a maximum of 0.32Mbps on the cell edge, 0.62Mbps on the cell average, and 0.65Mbps at the cell center.

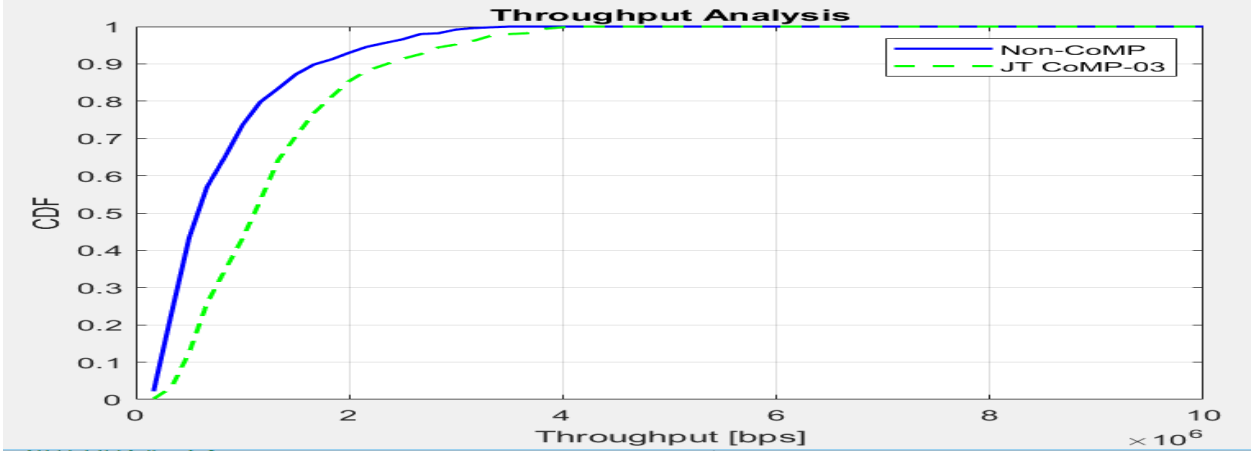

Figure 5.7 Throghput analysis of Non- CoMP wth JT CoMP-03

In terms of throughput, the JT CoMP-03 system can outperform the non-CoMP system. As a result, JT CoMP-03 may efficiently decrease ICI and enhance throughput in the Addis Ababa LTE-A for the specified area.

Figure 5.8 depicts the spectrum efficiency graph for both the existing network configuration and the JT CoMP-03 system. The spectral efficiency at the cell edge and for cell average UEs at the cell edge achieve a maximum of 0.22b/s/HZ at the cell edge, 0.41 at the cell average, and 0.41Mbps at the cell center, as indicated in the figure below.

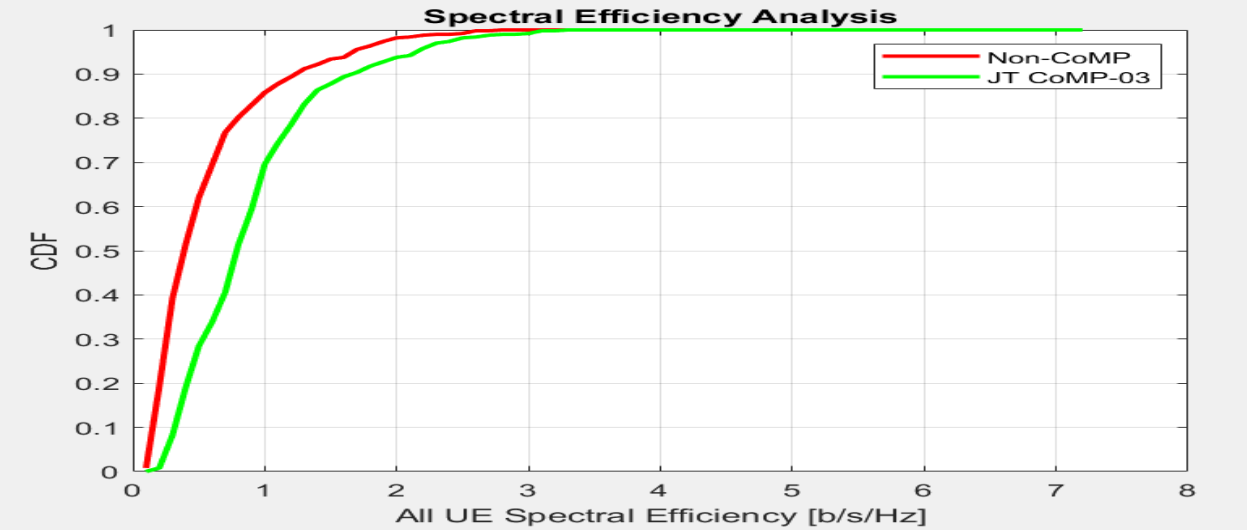

Figure 5.8 Spectral efficiency of JT CoMP-03

5.3.3. Performance Comparison

Figure 5.9 depicts the SINR graph for both the JT CoMP-03 and JT CoMP-07 systems. The comparison between the JT CoMP-03 and the JT CoMP-07 systems is discussed below. UEs at the cell edge obtain a maximum SINR of 4.16dB, UEs at the cell average achieve 4dB, and UEs at the cell center achieve 4.06dB using JT CoMP-07, as shown below. As a result, JT CoMP-03 has better cell edge and cell average improvements, while JT CoMP-07 outperforms the JT CoMP-03 system because a relatively high amount of interference is turned into a useful signal.This is to make it more interference reducing, as well as the desired signals are extremely high. In addition, almost all user positions have SINR above 0dB in inter-site JT CoMP-07 has a 95% due to efficient resource allocation and getting high signal strength, while in non-CoMP, 45% of user positions have SINR below 0dB.

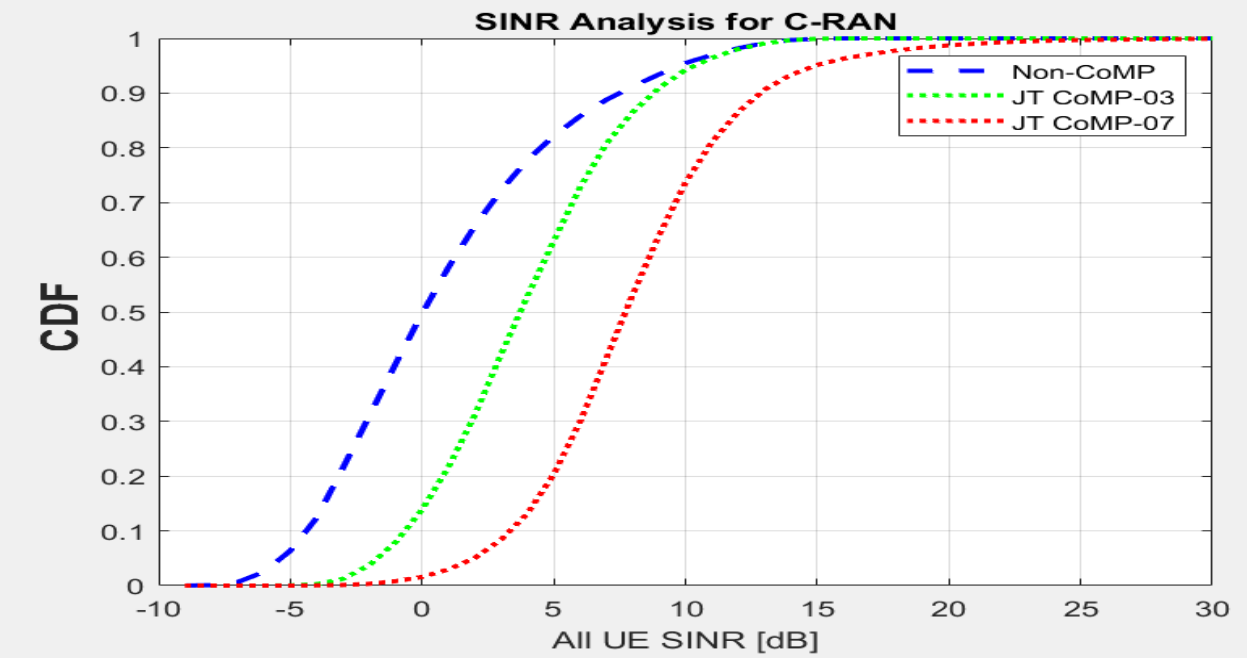

Figure 5.9 Comparison SINR of JT CoMP-03 with JT CoMP-07

Figure 5.9 indicates that SINR improvement appears between coordination. This enhancements address the fact that each UE operates the received power from various cell coordinators, reducing interference significantly. The reason for this is that when the amount of interference is minimal, there are more available desired signals for the user. Users, on the other hand, receive comparably

greater RBs as the number of cells coordinated increases as part of the JT CoMP-07 system's deployment. Furthermore, the proposed approach meets more user needs than existing methods since converting the interference signal to useful signal power results in higher SINR.

The throughput graph for both the JT CoMP-03 and JT CoMP-07 systems is shown in Figure 5.10. According to the graph below, UEs at the cell edge achieve a maximum of 0.6Mbps, and UEs obtain 0.61Mbps on average when using JT CoMP-07. As a result of this, the JT CoMP-07 system outperformed the JT CoMP-03 system. The figure shows that, based on the range of CDF plots, the gain in throughput is rather significant as compared to the basic non-CoMP systems. This is because, with JT CoMP-07 and JT CoMP-03 UEs data, data is available at several locations for the same time frequency resource, by default at all points to improve received signal quality and reduce interference.

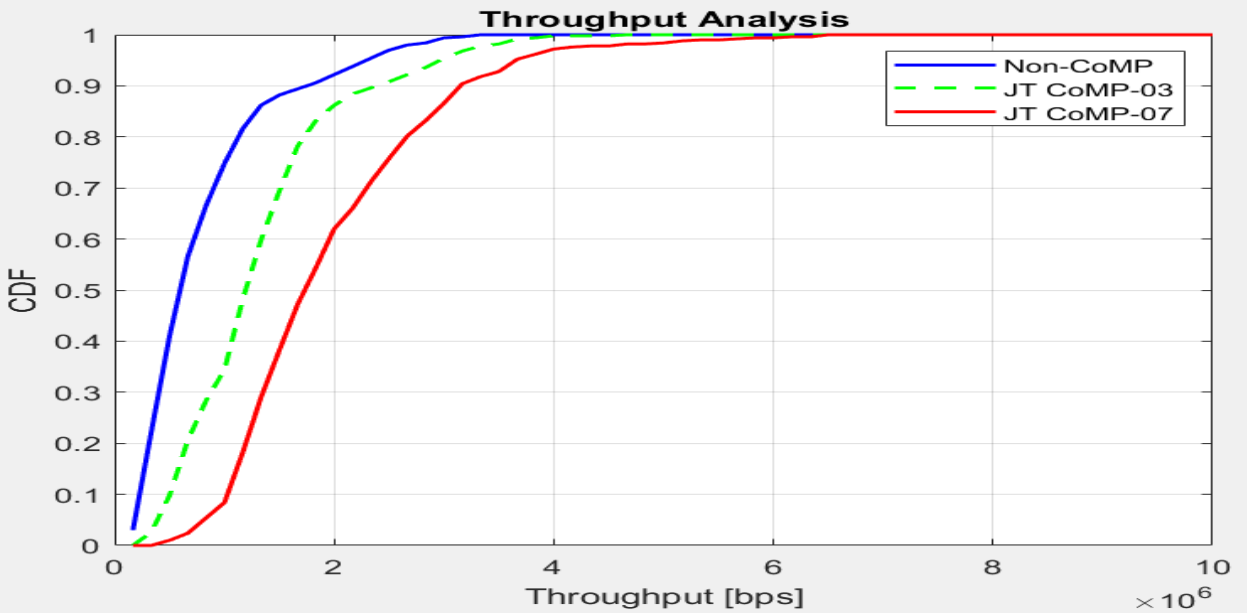

Figure 5.10 Comparison of throughput of JT CoMP-03 with JT CoMP-07

The graph below depicts the spectral efficiency performance gain. According to Figure 5.11, UEs at the cell edge achieve a maximum of 0.25b/s/HZ, UEs achieve 0.2b/s/HZ on average, and UEs in the cell center obtain 0.67b/s/HZ when implementing JT CoMP-07. This is because multiple coordination cells are deployed inside the coverage area, resulting in more cell boundaries, and the overlap of cells with different transmission strengths increases the interference area even more. As

a result, more UEs use JT CoMP-03 transmission techniques to reduce interference and boost signal strength. Furthermore, the JT CoMP-07 transmission adds greater performance advantages as compared to other JT CoMP-03 and non-CoMP systems. This is due to the demand for cooperating BSs to provide more information, which transforms the interference signal into a useful signal, resulting in better SINR and spectral efficiency.

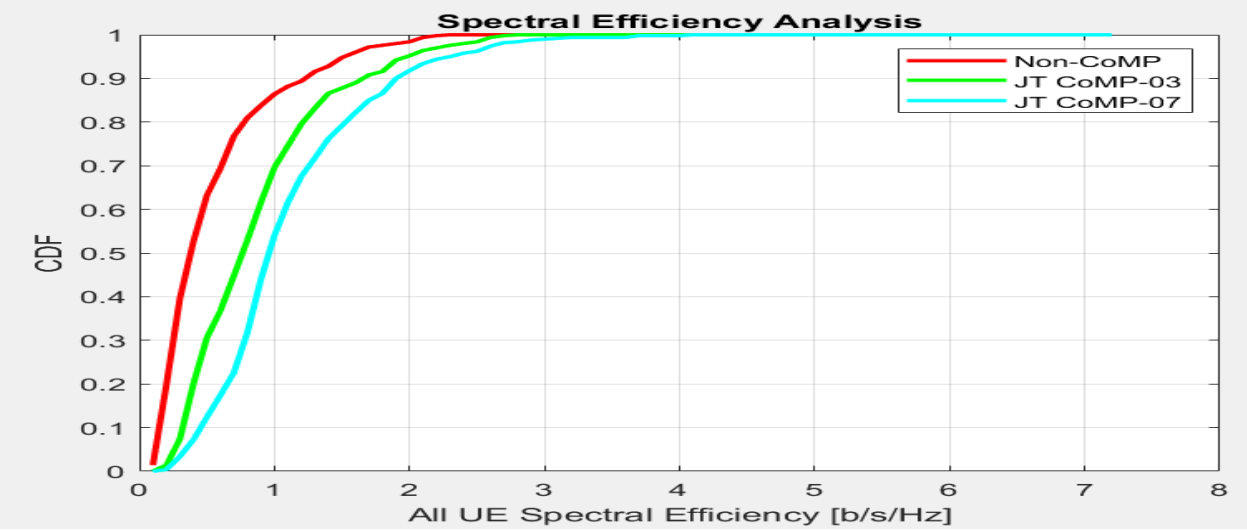

Figure 5.11 Comparison of Spectral efficiency of JT CoMP-03 with JT CoMP-07

The comparison between the non-CoMP and the JT CoMP-07 systems is discussed below based on SINR, throughput, and spectral efficiency.

Figure 5.12 shows the SINR performance. At the 20% tile, there is a noticiable improvement and also at the 50% tile, whereas there is small improvement at the 90% tile compared to the 20th and 50% tiles. To check the SINR performance of the selected power threshold values for the overall system, the whole user position SINR is used. Apparently, the SINR improvement obtained by the network with the JT CoMP-07 scheme for the system average and cell edge improved significantly. The performance improvement between JT CoMP-07 systems and those in non-CoMP systems is 7dB for cell edge and 8dB for cell average. The SINR performance for cell average users are slightly higher. Since the average user who already has a good channel condition is slightly higher. 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 JT CoMP-07 methods provide better system performance gains, which increase the entire SINR by 60%. Therefore Compared to non-CoMP performance, the CoMP and C-RAN SINR improved by 3.94dB–8dB for cell edge users

(20% CDF) and 3.69dB–7.4dB for cell users (50% CDF). Therefore, the JT CoMP-03 and JT CoMP-07 SINR improved by 3.94dB–8dB for cell edge users (at 20% CDF) and by 3.69dB–7.4dB for cell users (at 50% CDF) when compared to non-CoMP performance.

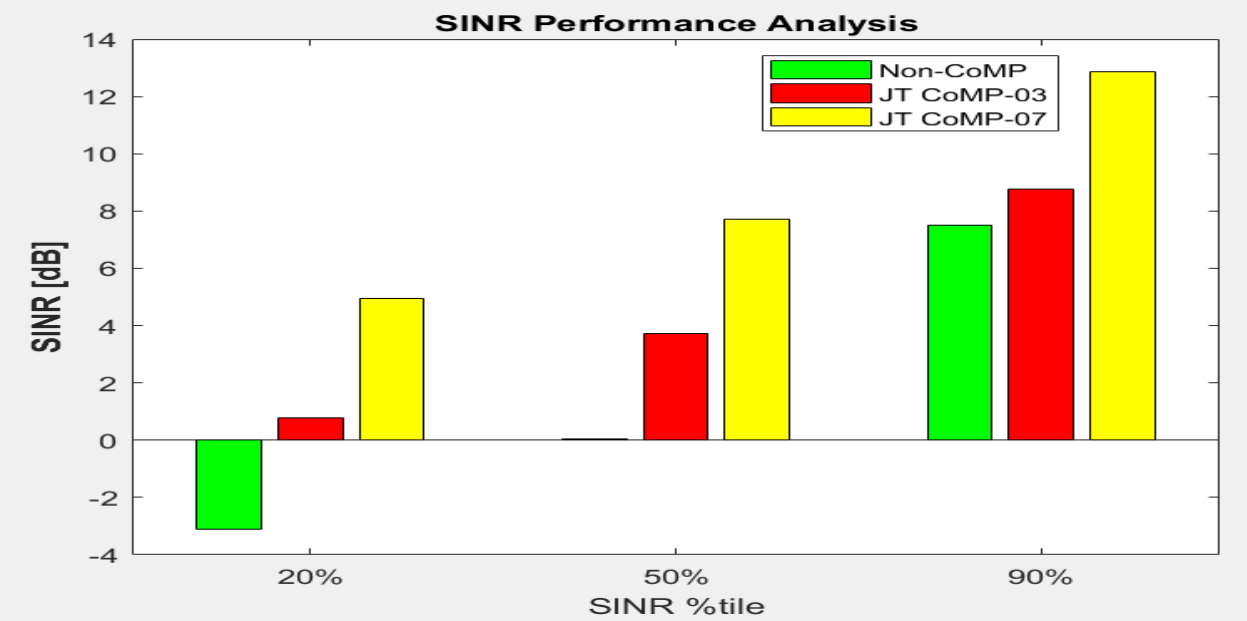

Figure 5.12 SINR performance comparison

Figure 5.13 displays the percentile of throughput performance. There has been some small improvement at the 20% tile. When comparing the 20th and 50% tiles, it shows higher progress at the 50% tile, while the best throughput performance is at the 50th and 90% tile. The figure shows that it is clear that all CoMP systems can achieve a throughput improvement compared to the baseline non-CoMP systems. The CoMP system throughput gains for cell-edge, cell-average, and cell-center users are depicted in Figure 11. In terms of throughput, all CoMP systems clearly outperform non-CoMP baseline systems. Using the non-CoMP system performance as a baseline, the throughput gain for JT CoMP 03 techniques can range from 30 to 104 percent, and 50 to 193.5 percent for JT CoMP-07 techniques. The JT CoMP-07 is the most interesting one in terms of employing a method to mitigate the strongest interference, since it gives the highest throughput. This confirms that it helps to obtain more significant cell edge throughput performance. The simulation result shows that having to mitigate interference is necessary to maintain good service. In particular, on 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 JT CoMP-07 technique is one of the important capacity enhancement methods that are being implemented.

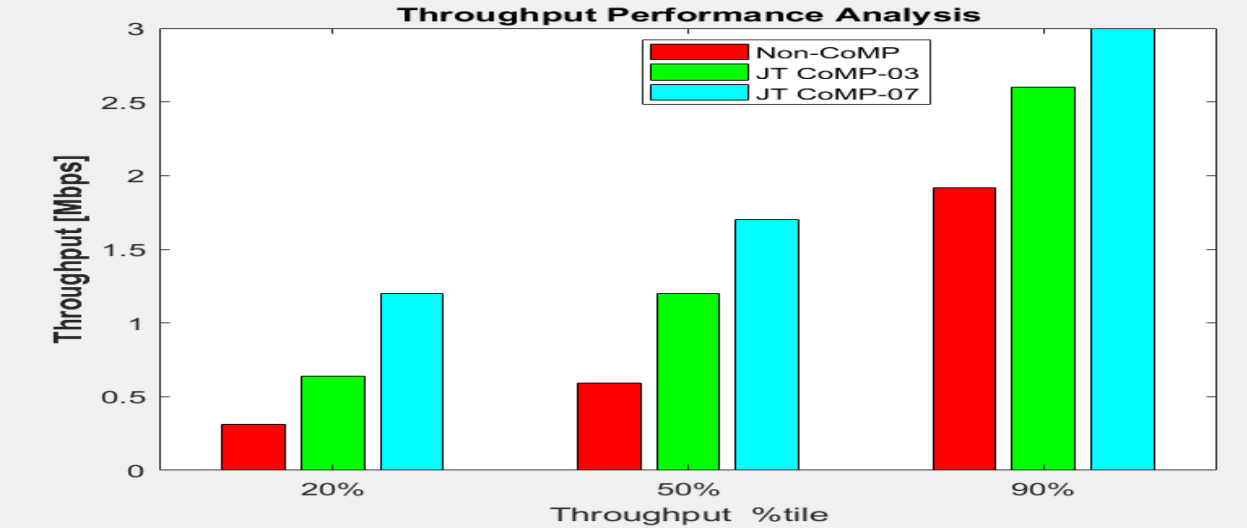

Figure 5.13 Throughput performance

Figure 5.14 displays the percentile of spectral efficiency performance. There has been some small improvement at the 20% tile. When comparing the 20th and 50% tiles, it shows higher progress at the 50% tile, while the best spectral efficiency performance is at the 90% tile. The figure shows the spectral efficiency performance for the cell edge and average users for the JT CoMP-03 systems, set to a baseline of non-CoMP systems. Actual enhancement for JT CoMP 03 techniques can range from 35 to 106 percent, while enhancement for JT CoMP 07 techniques can range from 41 to 162 percent. Therefore, all CoMP scheme cases provide the highest overall spectral efficiency gains compared with the non-CoMP scenarios.

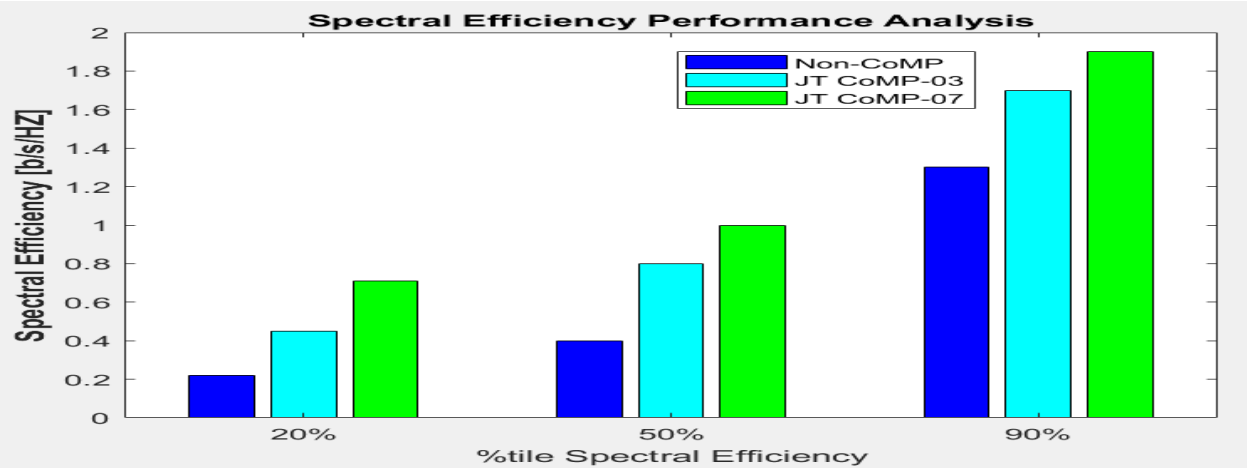

Figure 5.14 Spectral efficincy performance

Chapter 6

6. Conclusions and Future Work

6.1 Conclusions

The current Addis Ababa LTE-A network is employed to improve data service in this thesis study, but ICI has a significant impact on the network performance. The CoMP in LTE-A networks, as well as large-scale coordination in various sized CoMP coordination areas, were investigated. The CoMP system simulation results in the chosen area show a significant improvement in SINR, spectral efficiency, and throughput. According to the simulation results, CoMP improves both the cell edge and the average UE of CoMP systems. SINR improves by 1.3 dB to 8 dB when CoMP techniques are used. SINR performance improved when the number of cell coordination areas in the JT CoMP approach was increased. It has been proven that C-RAN is the better architecture to reduce inter-cell interference by using the CoMP technique. The paper investigates C-RAN as a solution for reducing interference and boosting network performance using large-scale CoMP coordination areas of various sizes. As a result, the paper also evaluates and compares the benefits of CoMP in different sizes of coordination in terms of UE performance. All CoMP systems can improve non-CoMP baseline systems in terms of throughput. In terms of employing a method to reduce the strongest interference, large-scale CoMP coordination is the most interesting. This confirms that it results in an improved cell average and cell edge from 50% to 193.5% throughput performance. Therefore, in the current ET LTE-A network, applying C-RAN with large scale CoMP coordination will be recommended.

6.2 Future Works

CoMP can actually degrade performance in a C-RAN with limited fronthaul capacity limits, where the network radio capacity is substantially higher than the fronthaul capacity. The reason for this is that with CoMP, the served user's data must be transferred from the BBU pool to all serving RRHs, putting a heavy load on the fronthaul links. As a result, network coverage and spectral efficiency may suffer as the number of users serviced declines due to restricted fronthaul capacity.

As a result, novel strategies are required to achieve CoMP performance benefits without utilizing a significant amount of fronthaul capacity that could affect other users. Optimal clustering of the cells and BBU pool assignability with minimal overhead and maximum gain is also a challenge. One BBU should achieve the maximum number of send and receive channels while minimizing the fronthaul delay and overhead in C-RAN systems.

Reference

[1] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2017–2022 https://s3.amazonaws.com/media.mediapost.com/uploads/CiscoForecast.pdf [accessed Oct 31, 2021]

[2] Salman, Tara. "C-RAN: Basics, advances, and challenges." *A Surv. C-RAN Basics Virtualization Resour. Alloc. Chall* (2016): 1-16.

[3] Chabbouh, Olfa, et al. "A novel cloud RAN architecture for 5G HetNets and QoS evaluation." 2016 International Symposium on Networks, Computers and Communications (ISNCC). IEEE, 2016.

[4] Cheng, Bobo, et al. "A real-time implementation of CoMP transmission based on cloud-RAN infrastructure." 2014 International Wireless Communications and Mobile Computing Conference (IWCMC). IEEE, 2014.

[5] Labana, Mohamed, and Walaa Hamouda. "Advances in CRAN Performance Optimization." IEEE Network 35.3 (2020): 140-146.

[6] Huiyu, Yuan, et al. "Performance evaluation of coordinated multipoint reception in CRAN under LTE-Advanced uplink." 7th International Conference on Communications and Networking in China. IEEE, 2012.

[7] Liu, Junyu, et al. "CoMP transmission in cloud radio access networks." 2015 IEEE Globecom Workshops (GC Wkshps). IEEE, 2015.

[8] Peng, Mugen, et al. "Recent advances in cloud radio access networks: System architectures, key techniques, and open issues." IEEE Communications Surveys & Tutorials 18.3 (2016): 2282-2308.

[9] Zhang, Xinran, et al. "Performance analysis and evaluation of cloud radio access networks." 2018 International Conference on Computing, Networking and Communications (ICNC). IEEE, 2018.

[10] Ali, Md Shipon, and Mojaiana Synthia. "Performance analysis of JT-CoMP transmission in heterogeneous network over unreliable backhaul." 2015 International Conference on Electrical Engineering and Information Communication Technology (ICEEICT). IEEE, 2015.

[11] Davydov, Alexei, et al. "Evaluation of joint transmission CoMP in C-RAN based LTE-A HetNets with large coordination areas." 2013 IEEE Globecom Workshops (GC Wkshps). IEEE, 2013.

[12] Huiyu, Yuan, et al. "Performance evaluation of coordinated multipoint reception in CRAN under LTE-Advanced uplink." 7th International Conference on Communications and Networking in China. IEEE, 2012.

[13] Jiang, Dajie, et al. "Uplink coordinated multi-point reception for LTE-advanced systems." 2009 5th International Conference on Wireless Communications, Networking and Mobile Computing. IEEE, 2009.

[14] Nagate, Atsushi, et al. "Field experiment of CoMP joint transmission over X2 interface for LTE-Advanced." 2013 IEEE 77th Vehicular Technology Conference (VTC Spring). IEEE, 2013.

[15] Li, Lei, et al. "Field test of uplink CoMP joint processing with C-RAN testbed." 7th International Conference on Communications and Networking in China. IEEE, 2012.

[16] Marsch, Patrick, Michael Grieger, and Gerhard Fettweis. "Large scale field trial results on different uplink coordinated multi-point (CoMP) concepts in an urban environment." 2011 IEEE Wireless Communications and Networking Conference. IEEE, 2011.

[17] Jungnickel, V., et al. "Field trials using coordinated multi-point transmission in the downlink." 2010 IEEE 21st International Symposium on Personal, Indoor and Mobile Radio Communications Workshops. IEEE, 2010.

[18] Makhanbet, Meruyert, et al. "An overview of cloud RAN: Architecture, issues and future directions." International Conference on Emerging Trends in Electrical, Electronic and Communications Engineering. Springer, Cham, 2016.

[19] Holma, Harri, and Antti Toskala. LTE for UMTS: Evolution to LTE-advanced. John Wiley & Sons, 2011.

[20] https://www.3gpp.org/technologies/keywords-acronyms/98-lte [accessed October 25,2021]

[21] Checko, Aleksandra, et al. "Cloud RAN for mobile networks—A technology overview." IEEE Communications surveys & tutorials 17.1 (2014): 405-426.

[22] Lescuyer, Pierre, and Thierry Lucidarme. Evolved packet system (EPS): the LTE and SAE evolution of 3G UMTS. John Wiley & Sons, 2008.

[23] Tarokh, Vahid, ed. New directions in wireless communications research. Heidelberg: Springer, 2009.

[24] Hailu, Dawit Hadush, et al. "Mobile fronthaul transport options in C-RAN and emerging research directions: A comprehensive study." Optical Switching and Networking 30 (2018): 40-52.

[25] Singh, Satnam, et al. "Coordinated Multipoint (CoMP) Reception and Transmission for LTE-Advanced/4G 1." (2012).

[26] Samal, Soumya Ranjan. "Interference Management Techniques in Small Cells Overlaid Heterogeneous Cellular Networks." Journal of Mobile Multimedia 14.3 (2018): 273-306.

[27] Chen, Yiye. "Coordinated Multipoint Communications In Heterogeneous Networks." (2013).

[28] Alade, Temitope, and Qasim Zeeshan Ahmed. "Performance Comparison of Small Cell and Distributed Antenna Systems for In-Building Mobile Communications." 2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring). IEEE, 2019.

[29] Chen, K., Duan, R.: C-RAN the road towards green RAN, White Paper, vol. 2. China Mobile Research Institute (2011)

[30] Suryaprakash, Vinay, Peter Rost, and Gerhard Fettweis. "Are heterogeneous cloud-based radio access networks cost effective?." IEEE Journal on Selected Areas in Communications 33.10 (2015): 2239-2251.

[31] Chih-Lin, I., et al. "Recent progress on C-RAN centralization and cloudification." IEEE Access 2 (2014): 1030-1039.

[32] Beyene, Yihenew Dagne, Riku Jäntti, and Kalle Ruttik. "Cloud-RAN architecture for indoor DAS." IEEE Access 2 (2014): 1205-1212.

[33] Gavrilovska, Liljana, et al. "Flexible C-RAN: Radio technology for 5G." 2017 13th International Conference on Advanced Technologies, Systems and Services in Telecommunications (TELSIKS). IEEE, 2017.

[34] Chen, Yuh-Shyan, Wen-Lin Chiang, and Min-Chun Shih. "A dynamic BBU–RRH mapping scheme using borrow-and-lend approach in cloud radio access networks." IEEE Systems Journal 12.2 (2017): 1632-1643.

[35] Namba, Shinobu, Takayuki Warabino, and Shoji Kaneko. "BBU-RRH switching schemes for centralized RAN." 7th International Conference on Communications and Networking in China. IEEE, 2012.

[36] Simeone, Osvaldo, Elza Erkip, and Shlomo Shamai. "Full-duplex cloud radio access networks: An information-theoretic viewpoint." IEEE Wireless Communications Letters 3.4 (2014): 413-416.

[37] Checko, Aleksandra, et al. "OTN transport of baseband radio serial protocols in C-RAN architecture for mobile network applications." (2014).

[38] Haile, Beneyam B., Edward Mutafungwa, and Jyri Hämäläinen. "Coordinated multi-point transmission for relaxation of self-backhauling bottlenecks in heterogeneous networks." EURASIP Journal on Wireless Communications and Networking 2015.1 (2015): 1-17.

[39] Altair, About. [online] Available at: https://altair.com/about/ [Accessed 31 Oct. 2021].

[40] Wahl, René, et al. "Dominant path prediction model for urban scenarios." 14th IST Mobile and Wireless Communications Summit, Dresden (Germany) (2005).

[41] Mogensen, Preben, et al. "LTE capacity compared to the Shannon bound." 2007 IEEE 65th vehicular technology conference-VTC2007-Spring. IEEE, 2007.

Appendix

Performance Evaluation of CoMP in C-RAN-based LTE Advanced Networks: The Case of Addis Ababa, Ethiopia

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Abstract- Mobile broadband traffic has been rapidly increasing over the last few years. Because mobile services are becoming increasingly vital in our daily lives. Inter-Cell Interference (ICI) is caused by a short inter-site distance paired with the use of frequency reuse factor one. ICI has a major impact on mobile data network performance, particularly for users at cell edges.The concept behind C-RAN is to move traditional cell site digital baseband processing units and radio remote heads to the Base Band Unit (BBU) pool for centralized signal processing and management. This allows for support of the CoMP technique in mobile networks to mitigate ICI, and allowing for higher throughput. The Signal to Interference plus Noise Ratio (SINR), spectral efficiency, and system throughput performance metrics were used to compare and evaluate CoMP coordination and non-CoMP systems of various sizes. The simulation is implemented in MatLab, and network radio propagation is computed in WinProp. The simulation findings show that utilizing CoMP on C-RAN improves the signal to interference plus noise ratio and throughput for both average and cell-edge users significantly in comparison to traditional CoMP. In terms of employing a method to reduce the strongest interference, large-scale CoMP coordination is the most interesting. This confirms that it results in an improved cell average and cell edge of up to 193.5\% throughput performance.

1. INTRODUCTION

Mobile broadband traffic has been rapidly increasing over the last few years. The total number of people that use mobile broadband is growing in line with the mobile network's data traffic. Mobile users are dissatisfied with service quality as the number of subscribers grows due to resource sharing and increased interference [1,2].

Data traffic is expanding at an exponential rate, making it difficult for telecom operators to upgrade their networks. Traditional RAN infrastructure has several issues, including restricted system capacity and low system use. The C-RAN is a new cellular architecture that is intended to meet this issue [2,3,4,5].

The rapid advancement of mobile communication technology has greatly enhanced the speed and quality of wireless transmission. C-RAN offers the ability to

lower network deployment and operation costs while also improving the system, mobility, coverage, and energy efficiency (EE). C-RANs, particularly for dense networks, can achieve low energy consumption, low interference, and low implementation costs. Fiber is the most notable solution for dealing with high bandwidth (BW), tight latency, and jitter requirements for transport networks between remote radio heads (RRHs) and BBU pools situated in the cloud. The cost of fiber in a C-RAN deployment, on the other hand, is very high [3,4].

Present RAN cannot provide close coordination between multiple cells. CoMP is a good solution for increasing cell-edge data rate and system spectrum efficiency. C-RAN has the potential to meet the high data rate demands of 4G mobile networks [5,6].

Coordinated Multi Point (CoMP) is expected to play a significant role in 5G systems and beyond. CoMP can be used as a viable solution to reduce inter cell interference(ICI) while also improving spectral efficiency (SE) [7].

2. INTER-CELL INTERFERENCE AND COORDINATED INTERFERENCE MANAGEMENT

In the C-RAN, many RRHs from various cell sites are coupled to BBUs that share the same BBU pool. This reduces the amount of interference generated by users moving between cell sites. In the traditional RAN, users migrate between cells, changing the coverage area of the linked BSs [2,4].

eICIC and CoMP introduced for LTE-Advanced (LTE-A) to increase spectrum efficiency and throughput. eICIC and CoMP capabilities are considerably helped by the pooling of BBU resources in a C-RAN, as signal processing from multiple cells may be done across one BBU Pool [8].

C-RAN enables efficient interference management to boost mobile network capacity. When all of the cells in a CoMP set are served by a single BBU pool, signal processing is handled by one entity. As a result, interference can be kept to a minimum, allowing throughput to be enhanced [9].

A. Multi-Cell Coordination

Multi-cell coordination is intended to increase system throughput and coverage, satisfy traffic demands, optimize radio resource consumption, and improve SE per unit area. It works by reducing inter-cell interference and thereby increasing system capacity. Multi-cell coordination happens among numerous neighboring cells, which means cooperative cells share scheduling or data information with one another to reduce inter-cell interference or increase the power of received signals at the user end [11]. The Figure 1 shows multi-cell coordination.

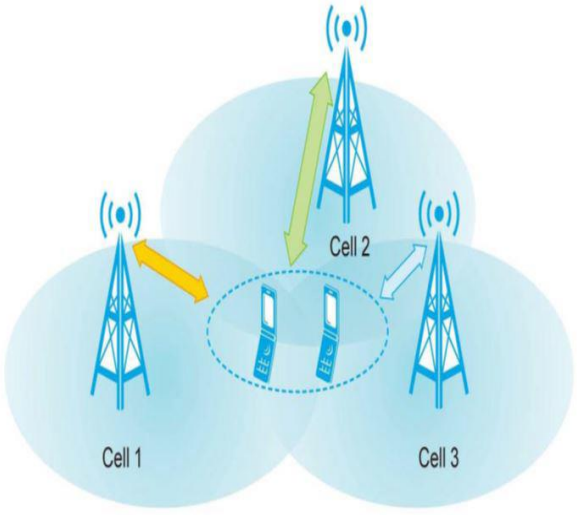

Fig. 1: Multi-cell coordination [11]

B. Coordinated Multipoint

CoMP's main idea is that multiple BSs in a cooperating set serve the same UE at the same time,

either by sending/receiving the same data or by scheduling UEs in coordination to avoid unnecessary interference. The coordinated transmission increases the power of desired signals while reducing interference power. The most advanced method of dealing with inter cell interference is CoMP, and it is based on the principle of changing interference into a useful signal. This enhances the mobile's SINR, resulting in greater achievable data rates. Release 11 of the specifications includes it. Using CoMP, several cells, organized into a so called CoMP set, work together to serve one or more users based on feedback from the mobile devices. This needs precise synchronization and cooperation among the BSs in a CoMP system, especially in DL. CoMP allows for intra-site or inter-site cooperation. The two types of CoMP systems are depicted in Figure 2 [8,10,11].

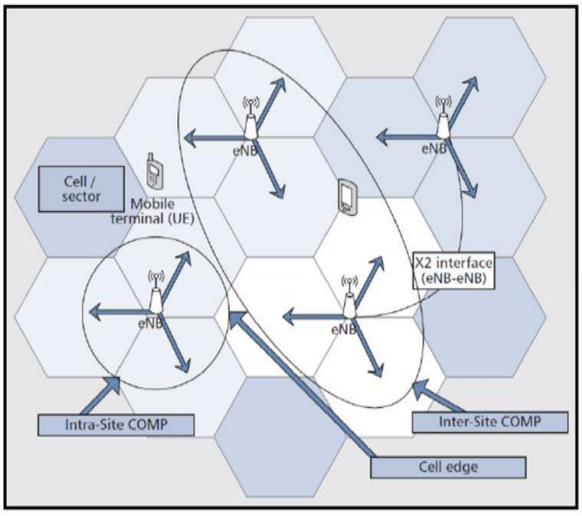

Fig. 2: Base station Cooperation: Inter-site and Intra-Site CoMP [11]

3. CLOUD RADIO ACCESS NETWORK

C-RAN is a new mobile architecture that, via the use of virtualization, can manage as many BSs as the network requires. Such an architecture would have the potential to decrease the cost as BSs are virtualized instead of physically deployed in different areas. The C-RAN is a break-through combination of emerging technologies from both the wireless network and information technology industries that has the potential to improve SE and EE. The core idea behind this concept is to pool baseband signal processing into a single physical location, which is referred to as a BBU pool. Baseband processing is aggregated and shared across sites in a virtualized BBU Pool using C-RAN.

A. C-RAN System Structure

A C-RAN system can be divided into fully centralized, partially centralized, and hybrid. The basic division depends on where the PHY, MAC layer, and network layer functions are handled. In the following, we will discuss each of these structures in brief below[2].

Fully Centralized

A fully centralized structure would move all physical, MAC, and network layers' functionalities to the BBU pool [2,12]. This architecture has the advantages of easy upgrading and network capacity expansion. It also has a better capability for supporting multistandard operation, maximum resource sharing, and is more convenient for signal processing. The large BW required between the BBU and the baseband I/Q signal is its main drawback [8,13].

Partially Centralized

In partially centralized structures, the PHY functions are done at RRUs while MAC and network layer functions are performed at BBUs. Because the baseband processing is built into RRH, it has limited upgradeability and is inconvenient for multi-cell collaborative signal processing [2,13].

In a partially-centralized architecture, PHY functions are integrated into RRHs, with other upper-layer functions incorporated into the BBU pool. L1 processing is colocated with the RRH in the partially centralized system depicted in Figure 3b. This technique is less ideal because resource sharing is severely limited and advanced features such as CoMP cannot be supported effectively [8,12].

Hybrid Centralized

In a hybrid centralized structure, part of the PHY functions are done in RRUs while others are done in BBU. RRU takes the responsibility of users or cell-specific functions that are mainly concerned with signal processing. Such a structure can be the most flexible one in resource sharing, besides having the potential to reduce energy consumption and communication over-head in BBUs [2].

Mobile operators may easily install and update their networks using any of these C-RAN architectures. To increase network coverage or boost capacity, the operator just needs to install more RRHs and link them to the BBU pool. As a result, a fully centralized solution is preferable.

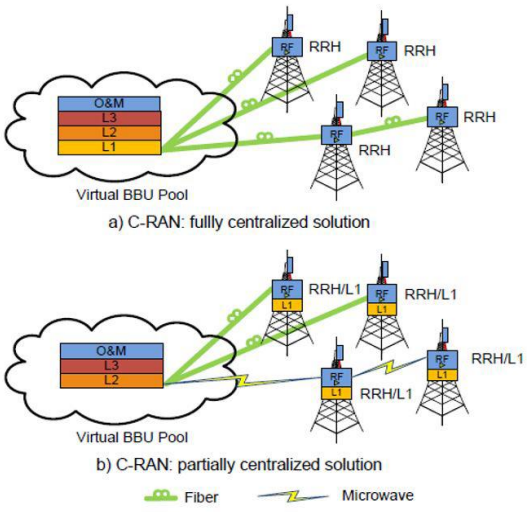

Fig. 3: C-RAN System Structure [8]

B. C-RAN Architecture and Components

The BBUs are in the cloud server, and the RRHs are geographically separated from the BBUs, according to the C-RAN architecture. In addition, BBU and RRH are connected via a fronthaul link, while BBU and the core network are connected via a backhaul link [14]. This innovative C-RAN architecture has various benefits to operators, including cost control, energy savings, greater SE and resource efficiency, increased network flexibility, and service on edge facilitation [15]. The below Figure 4 shows the C-RAN architecture.

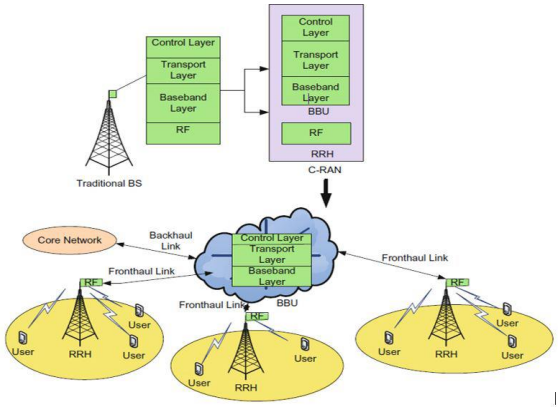

Fig. 4: C-RAN architecture [14]

The C-RAN architecture is made up of three primary components: 1) BBUs with real-time cloud infrastructure, 2) high-speed optical fiber transmission networks, and 3) distributed RRUs. Several BSs can be combined into central processing pools by using virtualization technologies[2,4,15,16]. Figure.4 above shows the overview of the C-RAN architecture, while the following summarizes the main components [2]:base band unit pool, remote radio head, and fronthaul network.

C. Virtualization in C-RAN

Network virtualization is critical in C-RAN and its deployment architectures. Such technology enables flexible control mechanisms, efficient resources, low cost, and diverse applications. Each BBU is a virtual node, and virtual links are used to communicate between them [2,16,17].

The C-RAN architecture promotes flexible control, low cost, efficient resource consumption, and diverse applications by deploying virtual networks. Virtualization of the C-RAN can be done at different levels. Virtualization of wireless networks, Hardware virtualization and Resource virtualization [18].

D. Benefits of C-RAN

Centralized BBUs in C-RAN can provide numerous benefits, including joint processing and resource sharing capabilities. This can enhance user satisfaction, improve resource utilization and reduce backbone server pressure. Services will move closer to the user and hence faster responses and better user satisfaction [2]. Some of the additional benefits are ease in network upgrades and maintenance, increased capacity and reduced inter-channel interference, improved system throughput and decrease of the delays [8,18].

E. Requirements and Challenges of C-RAN

The fronthaul issue and the difficulties of virtualization Because of the particular characteristics of wireless communication in particular, using virtualization techniques in cellular networks is significantly more challenging [2, 15]. High fronthaul capacities, BBU cooperation, cell clustering, latency, synchronization, virtualization technique, and security are some of the C-RAN needs and challenges [2,13,15].

4. METHODOLOGY FOR STUDY

For this thesis, the actual distribution of the BS in the Addis Ababa LTE-A network and the topography of the city are used for the study of the C-RAN-based CoMP system. In this study, C-RAN-based CoMP is proposed to overcome inter-cell interference. In order to develop the simulation, the Winprop and Matlab simulator tools are used.

A. Deployment Scenario

The study considers sites that are located around the Leghar area, which is a hot spot for high traffic data and is also considered an urban area. The area selected includes 24 eNodeBs with three sectors each. Each eNodeB's three sectors are regarded as a cell.The antenna for each cell is mounted on a cell tower or a few meters above the rooftop of a building. In addition the distribution of the eNodeBs is non-uniform with different distances between the eNodeBs. Currently, ET has not deployed the C-RAN. Therefore, for simulation purposes, the selected base stations are pooled into three groups. The selected area of the outdoor scenario based on 2.1km x 2.3km in the Legehar area was selected, which consists of hotels and cafeterias, a national stadium, Meskel Square, hospitals, and also populated buildings with business shops and residential areas where potential mobile users found. The Signal to Interference plus Noise Ratio (SINR), spectral efficiency, and system throughput performance metrics of the modified Shannon formula were used to compare and evaluate CoMP coordination and non-CoMP coordination

systems of various cell sizes.The below Figure 5 show the deployment of cell site in Winprop.

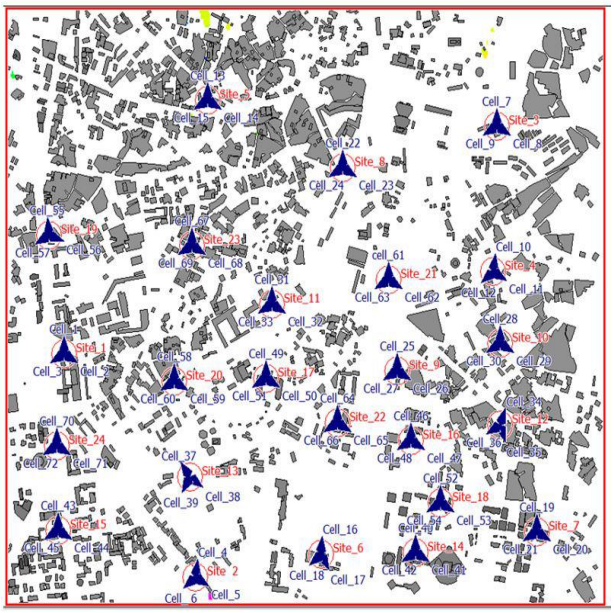

Fig. 5: Selected sites with Macrocells in WinProp

B. Simulation Parameters and Assumptions

In Table 1 below, the important simulation parameters related to macro cell configuration and network scenario are summarized.

TABLE I: Simulation parameters and assumptions

Common Parameters	**Values/Assumptions**	
Deployment Scenario	24 Macro sites/72 cells	
Carrier Frequency/ Duplex Mode	2600 MHz / FDD	
CoMP threshold	10 dB	
Simulations	Radio propagation modeling (WinProp), System level simulator (Matlab)	
Resolution of prediction	5 m	
Bandwidth	20MHz	
SINR-throughput mapping	SINRmin (dB)	-10
	Bw_eff	0.62
	SINR_eff	1.8
Macro Cells Parameters		
Tx power	46dBm	
Antenna height/Azimuth/Tilt/Location	Based on ET engineering parameters	
Antenna Pattern	Kathrein 742212	
UE Parameters		
UE number	864	
UE height	1.5m	
Receiver noise figure	9 dB	
Thermal noise density	-174 dBm/Hz	
Shadow Fading and Scheduling Characteristics		
Shadow Fading	Log-normal with standard deviation of 8 dB and decorrelation distance 50 m	
Cell association	Based on RSRP	
Scheduling	Round robin scheduling	

C. Simulation Approaches

Now that the investigation area and base station serving the area have been defined, and user distributions have been established based on the traffic intensity map, we may input key study area parameters into the simulation environment. This research makes use of a Matlab-based LTE system-level simulator. The propagation environment, commonly known as path loss data, is the major input data to the simulator. WinProp is used to calculate the propagation environment (path loss data). Relevant data, such as a digital building map and landscape, must be imported to do so. After that, properly configure macro parameters configured, as well as building and terrain data. We conduct propagation computation after

specifying the settings in WinProp to acquire path loss data in text format. The path loss data obtained from WinProp is not acceptable for use in the LTE simulator. As a result, the path loss data is transformed into a format ".mat" files that the LTE simulator can understand. For optimization, the translated path loss of each cell is fed into the Matlab LTE simulator's CoMP algorithm. For each pixel from each site, the LTE system level simulator gathers path loss, cell location information, and azimuth, transmit power, and antenna height from the converted pass loss data.

5. SIMULATION RESULT AND DISCUSSION

A. SINR Performance Analysis

Figure 6 depicts the SINR graph for both the JT CoMP-03 and JT CoMP-07 systems. The comparison between the JT CoMP-03 and the JT CoMP-07 systems is discussed below. UEs at the cell edge obtain a maximum SINR of 4.16dB, UEs at the cell average achieve 4dB, and UEs at the cell center achieve 4.06dB using JT CoMP-07, as shown below. As a result, JT CoMP-03 has better cell edge and cell average improvements, while JT CoMP-07 outperforms the JT CoMP-03 system because a relatively high amount 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-07 has a 95\% due to efficient resource allocation and getting high signal strength, while in non-CoMP, 45\% of user positions have SINR below 0dB.

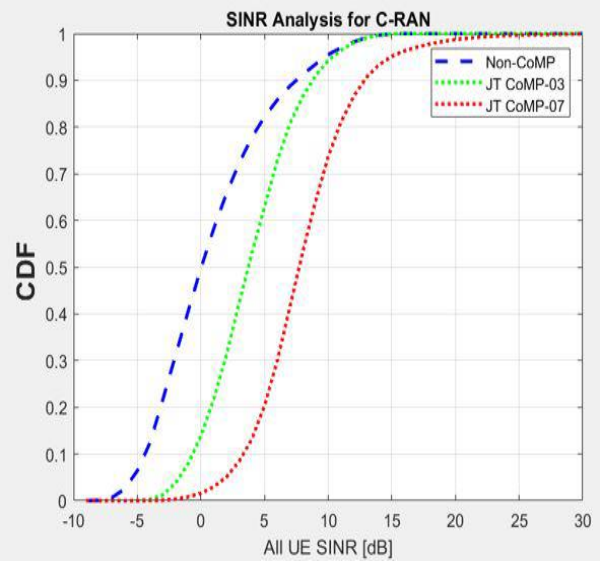

Fig. 6: Comparison SINR of JT CoMP-03 with JT CoMP-07

The above Figure 6 indicates that SINR improvement appears between coordination. These enhancements address the fact that each UE operates the received power from various cell coordinators, reducing interference significantly. The reason for this is that when the amount of interference is minimal, there are more available desired signals for the user. Users, on the other hand, receive comparably greater RBs as the number of cells coordinated increases as part of the JT CoMP-07 system's deployment. Furthermore, the proposed approach meets more user needs than existing methods since converting the interference signal to useful signal power results in higher SINR.

Figure 7 shows the SINR performance. At the 20 \%tile, there is a noticiable improvement and also at the 50\%tile, whereas there is small improvement at the 90\% tile compared to the 20th and 50\% tiles. To check the SINR performance of the selected power threshold values for the overall system, the whole user position SINR is used. Apparently, the SINR improvement obtained by the network with the JT

CoMP-07 scheme for the system average and cell edge improved significantly.

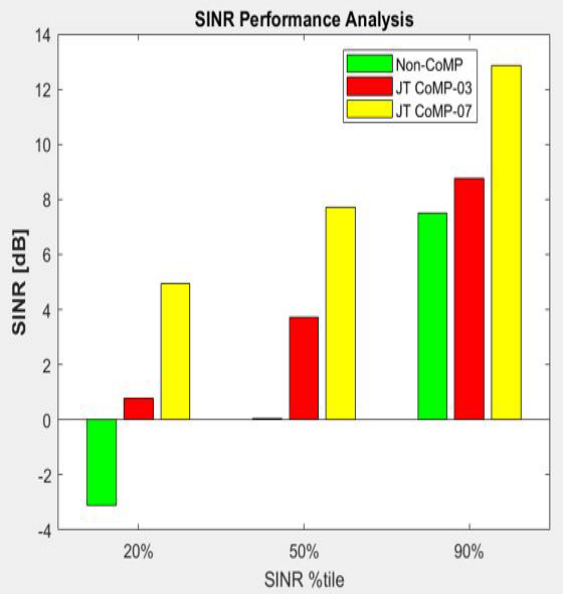

Fig. 7: SINR performance comparison

The performance improvement between JT CoMP-07 systems and those in non-CoMP systems is 7dB for cell edge and 8dB for cell average. The SINR performance for cell average users are slightly higher. Since the average user who already has a good channel condition is slightly higher. 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 JT CoMP-07 methods provide better system performance gains, which increase the entire SINR by 60\%. Therefore Compared to non-CoMP performance, the JT CoMP-03 and JT CoMP-07 SINR improved by 3.94dB–8dB for cell edge users (20\% CDF) and 3.69dB–7.4dB for cell users (50\% CDF). Therefore, the JT CoMP-03 and JT CoMP-07 SINR improved by 3.94dB–8dB for cell edge users (at 20\% CDF) and by 3.69dB–7.4dB for cell users (at 50\% CDF) when compared to non-CoMP performance.

B. Spectral efficiency Performance Analysis

The graph below depicts the spectral efficiency performance gain. According to Figure 8, this is because multiple coordination cells are deployed inside the coverage area, resulting in more cell boundaries, and the overlap of cells with different transmission strengths increases the interference area even more. As a result, more UEs use JT CoMP-03 transmission techniques to reduce interference and boost signal strength. Furthermore, spectral efficiency performance gain is significant when using JT CoMP-07, which reduces interference and boosts signal strength. This is due to the demand for cooperating BSs to provide more information, which transforms the interference signal into a useful signal, resulting in better SINR and spectral efficiency.

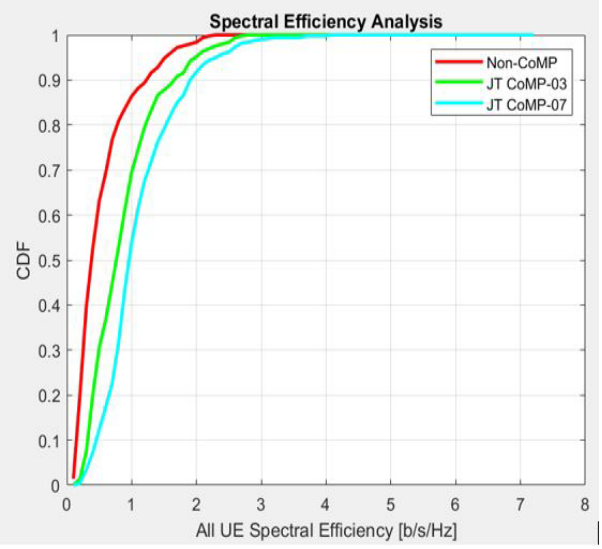

Fig. 8: Comparison of Spectral efficiency of JT CoMP-03 with JT CoMP-07

In Figure 9 displays the percentile of spectral efficiency performance. There has been small

improvement at the 20\% tile. When comparing the 20th and 50\% tiles, it shows higher progress at the 50\% tile, while the best spectral efficiency performance is at the 90\% tile. The figure shows the spectral efficiency performance for the cell edge and average users for the JT CoMP-03 systems set to a baseline of non-CoMP systems.

Actual enhancement for JT CoMP 03 techniques can range from 35 to 106 percent, while enhancement for JT CoMP 07 techniques can range from 41 to 162 percent. Therefore, all CoMP scheme cases provide the highest overall spectral efficiency gains compared with the non-CoMP scenarios.

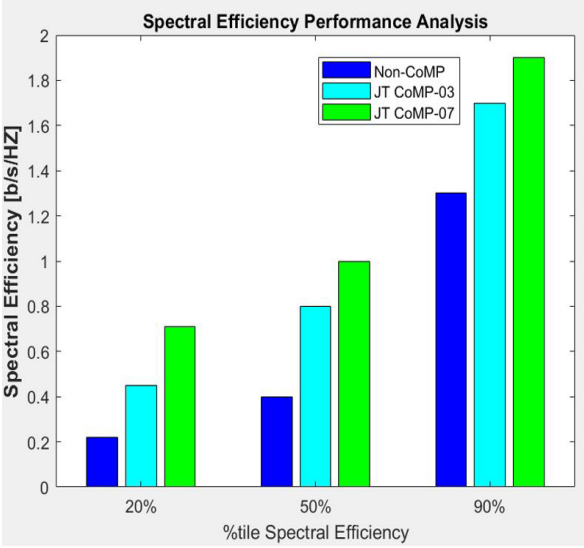

Fig. 9: Spectral efficincy performance

C. Throughput Performance Analysis

The throughput graph for both the JT CoMP-03 and JT CoMP-07 systems is shown in Figure 10 according to the graph below, UEs at the cell edge achieve a maximum of 0.6Mbps, UEs obtain 0.61Mbps on average when using JT CoMP-07. As a result of this, the JT CoMP-07 system outperformed the JT CoMP-03 system. The figure shows that, based on the range of CDF plots, the gain in throughput is rather significant as compared to the basic non-CoMP systems. This is because, with JT CoMP-07, JT CoMP-03 UEs data is available at several locations for the same time frequency resource, by default at all points to improve received signal quality and reduce interference.

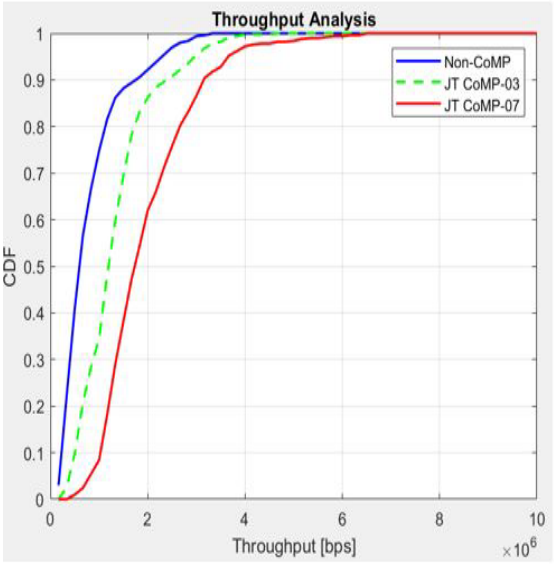

Fig. 10: Comparison of throughput of JT CoMP-03 with JT CoMP-07

In Figure 11 displays the percentile of throughput performance. There has been small improvement at the 20\% tile. When comparing the 20th and 50\% tiles, it shows higher progress at the 50\% tile, while the best throughput performance is at the 50 th and 90\% tile. The figure shows that it is clear that all CoMP systems can achieve a throughput improvement compared to the baseline non-CoMP systems.

The CoMP system throughput gains for cell-edge, cell-average, and cell-center users are depicted in Figure 11. In terms of throughput, all CoMP systems clearly outperform non-CoMP baseline systems. Using the non-CoMP system performance as a baseline, the throughput gain for JT CoMP 03

techniques can range from 30\% to 104\%, and 50\% to 193.5\% for JT CoMP-07 techniques.

The JT CoMP-07 is the most interesting one in terms employing a method to mitigate the strongest interference, since it gives the highest throughput. This confirms that it helps to obtain more significant cell edge throughput performance. The simulation result shows that having to mitigate interference is necessary to maintain good service. In particular, the LTE network for the selected area, CoMP systems can efficiently mitigate the ICI and improve the coverage and throughput. Therefore, it is obvious that the JT CoMP-07 technique is one of the important capacity enhancement methods that are being implemented.

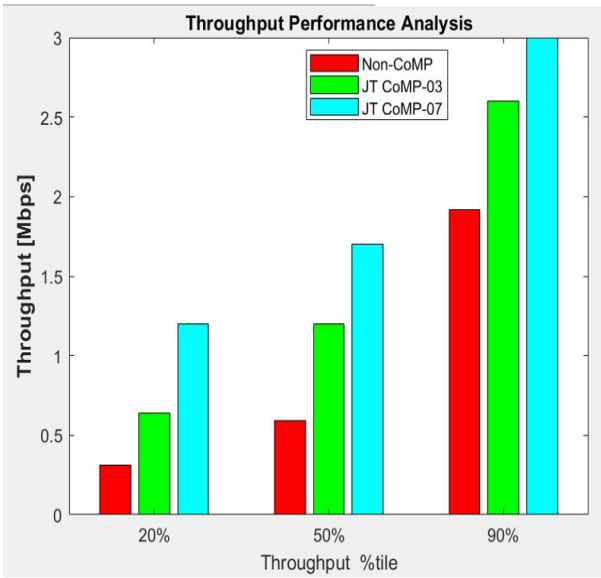

Fig. 11: Throughput performance

CONCLUSIONS

CoMP system simulation results on the chosen area show a significant improvement in SINR, spectral efficiency, and throughput. According to the simulation results, CoMP improves both the cell edge and the average UE of CoMP systems. SINR improves by 1.3dB - 8dB when CoMP techniques are used. When the number of cell coordination areas in the JT CoMP approach was increased, SINR performance improved. It has been proven that C-RAN is the better architecture to reduce inter-cell interference by using the CoMP technique. The paper investigates C-RAN as a solution for reducing interference and boosting network performance using large-scale CoMP coordination areas of various sizes. As a result, the paper also evaluate and compare the benefits of CoMP in different sizes of coordination in terms of UE performance. All CoMP systems can improve non-CoMP baseline systems in terms of throughput. In terms of employing a method to reduce the strongest interference, large-scale CoMP coordination is the most interesting. This confirms that it results in improved cell average and cell edge from 50\% to 193.5\% throughput performance.

CoMP can degrade performance in a C-RAN with limited fronthaul capacity limits. With CoMP, the served user's data must be transferred from the BBU pool to all serving RRHs. As a result, network coverage and spectral efficiency may suffer. Therefore, novel strategies are required to achieve CoMP performance benefits without utilizing a significant amount of fronthaul capacity that could affect other users.

REFERENCE

[1] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2017–2022 https://s3.amazonaws.com/media.mediapost.com/uploads/CiscoForecast.pdf [accessed Oct 31, 2021]

[2] Salman, Tara. "C-RAN: Basics, advances, and challenges." A Surv. C-RAN Basics Virtualization Resour. Alloc. Chall (2016): 1-16.

[3] Chabbouh, Olfa, et al. "A novel cloud RAN architecture for 5G HetNets and QoS

evaluation." 2016 International Symposium on Networks, Computers and Communications (ISNCC). IEEE, 2016.

[4] Cheng, Bobo, et al. "A real-time implementation of CoMP transmission based on cloud-RAN infrastructure." 2014 International Wireless Communications and Mobile Computing Conference (IWCMC). IEEE, 2014.

[5] Labana, Mohamed, and Walaa Hamouda. "Advances in CRAN Performance Optimization." IEEE Network 35.3 (2020): 140-146.

[6] Huiyu, Yuan, et al. "Performance evaluation of coordinated multipoint reception in CRAN under LTE-Advanced uplink." 7th International Conference on Communications and Networking in China. IEEE, 2012.

[7] Liu, Junyu, et al. "CoMP transmission in cloud radio access networks." 2015 IEEE Globecom Workshops (GC Wkshps). IEEE, 2015.

[8] Checko, Aleksandra, et al. "Cloud RAN for mobile networks—A technology overview." IEEE Communications surveys & tutorials 17.1 (2014): 405-426.

[9] Checko, Aleksandra, et al. "OTN transport of baseband radio serial protocols in C-RAN architecture for mobile network applications." (2014).

[10] Singh, Satnam, et al. "Coordinated Multipoint (CoMP) Reception and Transmission for LTE-Advanced/4G 1." (2012).

[11] Chen, Yiye. "Coordinated Multipoint Communications In Heterogeneous Networks." (2013).

[12] Peng, Mugen, et al. "Recent advances in cloud radio access networks:System architectures, key techniques, and open issues." IEEE Communications Surveys & Tutorials 18.3 (2016): 2282-2308.

[13] Chen, K., Duan, R.: C-RAN the road towards green RAN, White Paper, vol. 2. China Mobile Research Institute (2011).

[14] Makhanbet, Meruyert, et al. "An overview of cloud RAN: Architecture, issues and future directions." International Conference on Emerging Trends in Electrical, Electronic and Communications Engineering. Springer, Cham, 2016.

[15] Hailu, Dawit Hadush, et al. "Mobile fronthaul transport options in C-RAN and emerging research directions: A comprehensive study." Optical Switching and Networking 30 (2018): 40-52.

[16] Chih-Lin, I., et al. "Recent progress on C-RAN centralization and cloudification." IEEE Access 2 (2014): 1030-1039.

[17] Zhang, Xinran, et al. "Performance analysis and evaluation of cloud radio access networks." 2018 International Conference on Computing, Networking and Communications (ICNC). IEEE, 2018.

[18] Gavrilovska, Liljana, et al. "Flexible C-RAN: Radio technology for 5G." 2017 13th International Conference on Advanced Technologies, Systems and Services in Telecommunications (TELSIKS). IEEE, 2017.