



ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL AND COMPUTER
ENGINEERING

**Downlink Performance Evaluation of Coordinated Multi-Point:
The Case of Addis Ababa LTE Network**

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A thesis submitted to the School of Electrical and Computer Engineering in Partial Fulfillment of the requirements for the Degree of Masters of Science in Communication Engineering

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Addis Ababa, Ethiopia



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Declaration

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

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ABSTRACT

The current Addis Ababa Long Term Evolution (AA LTE) is deployed to provide better data service for users. But mobile data network performance is negatively affected - especially for cell edge users - by inter-cell interference (ICI) resulting from short inter-site distance and the use of frequency reuse factor 1. One method to overcome the ICI is the use of coordinated multi-point (CoMP). In this thesis the effect of CoMP joint transmission was studied for mitigating the ICI in the AA LTE.

To check the feasibility of the proposed solution, the performance of the current AA LTE is evaluated using simulation and considering CoMP joint transmission. Evaluation of the network performance is done for a selected test case area in Addis Ababa city and considering actual base station locations and the terrain data of the city. The simulation is done for a 20 MHz bandwidth and the round ribbon scheduling algorithm is used for radio resource allocation for both CoMP and non-CoMP system.

The results from the simulation show that by using CoMP the signal to interference noise ratio (SINR), and throughput for the average and cell-edge user show considerably significant improvement. The results show that the SINR increased by 1.5dB for the cell edge user and by 1.9dB for the average user in intra-site CoMP. For the inter-site CoMP system, an increase in SINR of 5.6dB and 4.3dB for the cell edge user and cell average user respectively is observed. In addition, the throughput for the cell edge user and average user improved by 14% and 6% respectively for intra-site CoMP and by 18 % and 10% for inter-site CoMP. These results show that CoMP joint transmission is worthy for deployment in the current AA LTE and can improve the coverage for cell edge users.



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List of Acronyms

3GPP	3rd Generation Partnership Project
4G	Fourth Generation
AAiT	Addis Ababa Institute of Technology
BS	Base Station
BW	Bandwidth
CDF	Cumulative Distribution Function
CoMP	Coordinated Multipoint
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CS/CB	Coordinated Scheduling/Beamforming
CSI	Channel State Information
DPS	Dynamic Point Selection
eNB	eNodeB
EPC	Evolved Packet Core
EPS	Evolved Packet System
ET	EthioTelecom
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
HSS	Home Subscriber Server
ICI	Inter-cell Interface
IEEE	Institute of Electrical and Electronics Engineers
IMS	IP Multimedia Subsystem
IMT	International Mobile Telecommunications



IRT	Intelligent Ray-Tracing
ITU	International Telecommunication Union
JP	Joint Processing
JR	Joint Reception
JT	Joint Transmission
LOS	Line-of-Sight
LTE	Long Term Evolution
MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MU-MIMO	Multi-User Multiple Input Multiple Output
OFDM	Orthogonal Frequency Division Multiplexing
PAPR	peak-to-average power ratio
PCRF	Policy and Charging Rules Function
PDCB	Packet Data Control Protocol
PDNGW	Packet Data Network Gateway
PDSCH	Physical Downlink Shared Channel
PL	Path Loss
PMI	Precoding Matrix Indicator
PRB	Physical Resource Block
QoS	Quality of Services
RAN	Radio Access Network
RB	Resource Blocks



RE	Resource Element
RF	Radio Frequency
RI	Rank Indicator
RLC	Radio Link Control
RNC	Radio Network Controller
RP	Reception point
RRH	Remote Radio Head
RSRP	Reference Signal Received Power
SC-FDMA	Single-carrier frequency division multiple access
SGW	Serving Gateway
SINR	Signal to Interference plus Noise Ration
SRS	Sounding Reference Signal
SRT	Standard Ray-Tracing
SU-MIMO	Single-User Multiple Input Multiple Output
TDD	Time Division Duplex
Tx	Transmission
UDP	Urban Dominant path
UE	User Equipment
UMTS	Universal Mobile Telecommunications System



Chapter 1

1 Introduction

To satisfy the increasing demand for mobile data, Ethio telecom (ET) has deployed Long Term Evolution (LTE) network in Addis Ababa. The Addis Ababa LTE (AA LTE) network consists of 329 eNodeBs. The cells are small in size, with the inter-site distance between neighboring cells less than 1000m. Cells are allocated 20 MHz bandwidth for the uplink and downlink each. The system uses frequency division duplex (FDD) and operates at 1800MHz with frequency reuse factor 1 in all cells. A reuse factor 1 means besides the desired signal from a cell to a user, signals with similar radio resources arrive at the receiver from all the other neighboring cells.

While full spectrum reuse in all cells is to increase the system capacity, it also makes the network interference limited [2]. This means high-bandwidth utilization that requires large SINR is difficult to achieve. One method for increasing user data rate is reducing the cell size so that cells transmitted to users at a lower signal power which also reduces the relative interference level in neighboring cells. But the resulting high user data rates are only available at the cell center and not over the entire cell.

One of the challenges in LTE is how to achieve better throughput at the cell edge where the user is at a position where it receives two or more signals that are roughly at the same power level. In the case of actual deployed networks like the AA LTE network where the distribution of base stations is non-uniform the overlapping area for two cells could be large. This means the possibility of a user receiving interference signals with almost the same power level as the desired signal is high, resulting in a degraded user throughput.



Coordinated Multi-Point (CoMP) is one of the technologies introduced in LTE Advanced that is proposed to mitigate the ICI at the cell edge [2]. By using CoMP transmission and reception, improvements in user data rate, cell-edge throughput, and overall system throughput within a network can be achieved. Moreover, CoMP can be implemented with minimum change in infrastructure, without changing the base station antennas and base station locations, by introducing CoMP algorithms. But it also requires backhaul with high data rate and low latency [2].

CoMP transmission can be implemented as coordinated scheduling or beamforming across transmission points thus avoiding the interference signals; or it can also be implemented by transmitting the same signal to a user from neighboring cells called joint processing, thereby converting the interfering signal to a desired signal.

1.1 Statement of the Problem

LTE has been implemented and is currently operating in AA. But as mentioned before the small cell size and the frequency reuse factor 1 means areas with high SINR are limited to only the cell center. This is because the signals from the serving cell and other neighboring cells for a user in a coverage area have small power difference, resulting in a large interference signal to the user. This leads to poor SINR which also means low user throughputs. The large interference signal is especially prominent for users at the cell edge.

In addition, in real networks the effect of ICI can be managed when the number of users is small, by scheduling different radio resource in each cell. But with increasing number of users in each cell all the available resources are being used and managing the ICI becomes difficult.



In this thesis downlink CoMP joint transmission (JT) is evaluated considering the current AA LTE network. Furthermore, the effect of CoMP on the AA LTE network with the introduction of user scheduling need to be investigated since using multiple base station's radio resources on CoMP users reduces the available resource for the other non-CoMP users affecting the overall users data rates.

1.2 Objective

1.2.1 General Objective

In this thesis, the performance of CoMP joint transmission was studied in the context of the current AA LTE network using simulation. The CoMP system was evaluated using simulation, in an intra-site and inter-site coordination scenario. The system performance was mainly evaluated using SINR and throughput.

1.2.2 Specific Objectives

The specific objectives of the study are:

- a) To evaluate the performance of cell average and cell edge users by comparing CoMP and non-CoMP systems for a test case area in Addis Ababa LTE network.
- b) To evaluate the performance of CoMP joint transmission at 1, 3, 5, and 10dBm power threshold values for selecting CoMP users.
- c) To find the optimal power threshold value for CoMP transmission in the proposed system by comparing the percentage of CoMP users and the resulting CoMP gain for the users
- d) To measure and evaluate the performance of intra-site and inter-site CoMP for the current AA LTE network.



- e) To evaluate the impact of user scheduling on the performance of the CoMP system.

1.3 Related Works

V. Jungnickel et al., Michael A.Jensen et al., Ali H. Muqaibel et al, and others have shown how CoMP can be used to mitigate ICI and improve data rate and spectral efficiency in ideal and real networks.

The evaluation results obtained by various sources for the four CoMP deployment scenarios using joint processing or coordinated beamforming/scheduling are given in [3]. The four deployment scenarios are intra-site CoMP, inter-site CoMP, heterogeneous network (HetNet) CoMP with low power remote radio heads (RRHs) with different cell IDs to the macro cell, and HetNet CoMP with low power RRHs with same cell IDs as the macro cell. For the different CoMP scenarios, simulation results from a total of 8 sources were included in the document. The results from the different sources are given as absolute performance for CoMP user and single cell user. They are also given as CoMP user spectral efficiency relative to a single cell operation. The results from the different sources show on average there is a performance improvement when using CoMP joint transmission. Although the results from the different sources in the paper show a favorable benefit in using CoMP, there were still some results that showed small or no gain in using CoMP. The results were also not clear on how much the performance benefit of CoMP is affected when considering deployed networks.

R. Tian et al evaluated CoMP with Single-User Multiple Input Multiple Output (SU-MIMO) transmission scheme in an urban environment using the three sectors of a base station using field trials [4]. The results show the capacity gain from the cooperative transmission can reach 40% for 25% of the coverage area. The project also showed that



the largest CoMP gain is achieved near the border of adjacent sectors i.e. at the cell edge. The experiment was done for intra-site CoMP considering only an isolated base station with three sectors and did not consider the effect of neighboring cells.

Another work on the analysis of the capacity that can be achieved by the cooperative transmission of a base station's three sectors was given in [5]. The project was done in a Multi-User MIMO (MU-MIMO) system using field trials. The study was made at a carrier frequency of 2.65GHz with 20MHz channel for both the uplink and downlink. The result of the study showed that using three sector cooperation a median capacity gain of 30% and 80% is achieved for the uplink and downlink respectively. It is also shown in the paper that 10% of the measured positions have capacity gain of over 65% and 110% in the uplink and downlink respectively. Similar to the previous paper, this paper was also done for only intra-site CoMP. In addition, to minimize the complexity a two user scenario was used in the system. Therefore, it does not show the performance for a system with multiple users.

Jungnickel et al. in [6] also evaluated downlink CoMP transmission on mobile radio network using field trials. They did the evaluation for both intra-site and inter-site CoMP. The result they obtained from the study shows that a cell throughput improvement ranges between 27% and 78% for the downlink CoMP. Although the study showed that there is a throughput improvement, the experiment was done using only two isolated cells without considering interference from the surrounding non-cooperating base stations.

Practical deployment of CoMP and its gains in SINR and spectral efficiency for inter-site and intra-site coordination is examined in [7]. To evaluate the real CoMP network they used the topography and terrain data of Al-Khobar city in Saudi Arabia. They did the evaluation using the received power and SINR and by comparing ideal and real CoMP



networks in different types of clustering. They showed that the real CoMP can improve the SINR close to ideal CoMP networks. In addition, they investigated the effect of clustering on the SINR and showed that small clusters perform better than large clusters. While this study showed that CoMP performance in realistic network by using clustering they did not include the effect of user scheduling on the CoMP performance.

In general, while the results from the above literature reviews show using CoMP improves the network performance, there is a need to check its feasibility on a network when considering deployment in a realistic network scenario.

1.4 Methodology

The methods employed to achieve the objectives of the research are:

Literature review: which includes reading books, articles, and other resources from the Internet that are related to CoMP and LTE technologies. In addition, study of the current AA LTE network is done.

System modeling: includes selecting and setting-up the test case area used for the simulation, selecting a mathematical model for the CoMP system including the parameters used for displaying results, outline workflow for evaluating the systems, and identifying all input parameters for the simulations.

Simulation: involves simulating the modeled LTE system using WinProp and Matlab. ProMan propagation software of the WinProp software suite, was used for propagation modeling of the test case area to accurately predict received power and path loss for all the cells in the downlink. Then, Matlab is used for modeling the non-CoMP and CoMP systems and for evaluating the systems using the path loss information obtained from the WinProp simulation.



Analysis of results: the results from the simulation are analyzed and the performance of the CoMP system is evaluated and reported. There are different parameters that can measure the system performance and in this thesis the SINR and throughput are used.

1.5 Contribution

As mentioned in prior sections, this thesis work studies the gain in coverage and user data rate that can be achieved by applying CoMP in the AA LTE network. Furthermore, the study includes the use of the actual location of base stations, and the topography and terrain data for AA for the simulation. These can give a more accurate prediction in the study of the performance of the system. Therefore, this research will serve as a good resource in the future when the need arises to upgrade the current AA LTE network.

The other contribution of this thesis work is that it has tried to show the performance of the CoMP joint transmission system with user scheduling which is a big issue when considering actual deployment of CoMP in operational LTE networks.

1.6 Organization

This thesis is organized as follows. In Chapter 2 an overview of CoMP and literature review on CoMP is done. In Chapter 3, an overview of the test case area in AA LTE network is given. The propagation modeling software WinProp is also introduced in this chapter. In addition, the parameters for the WinProp simulation are shown in this chapter. In Chapter 4, the system model for the selected AA LTE network with CoMP is presented. This includes different CoMP schemes and scenarios including CoMP UE selection criterion to be used. In addition, the SINR and throughput equations for the evaluation of the different CoMP and the non-CoMP system are shown in this chapter. In



Chapter 5, the simulation results and discussions on the results are presented. Finally, conclusions and possible future works are presented in Chapter 6.



Chapter 2

2 Coordinated Multi-Point Overview

As mentioned previously ICI is a big issue in a cellular network and especially affects the cell-edge performance. CoMP is one of the techniques used in LTE to mitigate the ICI. It works by controlling the interference so that the SINR of the user is improved.

In this chapter, the basic principle of CoMP, implementation methods and challenges are introduced. But before that, first a brief overview of LTE is given.

2.1 LTE

2.1.1 LTE Architecture

The LTE system architecture that is defined by 3GPP is called the Evolved Packet System (EPS), and consists of the Evolved Packet Core (EPC) and the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) [1]. Figure 1 shows the EPC and E-UTRAN and their components. Other nodes from the classical Universal Mobile Telecommunication System (UMTS) architecture are also displayed in the figure. This includes the UMTS Access Network (UTRAN), the packet switched core network and circuit switched core network. The IP Multimedia Subsystem (IMS) is also shown on top of the packet core network and provides access to the IP networks and the public telephone network. The Home Subscriber Server (HSS), which manages the user subscription information, is shown as a central node and provides services to all Core Network blocks of 3G and 4G networks.

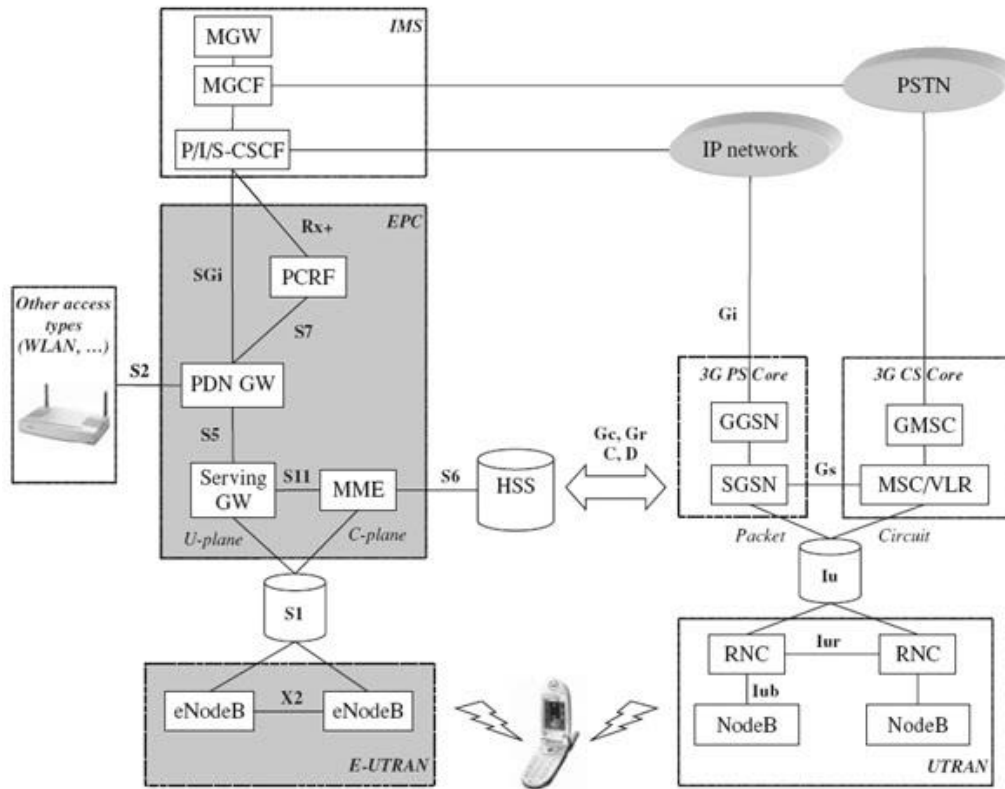


Figure 1 LTE EPS architecture [32].

The EPC from Figure 1 has four functional elements. These are

1. The Serving Gateway (SGW): which is used for routing and forwarding user data. It also manages user mobility for inter-eNodeB handovers and for mobility between LTE and other 3GPP technologies. In addition, the SGW manages and stores UE information.
2. Mobility Management Entity (MME): is the control-node for accessing the LTE network and is used for tracking and paging the UE in idle mode. MME also selects the SGW for a UE during initial connection and during handover involving changing core network node. The MME interacts with the HSS -a master user database supporting IMS for storing subscriber information - when authenticating the user.

3. Packet Data Network Gateway (PDN GW):- is used for the connecting the UE to external packet data networks. In addition, the PDN GW also enables user mobility between 3GPP and non-3GPP technologies like WiMAX, CDMA 1X and EvDO
4. Policy and Charging Rules Function (PCRF) manages the service policy and sends quality of service (QoS) setting information and accounting rule information for each user session.

The E-UTRAN from Figure 1 consists of a single Radio Access Network node named the eNodeB (eNB). The eNBs provide the E-UTRA user-plane and control-plane protocol for the user equipment (UE) [1]. The eNB includes the radio network controller (RNC) functionality to reduce the system complexity and to reduce network latency. The eNB hosts the physical layer (PHY), Medium Access Control layer (MAC), Radio Link Control layer (RLC), and Packet Data Control Protocol (PDCB) layers [25].

The eNBs are interconnected by means of the X2 interface and they are also connected to the MME by the S1-MME interface and to the SGW by the S1-U interface [25]. The functions of the eNB are radio resource management, admission control, scheduling, and compression/decompression of user plane packet headers [1].

2.1.2 LTE Physical Layer

LTE Physical Layer uses asymmetric multiple access schemes for transmission [1]. The multiple access schemes in the downlink is orthogonal frequency division multiple access (OFDMA) with a cyclic prefix (CP). OFDMA is particularly suited for frequency-selective channels and high data rate [25]. The uplink multiple access scheme in LTE is single-carrier frequency division multiple access (SC-FDMA) with CP. The advantage of SC-FDMA in the uplink is its relatively lower peak-to-average power ratio (PAPR) value compared to OFDMA [25].



LTE supports MIMO with up to four transmit or receive antennas. Different downlink MIMO modes are supported in LTE, which can be adapted based on channel condition, traffic requirements, and UE capability. The MIMO transmission modes includes transmit diversity, open-loop spatial multiplexing (no UE feedback), closed-loop spatial multiplexing (with UE feedback), and multi-user MIMO (more than one UE is assigned to the same resource block).

In order for MIMO schemes to work properly, each UE has to report information about the channel to the eNB. The reporting includes: channel quality indicator (CQI) which indicates the downlink radio channel quality for the UE, precoding matrix indicator (PMI) which indicates the optimum precoding matrix to be used for a given radio condition, and rank indication (RI) which indicates the number of transmission layers to be used for spatial multiplexing. For the measurement of the CQI, PMI and RI at the UE, reference signals are used. LTE defines different types of reference signals for channel estimation.

There are multiple steps in LTE physical channel processing. Figure 2 shows the steps for the downlink.

- scrambling of coded bits in each of the codewords to be transmitted on a physical channel
- Modulation of scrambled bits to generate complex-valued modulation symbols. The baseband modulation schemes supported in the downlink and uplink of LTE are QPSK, 16QAM, and 64QAM.
- mapping of the complex-valued modulation symbols onto one or several transmission layers

- precoding of the complex-valued modulation symbols on each layer for transmission on the antenna ports
- mapping of complex-valued modulation symbols for each antenna port to resource elements
- generation of complex-valued time-domain OFDM signal for each antenna port

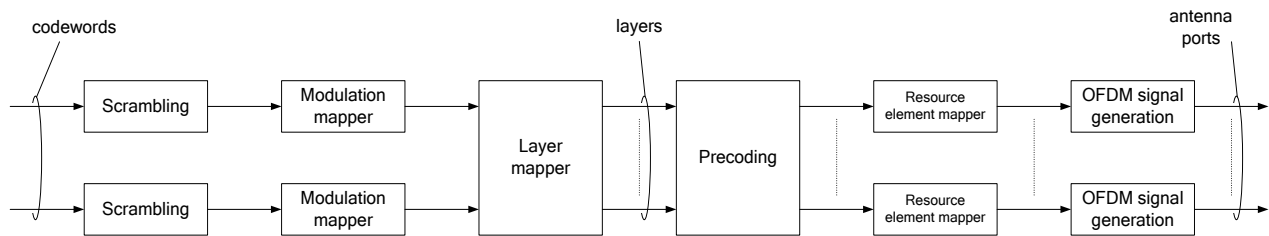


Figure 2 Overview of physical channel processing [31].

2.1.3 LTE Advanced

To meet the ITU's requirements for IMT-Advanced, 3GPP started to study how to enhance the capabilities of LTE [1]. The main output from the study was a specification for a system known as LTE-Advanced (LTE-A), in which the main requirements were to deliver a peak data rate of 1000 Mbps in the downlink, and 500 Mbps in the uplink. In addition, LTE-A is designed to be backwards compatible with LTE. The following are some of the unique features that are included as part of LTE-Advanced.

1. RF carrier aggregation: which is used to enable downlink transmission bandwidths that are larger than 20 MHz. To accomplish this, two or more component RF carriers of bandwidth up to 20 MHz are aggregated.
2. Spatial multiplexing with 8x8 MIMO using 8 layers in the downlink. For the uplink spatial multiplexing up to 4 layers is used.

3. CoMP transmission and reception: which is used as a tool to improve the coverage of high data rates, improve the cell-edge throughput and to increase the system throughput.
4. Relaying: which is proposed to improve the coverage and throughput, group mobility, temporary network deployment and to provide coverage in new areas. The relay node is connected to the radio access network.

2.2 CoMP

CoMP is a 3GPP Release 11 feature that can improve the signal for a UE in high interference area. It manages the ICI to improve the performances of UEs, especially those experiencing poor QoS. The basic idea of CoMP is that multiple base stations simultaneously serve a UE cooperatively either sending/receiving the same data or scheduling UEs in each base station (BS) to avoid the ICI. This will result in an increase of the received desired power and the reduction of the interference power. The coordination in CoMP can be intra-site or inter-site [8]. Figure 3 shows the basic principle of the two types of CoMP systems. In intra-site CoMP the coordinating cells are sectors of the same eNodeB but in inter-site CoMP the coordinating cells are located in different eNodeBs.

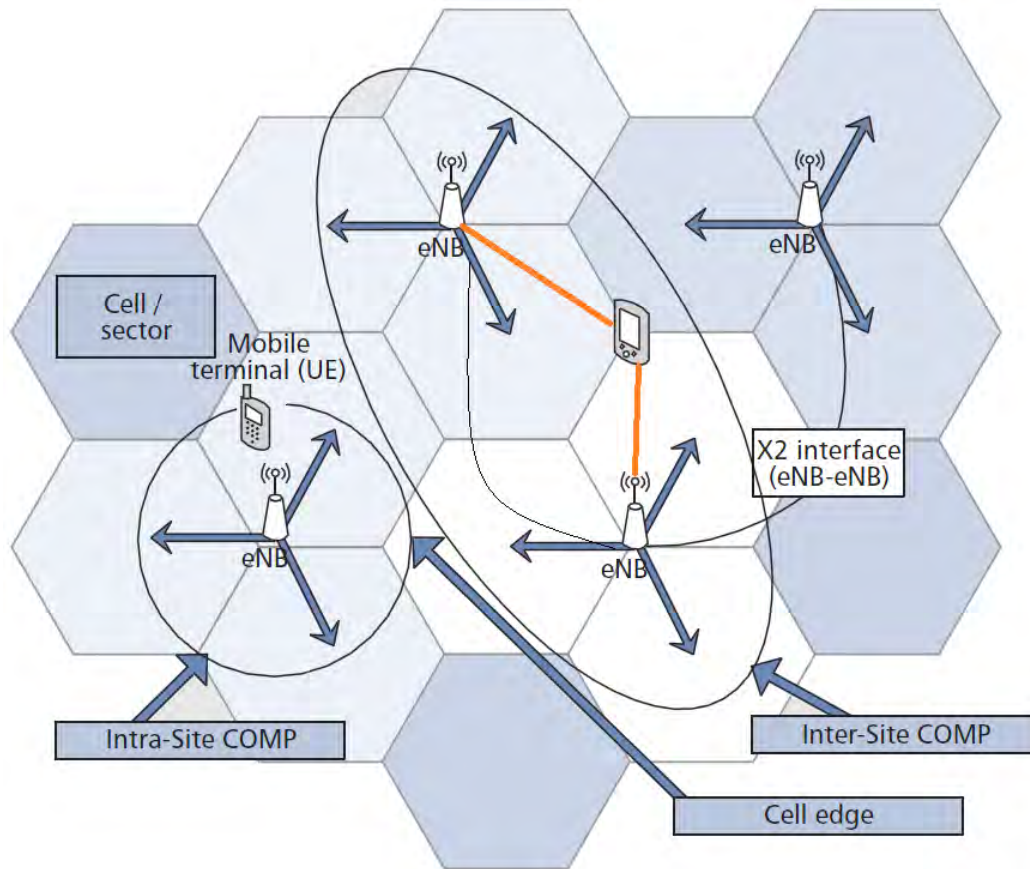


Figure 3 CoMP in LTE [8].

The implementation of CoMP has a large impact on the architecture of the LTE radio interface. Two approaches are available for the implementation of CoMP—centralized and decentralized [14]. In the centralized approach, the UE sends the channel state information (CSI) for all the cooperating cells to a central control unit, where scheduling decisions are made [14]. The central control unit can be located at one of the cells.

In a decentralized approach, the UE sends all the CSIs to all the cooperating cells [14]. Therefore, each cell will have all the available CSI for all the cells. Then, using this information, each cell can make its own scheduling decision. The main obstacle with this

approach is that error on the received feedback information will have a big impact on the performance [14].

Four CoMP deployment scenarios are defined by 3GPP [3]. These are:

- Scenario 1: Homogeneous network with intra-site CoMP
- Scenario 2: Homogeneous network with high transmission (Tx) power RRHs
- Scenario 3: Heterogeneous network with low Tx power RRHs within the macrocell coverage where transmission/reception points created by the RRHs have different cell IDs as the macro cell
- Scenario 4: Heterogeneous network with low Tx power RRHs within the macrocell coverage where the transmission/reception points created by the RRHs have the same cell IDs as the macro cell

CoMP can be implemented in the downlink (downlink CoMP) or uplink (uplink CoMP).

2.3 Downlink CoMP

Downlink CoMP in mobile communication systems involves coordination of multiple base stations in the transmission to one UE. This will result in an increase in the received signal power and/or decrease in the interference power at the UE [14].

3GPP has defined CoMP cell sets for downlink CoMP: cooperating set, transmission points, measurement set and a Radio Resource Measurement (RRM) set [3]. In a CoMP cooperating set, a set of points directly or indirectly participate in physical downlink shared channel (PDSCH) transmission to the UE. CoMP transmission points are a set of points actively transmitting PDSCH to the UE. They are a subset of the CoMP cooperating set. A CoMP measurement set is a set of cells about which channel state/statistical information (CSI) related to their link to the UE is reported. The CoMP measurement set

may be the same as the CoMP cooperating set. Channel state information reference signal (CSI-RS) configurations and zero-power CSI-RS configurations are defined for CoMP measurement set [3]. A RRM set is a set in support of RRM measurements that may be defined in Rel-8 and is, therefore, not CoMP-specific [3].

Two downlink CoMP scheme are defined by 3GPP for LTE. These are coordinated beam-forming/ scheduling (CS/CB) and joint processing (JP). JP is further divided into joint transmission and dynamic cell selection.

UE in JP and CS/CB schemes, report the CSI to the transmission points using one of the three feedback mechanisms defined by 3GPP[3]. These are:

- Implicit channel state information feedback where the feedback contains the precoder index that points to the precoder in the corresponding codebook at BSs
- Explicit channel state information feedback where the CSI directly includes the codebook that is more reliable and closely approximates the channel information
- Or for the case of time division duplex (TDD) LTE, UE transmission of sounding reference signal (SRS) is used for CSI estimation at the eNodeB using channel reciprocity.

2.1.1 Joint Processing

In joint processing (JP) CoMP both data and control information for a UE is available at more than one point in the CoMP cooperating set for a given time-frequency resource. Figure 4 shows CoMP joint processing. In JP, multiple BSs have the same data to be transmitted to a UE and send the data simultaneously to minimize the ICI. CoMP JP is divided into two schemes based on the selection of the transmission points. These are: joint transmission (JT) and dynamic point selection (DPS). JT CoMP sends data to a UE

from multiple transmission points simultaneously. On the other hand DPS CoMP dynamically selects one transmission point with the best channel condition to send data at each sub-frame.



Figure 4 Downlink Joint Processing [13].

Joint Transmission (JT): In JT the same Physical Resource Block (PRB) with a particular time and frequency resource of the PDSCH is transmitted from the cooperating cells. Transmission from the different transmitters can be coherent or non-coherent.

In **coherent** joint transmission full channel knowledge of all the transmission points is assumed at the transmitter and selects transmission weights accordingly [14]. To obtain coherent combination of the transmitted signals in coherent JT, data sent from each cell is multiplied by a phase factor. Coherent JT can be seen as a beam-forming with the participating antennas corresponding to different transmission points. Here phase factor θ with two transmission points is given as

$$\theta = \max_{\theta} \sum_k \|H_k^1 W_k^1 + H_k^2 W_k^2\|^2 \quad (2.1)$$

Where H is the channel matrix and W is the precoding matrix.

Using field trials [12] has shown that by applying coherent JT an average capacity gain of 53% can be achieved in the downlink.

Non-coherent joint transmission does not need the full channel knowledge for joint transmission. In non-coherent JT, each transmission point precodes the same user data independently for transmission. Thus, the only gain of non-coherent joint transmission is a power gain from the transmission of the multiple points [14].

The use of non-coherent JT dependent on the power of the multiple transmission points and whether it is better to use them or transmission to other UE. In addition, the benefit also depends on the resulting harmful interference to other transmissions that results from the joint transmission. Therefore, non-coherent JT is beneficial at low network load where the other transmission points are not occupied with transmission to other UEs [14].

Dynamic point selection (DPS)/muting: in this transmission mode, the user data is transmitted from one point in a time-frequency resource. The transmitting/muting point may change from one sub-frame to another including varying over the PRB pairs within a sub-frame. This is possible because the data is available simultaneously at multiple points.

In DPS the cell with the minimum path loss to the UE is dynamically selected through fast scheduling at the ENodeB and the remaining cooperating cells are muted, which results in a maximum received power and a minimum inter-cell interference for the UE [14].



2.1.2 Coordinated Scheduling/Beamforming

Coordinated Scheduling/Beamforming (CS/CB) involves coordinating transmission decisions between the transmission points by sharing control information to reduce the interference levels. Unlike JP, in CS/CB, data for a UE is only available at and transmitted from one point in the CoMP cooperating set. But based on the channel condition, decisions for selecting the transmission point are made with coordination with the multiple transmitters in the CoMP cooperating set.

CS/CB dynamically prevents transmission at a certain time-frequency resource in a cell to reduce the interference that will be experienced in other cells. This can be seen as a Dynamic Point Blanking [14]. It can be implemented using Coordinated Power Control - dynamically adjusting the transmit power – or using Coordinated Beam-Forming - dynamically adjusting the transmission direction.

The decision to enable CS/CB is made by estimating the impact of a transmission to a UE. The expected impact can be in terms of predicted channel quality from transmissions of neighboring cells. It also includes identifying how much the channel quality would improve if transmissions from the neighboring transmission point would not take place. The CSI reporting mechanisms defined for LTE can be used for reporting the channel quality. And by using the CSI reports, the network can estimate if a gain can be achieved by applying CS/CB.

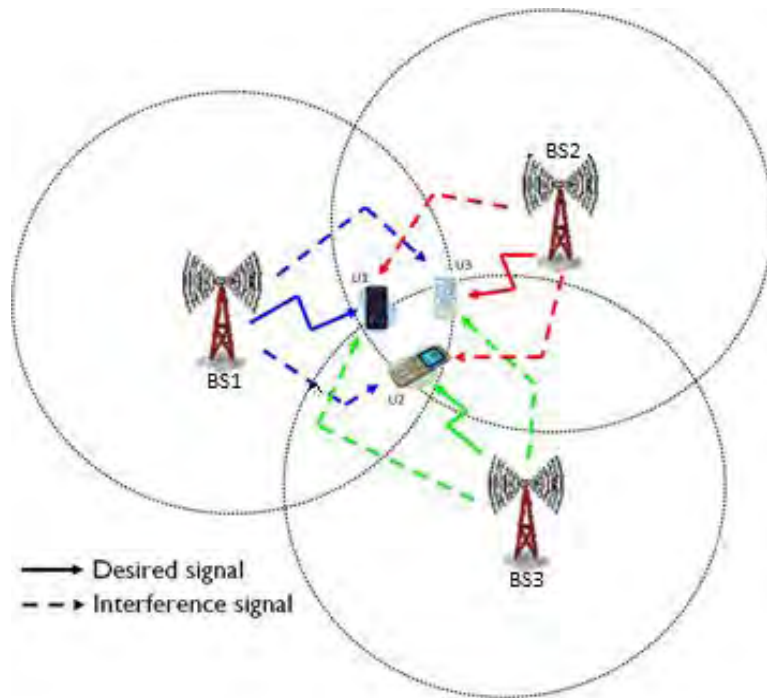


Figure 5 CS/CB in downlink [13].

Figure 5 shows the principle of CS/CB. The different colors on the arrows are to show scheduling of beams with different resource blocks. CS/CB maximizes the SINR for a UE by avoiding the interference that can come from the adjacent cell.

In addition to the two downlink CoMP transmission schemes a hybrid scheme with JT and CS/CB is possible [3]. In this scheme while scheduling/beamforming decisions are made by coordinating between the cooperating set, the data for the UE is available in only some of the transmitters in the cooperating set. Therefore, data for the UE is sent from some of the transmitters using JP while the rest of the transmitters in the cooperating set may perform CS/CB.

2.4 Uplink CoMP

In uplink CoMP the different reception points coordinate in order to receive the signal from a UE. Uplink CoMP, similar to downlink CoMP, is categorized into joint reception (JR) of the transmitted signal at multiple points and/or coordinated scheduling (CS) among the reception points to minimize the interference and improve the coverage [3]. However, unlike downlink CoMP, uplink CoMP has very little impact on the radio-interface specifications [14].

Different CoMP sets are defined for the uplink [3]. These are CoMP cooperating set and CoMP reception points. CoMP cooperating set includes a set of points that may receive data from a UE. CoMP reception points are subset of the cooperating set and they receive data from the UE. The reception points in JR includes multiple points from the cooperating set while only one reception point is assigned in CS.

2.3.1 Joint Reception

In joint reception the multiple reception points receive the signal transmitted by a UE. Then the signals from the different reception points (RP) are jointly processed to produce the final output.

Joint reception schemes can be centralized or decentralized [14]. In centralized joint reception, after signals received at the multiple points, a central control unit is used for processing the received signals from the different points.

In decentralized joint reception, instead of a central control unit, each eNodeB simultaneously processes its signal by exchanging information with the other points in the CoMP cooperating set. The information exchanged between the reception points are only information related to the channel state information and user related information.

This is done to reduce the signaling overhead. Since there is no central control unit in the decentralized scheme, only a little change to the LTE architecture is needed [14].

2.3.2 Coordinated Scheduling

In uplink CS, UE scheduling and precoder selection decisions are made with coordination among the multiple reception points in the CoMP cooperating set. Only one reception point is used to receive the signal from a UE. In CS only CSI and user scheduling are exchanged among the cooperating set, and therefore, the load of the network is low.

The aim of the uplink CS, similar to downlink CS/CB, is to identify and avoid the interference that might result from a possible UE scheduling. But avoiding the inter-cell interference does not improve the system throughput too much but it improves the service for the cell edge user significantly [14].

Figure 6 shows the basic principle of uplink CoMP for both joint reception and coordinated scheduling.

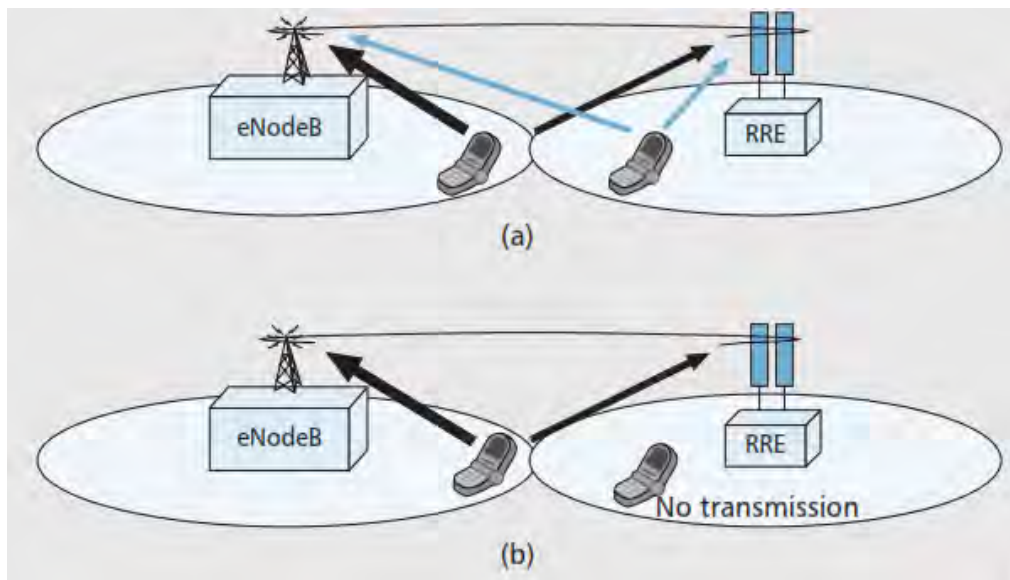


Figure 6 Uplink CoMP: a) Joint Reception b) Coordinated reception [2].

2.5 Challenge of CoMP

While many simulation and field trials have shown the potential and benefits of coordinated multipoint, there are still many challenges for implementing CoMP [14]. The common challenges in implementing CoMP are:

- 1) Backhauling- the amount of data to be transmitted over the backhaul depends on the chosen CoMP strategy. That is, whether the cooperation is only on control information sharing, coordinated scheduling/beamforming, or the cooperation is on both control and user data sharing, joint processing. Therefore, there is a need for a high capacity and low latency backhaul for implementing CoMP.
- 2) Pilot design (reference signals) - to obtain accurate CSI in the DL requirements on the pilot design is very high. The pilot design should enable channel estimation with sufficient accuracy and from different cells separately. In addition, the UE in some approaches needs to be able to decode a control channel of the neighboring cells. In order to attain the full CSI between all UEs and BS antennas in the cellular network, the UE channels should be jointly estimated at each antenna head.
- 3) Feedback design- TDD systems can exploit channel reciprocity to attain most of the required CSI at the transmitters. In FDD systems, the design of suitable feedback channels is an important issue. The information to be exchanged over the feedback link can include short-term or long-term CSI, preferred precoding matrix indices, received power from all the nodes etc.
- 4) Synchronization- in addition to complete CSI, coherent CoMP joint transmission requires synchronization of the frequency and phase between the transmission points. Non-coherent systems are less demanding. Time synchronization is required for all CoMP techniques, with more accuracy required for JP than for CS/CB.



2.6 CoMP Clustering

Ideally, the best set of base stations are selected for transmission when applying CoMP to a system. But in practical implementation of CoMP, only a limited number of BSs can coordinate in transmission to a UE. This is because serving all UE with the best set of cells is unfeasible due to the backhaul problem, and the amount of feedback required [14]. To overcome the signaling overhead resulting from a large cooperating set, clustering is introduced in CoMP. The clustering in CoMP means a limited number of cell will be assigned to a UE as the cooperating set and will result in a lower signaling overhead. Therefore, the network is divided into multiple clusters and a UE can only communicate with the cells in a cluster.

The clusters for CoMP transmission can be formed either statically or dynamically. In the static clustering, the cooperating cells for a UE are fixed. In dynamic clustering, the cooperating cells for a UE are updated periodically.

In static clustering scenario for CoMP, clusters of serving base station are created once and those clusters do not change. The clustering rule can vary i.e. from considering co-located stations, using inter-station path-loss, or can be done manually by a network planning team. Static clustering has a constant set of cooperating base stations. Therefore, very little overhead is required and it is easier for implementation. But if the UE is in a high mobility or the fading of channel fluctuates heavily, the performance of CoMP is significantly degraded. Therefore, having static clusters is not optimal and a better performance can be obtained using dynamic user-centric clustering.

Under dynamic clustering, cooperating BSs are dynamically picked by UE based on channel condition and UE location over time and radio resources. This means that we would have different overlapping clusters on each time-frequency pair for each UE.



Frequently updating the serving BSs makes scheduling and transmission or reception more complicated in dynamic clustering. However, despite the complexity, dynamic clustering achieves more gain than using static clustering [14].

Chapter 3

3 Overview of AA LTE Network

For this thesis, the actual distribution of base station in AA LTE network and the topography of the city are used for the study of the CoMP joint transmission system. The AA LTE network is designed and deployed to provide users with very high data rates- 2Mbps at peak hour- and improved capacity. And each user in the network is allocated to a base station based on the received signal strength. All the signals coming from the base stations other than the serving base station act as interference and significantly affect the user performance. In this study CoMP JT is proposed to overcome the inter-cell interference, and using simulation the performance of the AA LTE network is studied with the introduction of CoMP. For the study part of the AA LTE network is selected as a test case area. In this chapter an overview of the selected test case area for AA LTE is given.

3.1 Test Case Area

The area selected is part of the AA LTE network and it includes 25 eNodeBs with 3 directive sectors each. The eNodeBs are located around Bole area. The three sectors for each eNodeBs is considered as a cell. The antenna for each cell is mounted on a cell tower or a few meters above the rooftop of a building.

Figure 7 shows the satellite view of the selected area (area within the red rectangle) - using Google Earth®. Although each cell (sector of an eNodeB) is identified with its unique ID in the AA network, the 25 sites each with three sectors are numbered from 1 to 25 and are shown as such on the figure. In addition, on the figure it can be seen that

the distribution of the BSs is non-uniform with different distances between the Base stations.

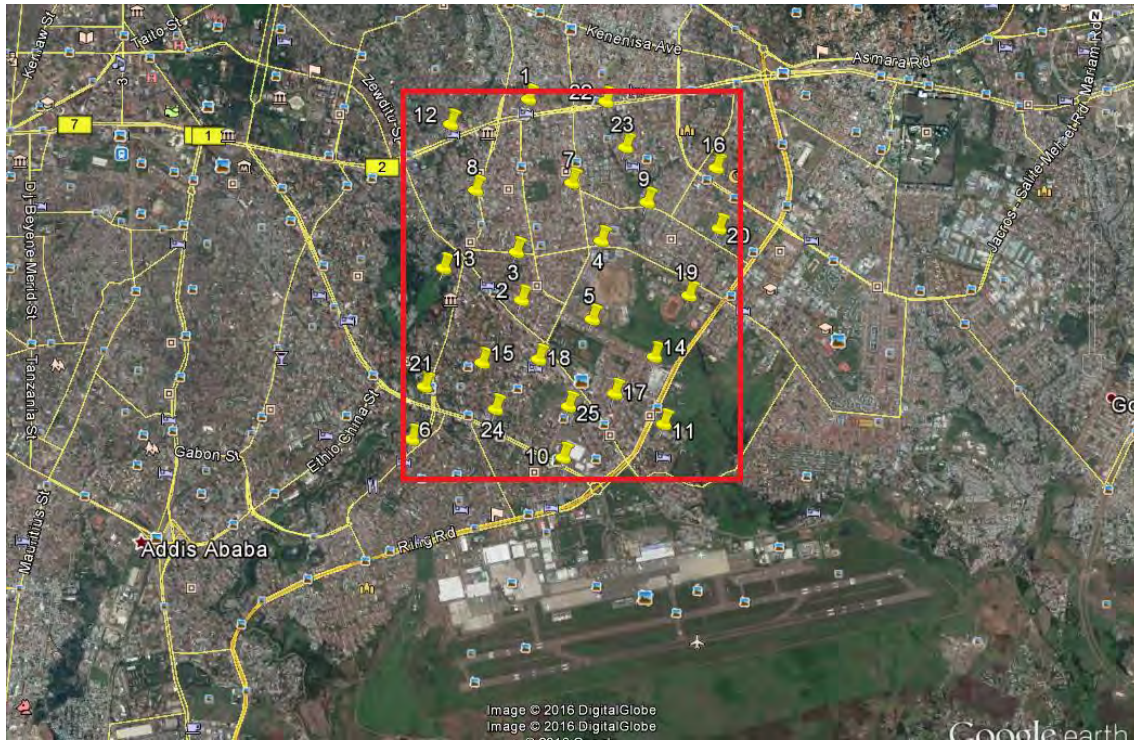


Figure 7 View for Selected Area for the study in AA (Google Earth).

3.2 Air Interface Parameters

The AA LTE network is of 20MHz bandwidth with Frequency Division Duplex (FDD) air interface using 2x2 MIMO OFDMA. The Uplink frequency is from 1727.5MHz to 1747.5MHz and the Downlink is from 1822.5MHz to 1842.5MHz. In the network each cell has a maximum transmitted power of 46 dBm. Selecting serving cell for a UE in the network is based on the highest received power and resulting with the required minimum SINR.

An accurate propagation model is required to predict coverage and interference of a cellular network that can show the performance of the real network. In this paper the Urban Dominant Path (UDP) model in WinProp is used for modeling the propagation. UDP model is selected because it combines the accuracy of the ray optical propagation models and the speed of empirical models [15]. For the AA LTE, the air interface parameters used for propagation modeling in the network are shown in the following table. These parameters are fed to the propagation modeling software. These values are the same as the values that were used when the network was initially designed.

Table 1 Propagation modeling parameters

Morphology	Urban
Data Channel Type	PDSCH
Duplex Mode	FDD
System Bandwidth (MHz)	20
MIMO Scheme	2×2
Max Total Tx Power (dBm)	46
RB to Distribute Power	100
Subcarriers to Distribute Power	1200
Subcarrier Power (dBm)	15.21
Tx Antenna Gain (dBi)	18
Rx Noise Figure (dB)	7
Receiver Sensitivity (dBm)	-128.66
Frequency (MHz)	1800

3.3 Prediction Tool

The software tool used to predict received power and pathloss (PL) for the selected area in this thesis is WinProp software suite. This software is designed for modeling radio propagation in different environments (rural, urban, and indoor) [30]. ProMan is the software package that is used from WinProp for this purpose.

ProMan is a propagation modeling and network planning tool which generates signal predictions for a desired area. ProMan includes ray tracing and empirical propagation models for the prediction. The propagation models includes Standard Ray-Tracing (STR), 3D Intelligent Ray-Tracing (IRT), Urban Dominant path (UDP) model, COST 231 Walfisch-Ikegami and Knife-edge diffraction models [30]. The deterministic Knife-edge diffraction model is use for determining the diffracting knife edges at buildings and resulting diffraction losses between the transmitter and the receiver using clutter height environment information. The Empirical COST 231 Walfisch-Ikegami diffraction model determines the path loss (in dB) using an equation given as:

$$PL = 46.3 + 33.9 \text{LOG}_{10}^{(F)} - 13.82 \text{LOG}_{10}^{(h_t)} - \alpha(h_r) + (44.9 - 6.55 \text{LOG}_{10}^{(h_t)}) \text{LOG}_{10}^{(d)} + C_m \quad (3.1)$$

Where, F is frequency in MHz,

d is distance between transmitter and receiver in kilometer (km),

h_t and h_r are transmitter and receiver antenna height in meter (m),

$\alpha(h_r)$ is set according to environment and is given as:

$$\alpha(h_r) = 3.2(\text{LOG}_{10}^{(11.75h_r)})^2 - 4.97, \text{ in urban environment for } f > 400 \text{ MHz,}$$

$$\alpha(h_r) = (1.1 \text{LOG}_{10}^{(f-0.7)})h_r - (2.56 \text{LOG}_{10}^{(f-0.8)}), \text{ in suburban,}$$

C_m is depends on type of environment and is 3dB in urban area.

For propagation modeling purpose, the selected area shown in Figure 5 was modeled using the 3D vector building database of AA. The vector building model uses polygons of any shape to model the buildings in 3D. The transmitter antennas were placed in the exact position and height with real azimuth and mechanical tilt values. The electrical beam pattern of the transmitter antennas were also included in simulation. Figure 8 shows the resulting area.

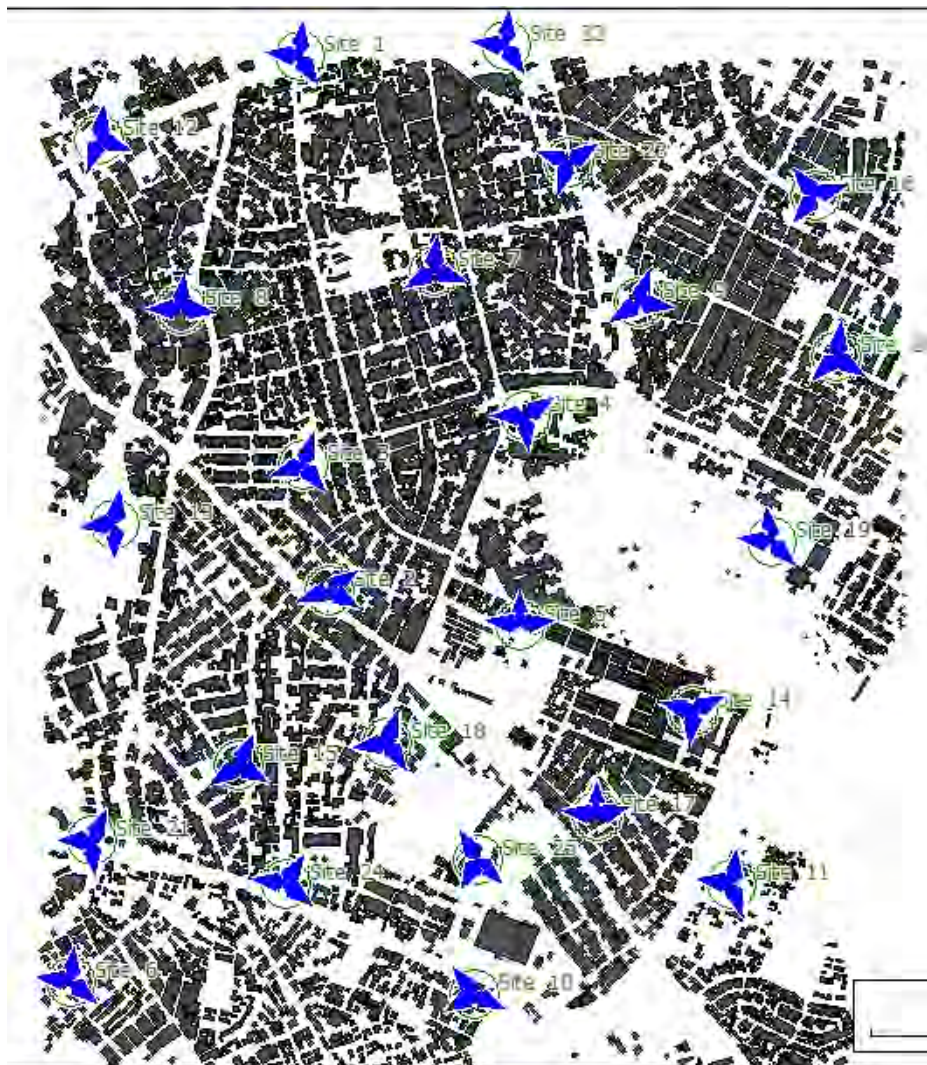


Figure 8 Prediction area using ProMan from WinProp software suite.



3.4 Propagation Model

In this thesis the propagation model used is the Urban Dominant path (UDP) model. WinProp has Ray-optical propagation models and empirical propagations models for received power and pathloss prediction. Ray-optical propagation models while giving accurate predictions are very time-consuming. In addition, Ray-optical models rely on a very accurate buildings vector database and small errors in the database influence the accuracy of the prediction [15].

The empirical propagation model COST 231(Walfisch-Ikegami) on the other hand, uses parameters outside the vector database and require short computational time. But the accuracy is lower than the Ray-Optical models [15].

Urban Dominant Path Model (UDP) is proposed to combine the accuracy of the ray optical models and the speed of the empirical models [15]. In addition the prediction is less dependent on the vector database compared to the Ray Optical model. UDP works by determining the dominant path between the transmitter and a receiver.

In this thesis, using the parameters from the above table and the selected area's WinProp model, the pathloss and received power for the test case area was calculated using the UDP propagation model. Then the obtained result was used for further analysis of the network.



Chapter 4

4 System Model

CoMP is part of the LTE Advanced release 11 standard proposed to improve the performance of areas with high interference signals using multiple transmission points. In chapter 2 the different CoMP implementation schemes for the uplink and downlink were discussed. In this chapter, the model for the downlink CoMP joint transmission system is presented. The model is then used to observe the effect of CoMP in the AA LTE network.

The model includes the deployment scenario and the interference situation for the cells. In addition, the system parameters and models used in the simulation are described. Observations and analysis of the results for the system model are made in the next chapter.

4.1 Signal Model

For the selected test case area in the AA LTE there are $L=75$ cells and in the model let us assume K is the set of all potential user locations. Each cell in the system represents a sector in a 3 sector eNodeB. For the AA LTE bandwidth allocated for a cell in the uplink and downlink is 20 MHz and the total transmitted power per cell (P_T^{Max}) for the 20MHz bandwidth is 46dBm. The minimum amount of resource allocated to a user in LTE is called a physical resource block (PRB) and it consists of 12 subcarriers with total bandwidth of 180 kHz. In each cell, for a 20MHz bandwidth, in one time slot (0.5ms), there are 100 PRBs. Then the assigned bandwidth for a UE in a cell with equal bandwidth allocation is given as

$$BW_{UE} = \frac{100 * BW_{RB}}{N_{UE}} \quad (4.1)$$

Where, N_{UE} is the number of UE in a cell, BW_{UE} is the BW assigned to a UE, and BW_{RB} is bandwidth of a PRB which is equal to 180 kHz.

Then the transmitted power in watt for a UE can be found from its allocated resource as

$$P_{ue} = P_T^{Max} \frac{PRB_{UE}}{100} \quad (4.2)$$

Where, $PRB_{UE} = \frac{100}{N_{UE}}$ is the number of resource blocks assigned to a UE.

The Addis Ababa LTE network is deployed to support 400000 subscribers with each cell having approximately 400 users each. Therefore for the study the number of users in each cells (N_{UE}) is taken as 400. Since N_{UE} is larger than the available PRBs in a time slot, user scheduling is used to assign PRBs to the users. For scheduling the round ribbon scheduling algorithm is used where PRBs are assigned to each user equally and in circular order without giving priority for any user.

The received signal for user k from a single cell l using the pathloss and transmitted power is given as

$$P_{r(k,l)}(watt) = P_{ue} * PL_{k,l} \quad (4.3)$$

PL_k in (4.3) is the pathloss from the transmitter to the receiver and P_{ue} is the transmitted power in watt. The pathloss (PL_k) for the system as mentioned in the previous chapter is calculated using the dominant path model (DPM). The DPM determines the dominant path between the transmitter and the UE and is given as [15]

$$PL_{k,l} = 20 * \log\left(\frac{4\pi}{\lambda}\right) + 10 * p * \log(l) + \sum_{i=0}^n f(\varphi, i) + \Omega + g_t \quad (4.4)$$

Where:

l is the Distance between the transmitter and the receiver,

p is the Path loss exponent and is equal to 2.4 in dense urban areas,

λ is the Wave length,

$f(\varphi, i)$ is diffraction loss, (changing the direction of propagation),

i is number of changes in direction

φ is angle between former direction and new direction

Ω is the empirical determined wave guiding for reflections and scattering,

g_t is transmitter antenna gain.

As explained in the previous chapter, WinProp is used for the measurement of the PL for all the 75 cells over the entire coverage area. Then this PL information is used for obtaining the received signal for a UE.

The total received signal at the UE is the sum of its signal and the signals to other UEs in the network that are using similar radio resource and act as interference to the UE. The serving cell for a UE is selected based on the received signal power. I.e. the signal with the highest power is chosen as the serving cell. The equation for the total received signal for UE k is given as

$$P_{r(k)} = P_{ue} * PL_{k,l} + P_{ue} \sum_{i=1, i \neq l}^L PL_{i,k} + N \quad (4.5)$$

In (4.5) N is the noise power and is calculated as [16]

$$N = NF * K * BT * BW; \quad (4.6)$$

Where NF is receiver noise floor, K is Absolute Temperature, BT is Boltzmann constant, and BW is the UE assigned bandwidth. P_{ue} and $PL_{k,l}$ and the transmitted and pathloss signal for a UE respectively.

4.2 Signal to Interference Plus Noise Ratio

In LTE the SINR is measured by UE on Resource Block (RB) basis. UE computes SINR on each RB, converts it to channel quality indicator (CQI) and reports it to eNodeB where it is used to select the most suitable modulation and coding scheme (MCS) for user data transmission in a particular RB. SINR can be defined as the ratio of the signal power to the summation of the average interference power from the other cells and the background noise. The SINR for user k in the system using a conventional LTE transmission is

$$SINR_k = \frac{P_{ue} * PL_{k,l}}{P_{ue} \sum_{i=1, i \neq l}^L PL_i + N} \quad (4.7)$$

To obtain the SINR for all the potential UE locations in the selected AA network the following steps are used.

For each potential user location k in the selected area:

- 1 Select serving cell l based on best received signal where $P_{r(k,l)} = P_{ue} * PL_{k,l}$
- 2 The received powers $P_{r(k,i \neq l)}$ from the rest of the cells are taken as interference.
- 3 calculate the SINR for each $k=1:K$ as

$$SINR_k = \frac{P_{ue} * PL_{k,l}}{P_{ue} \sum_{i=1, i \neq l}^L PL_{k,i} + N'}$$

Where N is the noise power and is calculated as in equation 4.5.

After obtaining the SINR information, it can be used to calculate the throughput for any potential UE in the coverage area.

4.3 Throughput Calculation

The throughput in LTE is measured using the modified Shannon formula, proposed by [17]. The modified Shannon capacity formula is meant to account for the system

bandwidth efficiency and the SINR efficiency of LTE. The spectral efficiency using the modified Shannon formula for user k is given as [17]:

$$C(k) \text{ (in bits / s / Hz)} = BW_{eff} * \log_2(1 + SINR_k / SINR_{eff}) \quad (4.8)$$

In (4.8) BW_{eff} and $SINR_{eff}$ are the bandwidth and the SINR implementation efficiency of LTE respectively. The approximate bandwidth efficiency of LTE, which accounts for pilot overhead, cyclic prefix and other control information, is about 0.83 [13]. In addition, the best value for the $SINR_{eff}$ for $BW_{eff} = 0.83$ is 1.6dB [13]. To calculate the throughput for a specific UE with a BW_k bandwidth, we can use the equation:

$$Throughput_k \text{ (bits/s)} = BW_k \cdot C(k) \quad (4.9)$$

Where, $C(k)$ is the spectral efficiency in bps/Hz given in equation 4.7.

In throughput calculation, the cell edge throughput is defined as the 5%-tile throughput and it is the UE throughput that is not exceeded by 5% of the all the UE. It should be noted that the location of the cell edge UE is not necessarily at the geometric border of a cell. The cell average throughput is defined as the 50%-tile throughput and is calculated as the throughput that is not exceeded by 50% of the UE.

4.4 Downlink CoMP

4.4.1 CoMP UE Selection Criteria

The condition to identify a UE as CoMP is based on the received signal power. In the system a UE that will apply CoMP is identified based on the power difference between the strongest and second strongest received signal. A defined power threshold is used as a condition for CoMP. In addition, the transmission points selected for cooperation can

be extended to the third strongest received signal and more others if the power for that BS satisfies the condition. The condition to identify a user as CoMP is shown below.

Conditions for CoMP

$|Prx1 - Prx2| < \text{Rx Power Threshold}$ and/or $|Prx1 - Prx3| < \text{Rx Power Threshold}$

$Prx1$: strongest Rx signal power

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

The above condition is the conventional CoMP UE selection criterion [13]. It is used to identify whether a UE applies CoMP or not. Based on this condition a UE which is meant to apply CoMP is selected based on the difference between the received signal power and the interference signal with the largest power. The received (Rx) power threshold is used as a condition to trigger CoMP. At the UE, when the power difference is below the threshold the UE is regarded as a victim UE needing to apply CoMP.

In our simulation, the CoMP scheme applied to make a comparison with the non-CoMP system is joint transmission (JT). JT has already been introduced in chapter 2. In JT CoMP a victim UE is served by multiple BS depending on the received signal powers from the different transmitters as defined in the above condition.

The received signal at the UE using CoMP joint transmission is given as

$$P_{r(k)} = P_{ue} \sum_{l \in L'} PL_{k,l} + P_{ue} \sum_{j \in L \setminus L'} PL_{k,j} + N \quad (4.10)$$

Where the first summation from (4.10) represents the useful received signal from the L' cooperating transmitters, the second summation represents the interference signals and N is the noise power.

Then the SINR for a CoMP UE can be calculated using the equation

$$SINR_k^{CoMP JT} = \frac{\sum_{l \in L'} P_{kl}}{\sum_{j \in L \setminus L'} P_{kj} + N} \quad 4.11$$

As mentioned above L' is the subset of L and consists of transmission points for a UE. From (4.11) it is obvious the SINR obtained by using CoMP is better than the non-CoMP SINR. But the gain in CoMP is due to using the radio resources to a UE that could otherwise can be used for transmission to other UEs. To account for the sacrifice of the transmission to other UEs, effective SINR was defined. The effective SINR for a UE k in cell l is given as:

$$SINR_k^{effective} = SINR_k^{CoMP JT} * (\% (nonCoMP UE) + \frac{\% (CoMP UE)}{Number\ of\ transmission\ points}) \quad (4.12)$$

In (4.12) $\% (nonCoMP UE)$ represents the percentage of UE in a cell that are using single point transmission and $\% (CoMP UE)$ is the percentage of CoMP UEs that are using multiple transmission points. Using the equation, if for example 10% of the UEs in the system are CoMP UEs using 2 transmission points then, the $SINR_k^{effective} = 95\% * SINR_k^{CoMP JT}$.

The throughput for the CoMP system can be calculated similarly to the non-CoMP system, using the modified Shannon's capacity for LTE which was given in (4.8) and (4.9).

The SINR gain that is achieved by CoMP transmission can be estimated by comparing the CoMP SINR with the SINR obtained by transmission without coordination. This can be applied for the evaluation of the different CoMP schemes.

4.5 Intra-Site and Inter-Site CoMP

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 points 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. And therefore the received signal defined in (4.10) can be written for intra-site CoMP as

$$P_{r(k)} = P_{ue} \sum_{l=1}^3 PL_{k,l} + P_{ue} \sum_{j \in I \setminus l} PL_{k,j} + N \quad (4.13)$$

Then using the received signal power the SINR and throughput can be calculated as defined in the previous sections.

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 power are assumed to for the cooperating set. Then using the cooperating set the CoMP selection criterion is used to decide if a UE is a CoMP UE.



Chapter 5

5 Results and Analysis

In this chapter the simulation results for the selected AA LTE system obtained using WinProp and Matlab are presented. The first simulation results show the existing network performance. Next the network is evaluated by including CoMP JT to the system. The first simulation of the CoMP system is the effect of the selected power threshold on the selection of the CoMP UEs and on the CoMP system. Here different power thresholds are selected to evaluate their effect on CoMP. After that, CoMP in intra-site and inter-site scenarios is presented. All the results are shown, using different kinds of graphs, in terms of SINR and throughput.

5.1 Simulation Parameters

Matlab is used in this thesis for the modeling of the CoMP and non-CoMP systems. The results obtained from the WinProp propagation modeling - the path loss information - are used as an input in the Matlab simulation. The path loss is calculated using the urban dominant path model given in (4.4) using ProMan from the WinProp software suite. Matlab is then used for the analysis of the path loss information to obtain the received power at each UE location. In addition, Matlab is also used for the modeling and evaluation of the downlink CoMP JT schemes. Then, the results from the Matlab simulations are presented in terms of SINR and throughput for the selected AA LTE network. Table 2 lists the key parameters used for the CoMP system in the Matlab codes.

Table 2 Simulation Parameters

Parameters	Values
eNodeB	25 eNodeBs, 3 sectors/eNodeB; 75 cells; 100 resource blocks/sectors;
UE	400 UEs / cell; 1 resource blocks / UE
CoMP Rx Power Threshold	1,3,5,10 dBm

5.2 Cumulative Distribution Function (CDF)

One of the methods used for plotting the simulation results is using the cumulative distribution function (CDF). The CDF gives a complete mathematical description of a random variable X and is defined as the probability X will take a value less than or equal to x and is given as

$$F_X(x) = P(X \leq x) \quad (5.1)$$

Where X is the random variable and x is a variable which takes a value from all the possible outcomes of the random variable. The CDF can be used to determine the probability a random variable is lower than a certain value, higher than a certain value, or between two values.

For our simulation the CDF is used assuming the SINR or the throughput values as a random variable.

5.3 Scheduling

For scheduling the common round robin scheduling is used for both the non-CoMP and CoMP system. For the CoMP system two kinds of UEs exist: Non-CoMP UEs and CoMP UEs. The radio resource in each cell is divided between the Non-CoMP and CoMP UEs. The UEs for each cell are uniformly distributed in the coverage area for that cell. Then the

UEs are identified as non-CoMP and CoMP UEs and are scheduled using the round ribbon scheduling algorithm.

5.4 Interference at UE Evaluation of Existing Network

Coverage analysis of the existing LTE network based on SINR was done for the system level analysis of the existing network. Figure 9 shows the SINR for all potential UE positions in terms of probability (CDF) for the coverage area where each UE position consists of 5m² area.

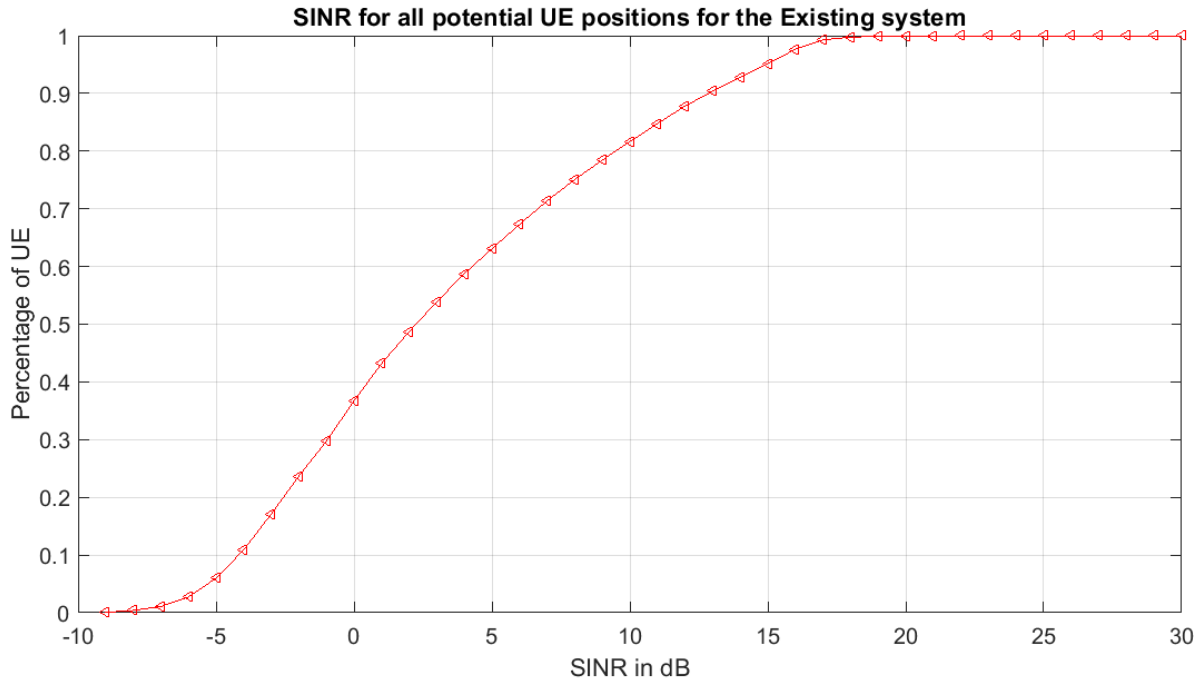


Figure 9 SINR for all Potential UE positions for existing system.

The result from Figure 9 shows that around 20 % of the UE have SINR below -3dB. The cell edge (5%ile) and the cell average (50%ile) SINR values for the system are -5dB and 2dB. In terms of spectral efficiency, based on equation 4.8, the results for the cell edge and average SINR correspond to a value of 0.475 bits/sec/Hz and 1.015 bits/sec/Hz. The above

simulation shows the results in terms of coverage considering all the potential UE positions. To observe the results in a system similar to the realistic situation a simulation was done assuming uniformly distributed users in each cell (uniformly dropping users in each cell's coverage area). Figure 10 shows the result from the simulation.

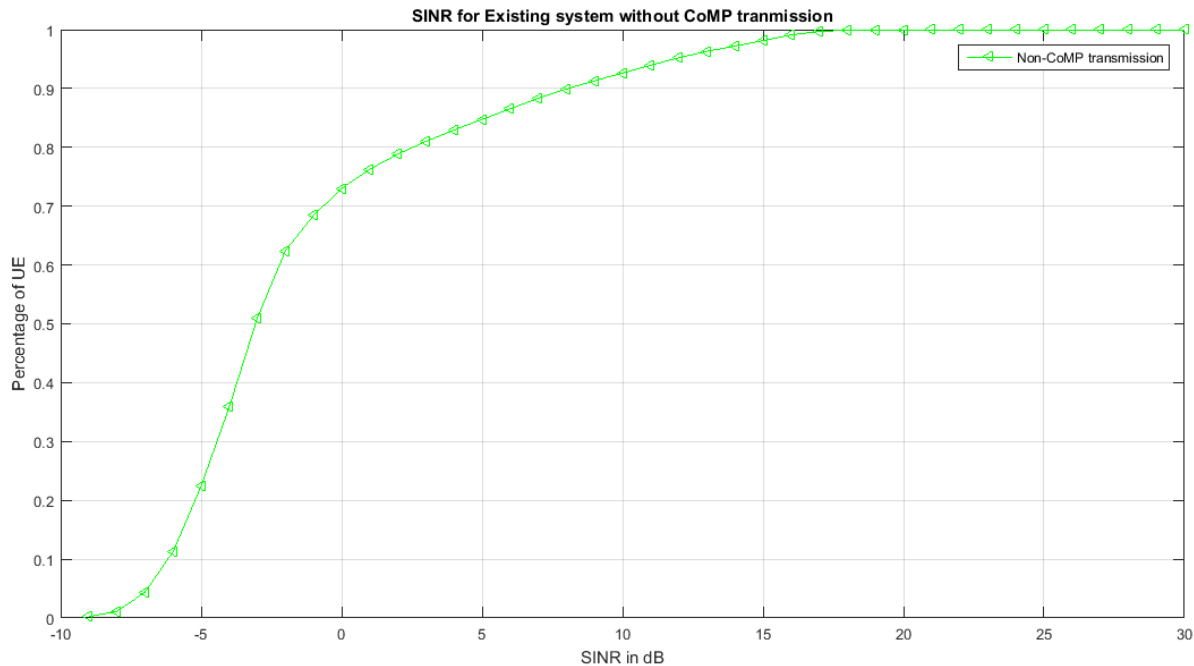


Figure 10 SINR for existing system with random UE distribution.

The result from Figure 10 show that the network performance is lower with a random distribution of users with around 50% of the users with SINR below -3dB. In addition from the figure it can be seen that the 5%ile (cell edge) SINR for the network is -7dB.

Next the performance of the system with CoMP is evaluated and the result are compared to the existing system.

5.5 CoMP Evaluation with Different Power Difference Threshold

The CoMP UE selection criterion defined in the previous chapter is used for selection of the CoMP UEs. The percentage of CoMP UEs is tested using different power threshold. The received power threshold are set to 1, 3, 5 and 10 dB to observe the effect on the performance. The serving transmission points for the CoMP system are selected from the signals with the highest received power. Then using the different power thresholds the percentage of UE locations that will have 1, 2 or 3 transmission points are shown using a bar graph. Figure 11 shows the result for the different power threshold.

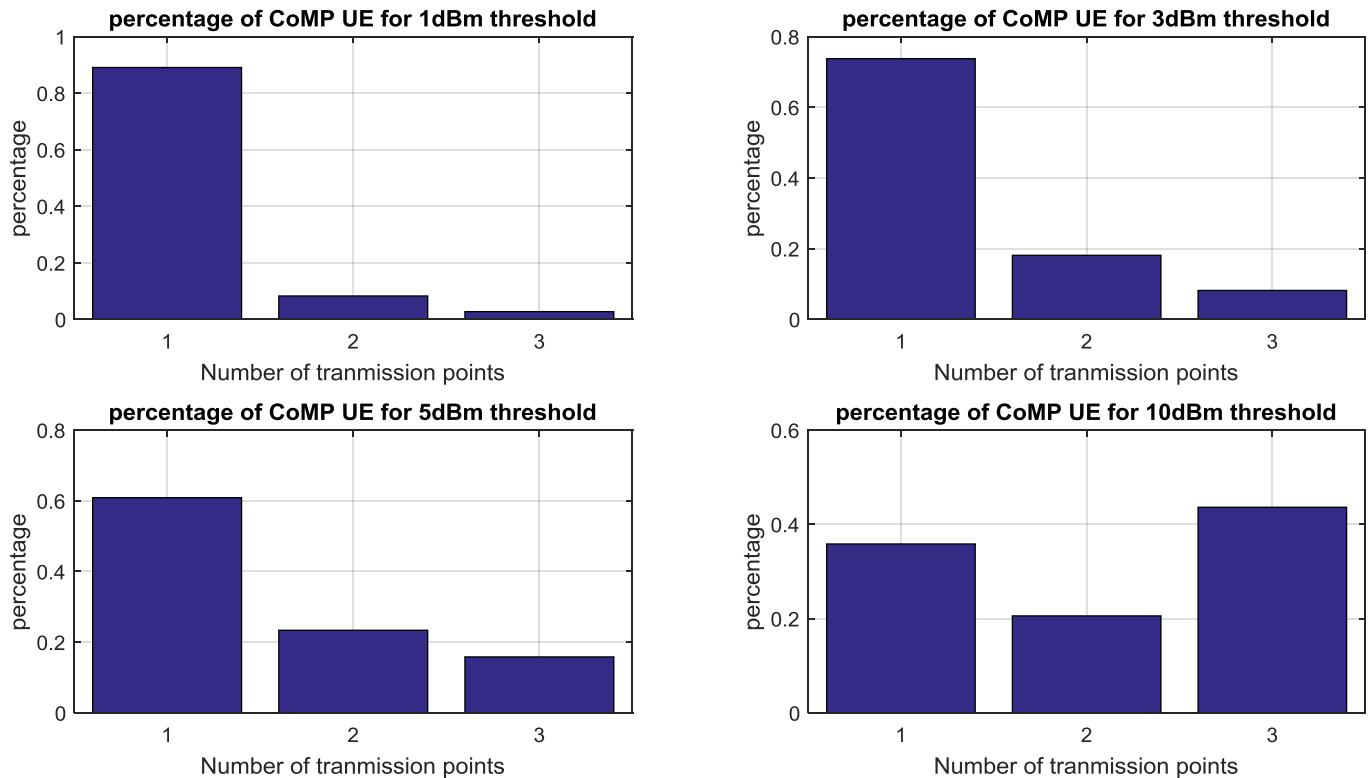


Figure 11 percentage of UEs positions with CoMP transmission having 1, 2, or 3 transmission points.

The graphs from Figure 11 show that increasing the received power threshold results in more CoMP UEs and fewer single cell UEs. At 10 dB power threshold, the percentage of CoMP UEs with 2 or 3 transmission points reaches around 60%.

While increasing the threshold increases the percentage of the CoMP UEs, to check the performance, the SINR for the CoMP UEs at different power threshold is tested next. For the evaluation of the CoMP system performance the effective SINR defined in the previous chapter is used.

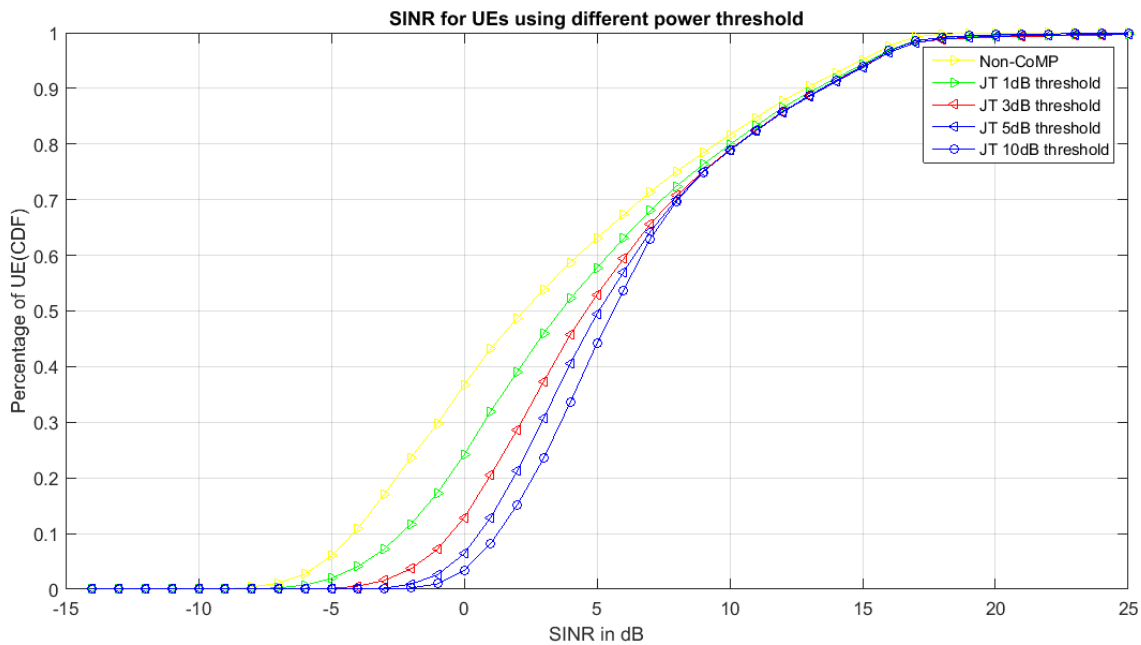


Figure 12 SINR for all UEs using different power thresholds.

The result from Figure 12 show that the percentage of UE positions with higher SINR increases with increasing threshold. For example the coverage of SINR above 3dB is around 75% for 10dB threshold and around 50% for 1dB threshold. From the result it can also be seen that a 5% increase in coverage can be achieved with 1dB threshold at the 3dB SINR level and with 10dB threshold 30% increase is achieved with 3dB and 5dB thresholds performance in between.

Figure 13 shows the actual CoMP UEs SINR gain at the different thresholds. From the graph it is clear that smaller value of threshold leads to a larger SINR gain for CoMP UEs. Chen Yiye in [13] explained the reason for a larger SINR gain at low threshold is because lower threshold means the power difference between the transmission points is small. In a non-CoMP system the second strongest signal is the dominant interferer and its effect on the SINR is high [18]. At low threshold when the relatively high interference is turned to useful signal, the SINR gain is high. On the other hand, at 10dB threshold, some UEs will have a large difference between the strongest two signals and their SINR gain will be lower than that of 1dB or 3 dB received power threshold.

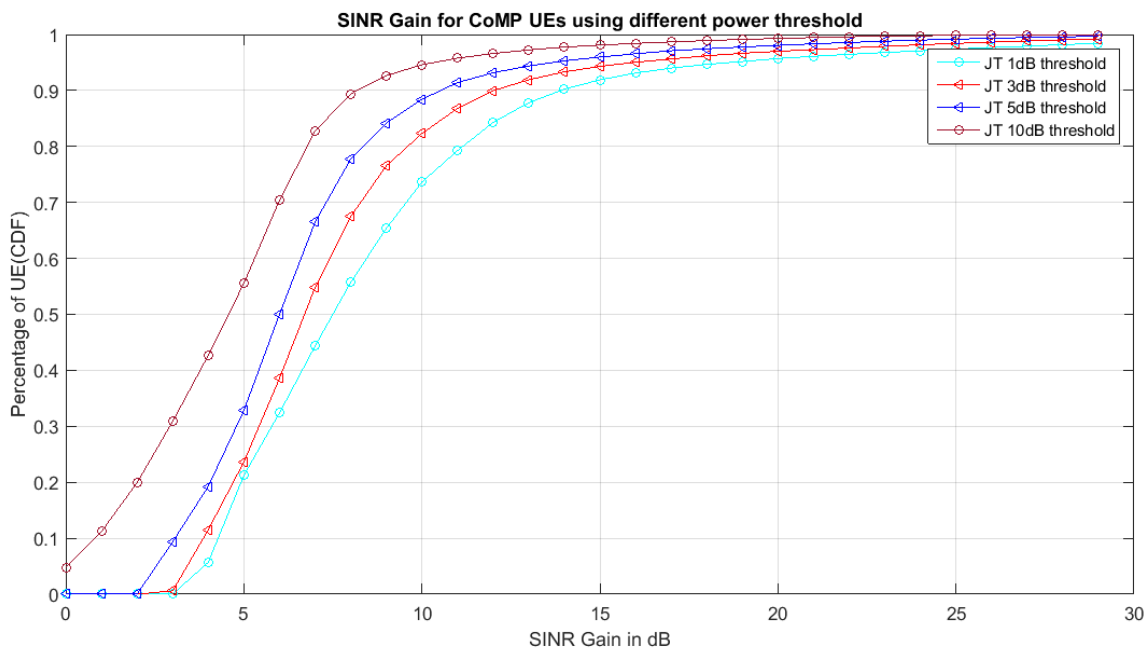


Figure 13 CoMP UE's SINR Gain using different power threshold.

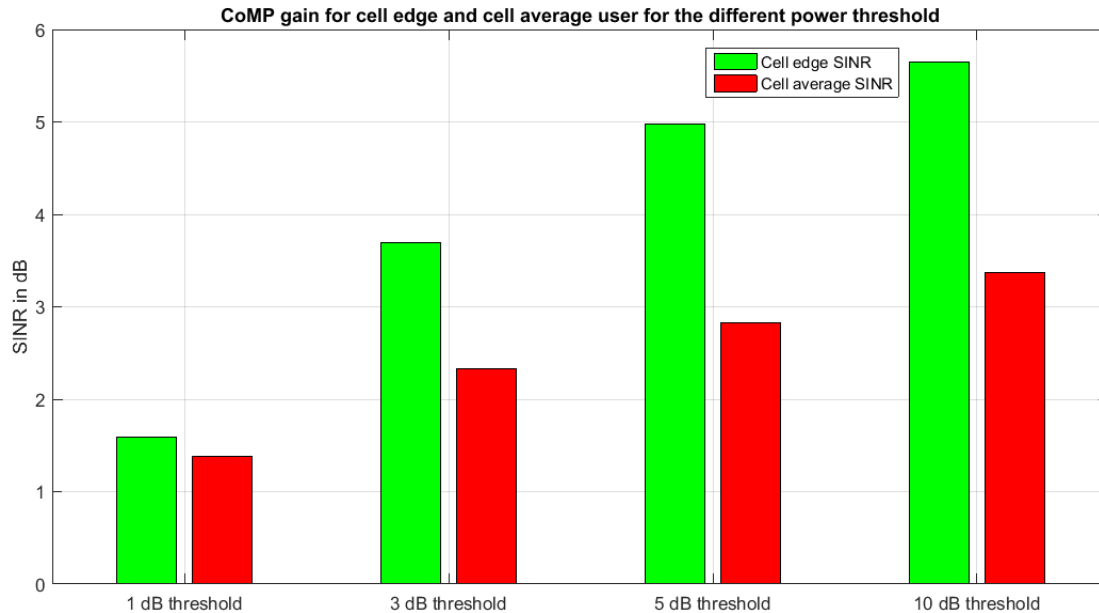


Figure 14 SINR gain for cell edge and average users for different power thresholds.

To check the SINR gain of the selected Power threshold values on the whole system, the average and cell edge user SINR are used. Figure 14 shows the SINR gain of cell edge and average users for the different power threshold values. The cell edge user represents the SINR at the 5% tile and the average user represents the SINR at the 50% tile. The figure shows with increasing received power threshold the system cell average and cell edge SINR improve much better. The gain for UEs with low SINR is very large. However the SINR gain for the average user who already have a good channel condition is slightly lower. Next we see how much throughput gain can be achieved.

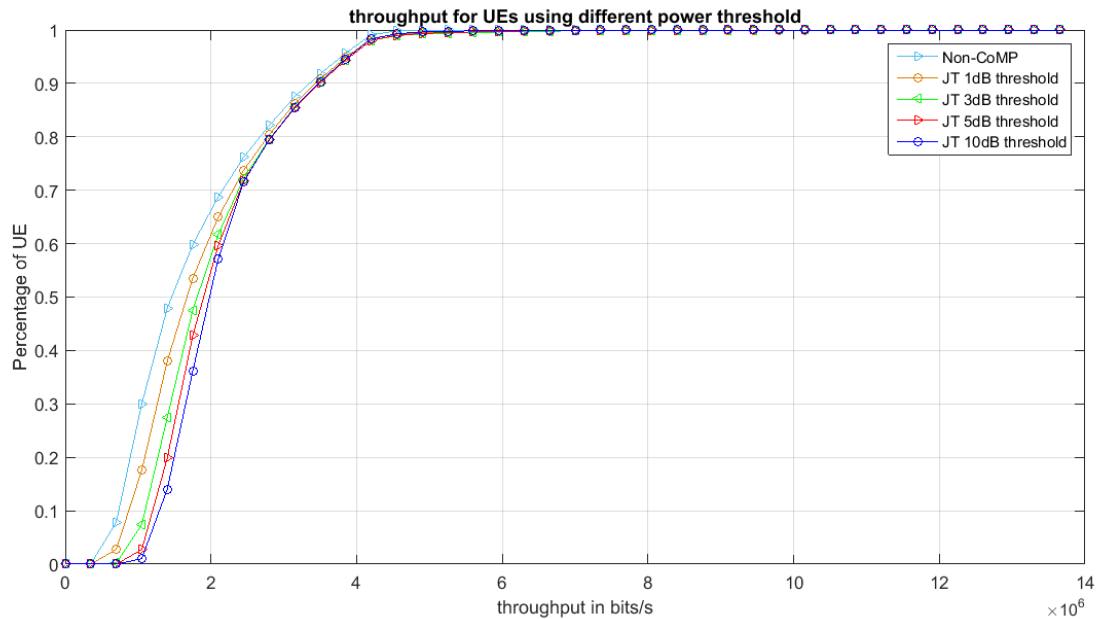


Figure 15 throughput for CoMP with different power threshold.

Figure 15 depicts the throughput for the different power threshold levels. Actually, almost 70% users benefit from CoMP for all the threshold values with the 10dB threshold value achieving more throughput gains than the others. If we observe the y-axis plot at 0.05 which stands for the cell-edge users, the improvement on throughput is quite significant almost double the non-CoMP system.

Therefore, we can conclude that the 10 dB threshold leads to a larger channel condition and throughput gain and it will be used in the latter simulation.

5.6 CoMP in Intra-Site and Inter-Site Scenario

CoMP implementation can be done in intra-site or inter-site scenario. As mentioned before, the three sectors of an eNodeB participate in transmission to a UE in intra-site CoMP and in an inter-site CoMP the cooperating sectors are found on different eNodeBs. For both system the CoMP transmission mode selection criterion defined in chapter 4 is used to decide if a UE is a CoMP user. In addition to the evaluation of the coverage, a

random distribution of users in each cell is assumed for the simulation to analyze the effect in real network scenario. To evaluate the performance of the two scenarios in downlink JT CoMP the highest threshold of 10dBm is used. The 10 dB threshold is used because its performance is better as seen in the previous section. The performance of the two systems is done in comparison with the non-CoMP system.

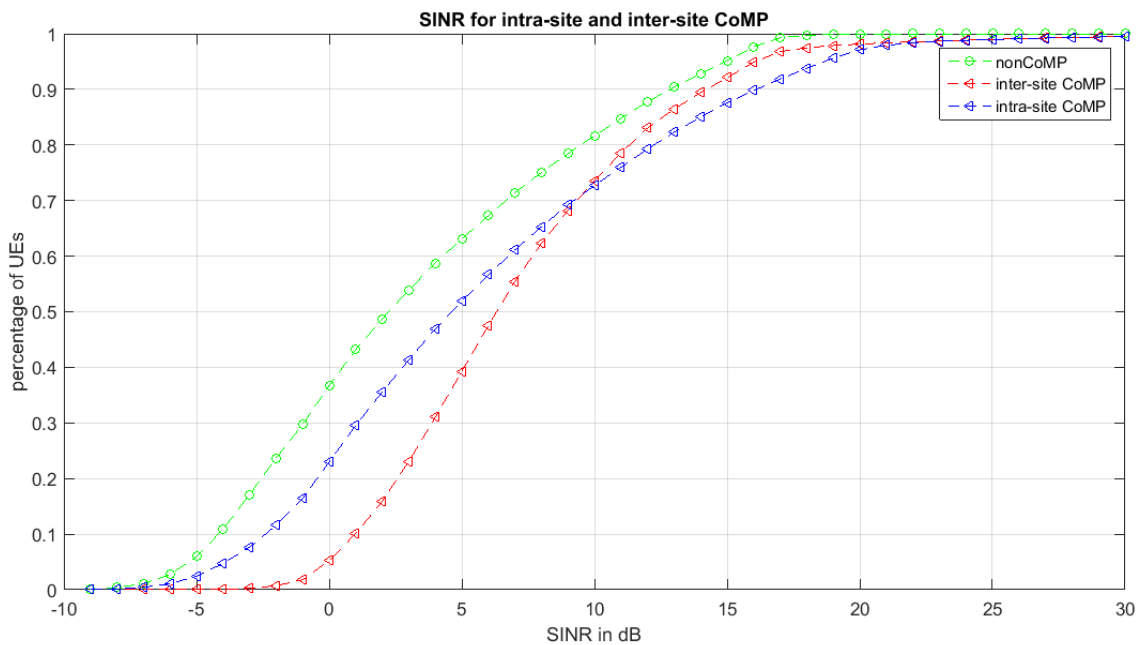


Figure 16 Intra-site and Inter-site CoMP performance comparison.

Figure 16 shows the performance of the intra-site and inter-site CoMP systems and the non-CoMP system. From the figure it can be seen that the inter-site CoMP system has a better performance than the intra-site CoMP. For example, 60% of the user positions have SINR above 5dB in inter-site CoMP while 50% of the user positions have SINR above 10dB for intra-site CoMP. In addition almost all user positions have SINR above -3dB in inter-site CoMP while 10% of user positions have SINR below -3dB. The reason for the inter-site CoMP to have an effect on more user position is that since the cooperating cells are at different geographical location they have a higher overlapping areas while for the

intra-site CoMP the cooperating cells are sectors of the same base stations and the overlapping area is limited to the cell border between the sectors.

From the figure it can also be seen that largest SINR value is achieved using intra-site CoMP. this is because since in intra-site coordination each transmitter is located at the same place, the sectors signal powers at the CoMP UEs can be very close and when combined will result in a high SINR by increasing the received power and removing the dominant interfering signal at the same time.

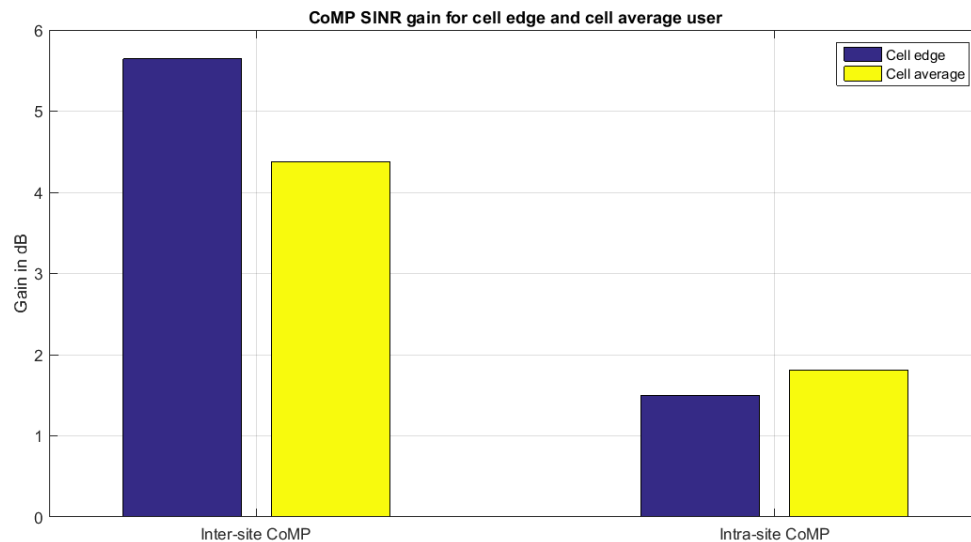


Figure 17 SINR gain for intra and inter-site CoMP.

Figure 17 shows the SINR gain of whole system separately for intra-site and inter-site. As in the previous simulations the 5% tile is used as the cell edge and the 50% tile as the cell average. The result shows that the cell edge and average user SINR gain obtained by the network with inter-site CoMP is almost twofold, but the value for the intra-site CoMP is not as large. Since in CoMP, we are mainly interested in the SINR or throughput for cell edge UEs, the SINR performance of the inter-site CoMP system is better compared to the intra-site system.



The result from Figure 17 shows, applying either of the two schemes provides gain in SINR in the coverage area. Then the system is tested if a gain can be achieved from the perspective of UEs in real network scenario. To achieve this, the system is simulated using a uniform distribution of users in each cell and applying the round ribbon scheduling algorithm for the assigning of the PRB in each time slot. In addition, for the CoMP transmission only cell edge (5%ile) UEs were considered. This is because the main use of CoMP transmission is for improving cell edge user data rates and extending the use of CoMP to the rest of the users will result in degradation of the system performance. The effective SINR given in Equation 4.11 is used for the calculation of the SINR for CoMP UEs. This equation puts into consideration the effect of CoMP JT UEs on the available resource for other UEs. The simulation result for the cell-edge and average users is given in Figure 16.

Figure 18 displays the SINR for the systems with the two CoMP schemes and the non-CoMP system. The result shows, with a uniform distribution of users, both systems achieve a large improvement in SINR with inter-site CoMP performing better than the intra-site CoMP. The SINR gain achieved by the CoMP users for inter-site and intra-site systems at the cell edge are around -0.5dB and -4dB respectively with a higher gain achieved for the cell average user: 5dB for inter-site CoMP and 3dB for intra-site CoMP. From the figure it is clear that the inter-site CoMP system has a larger gain for a user compared to the intra-site CoMP system. Figure 18 also reflects the fact that intra-site CoMP can still performs highly in realistic network with random distribution of users although not as good as inter-site CoMP. Next we see how much throughput gain can be achieved.

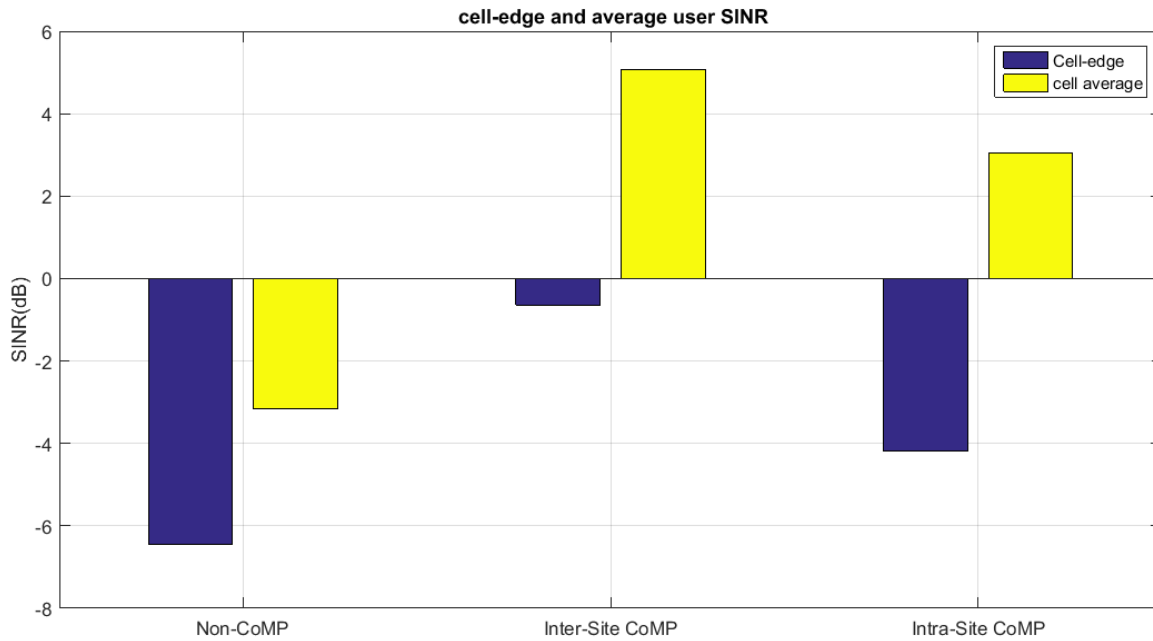


Figure 18 SINR for cell-edge and average users for different network scenarios.

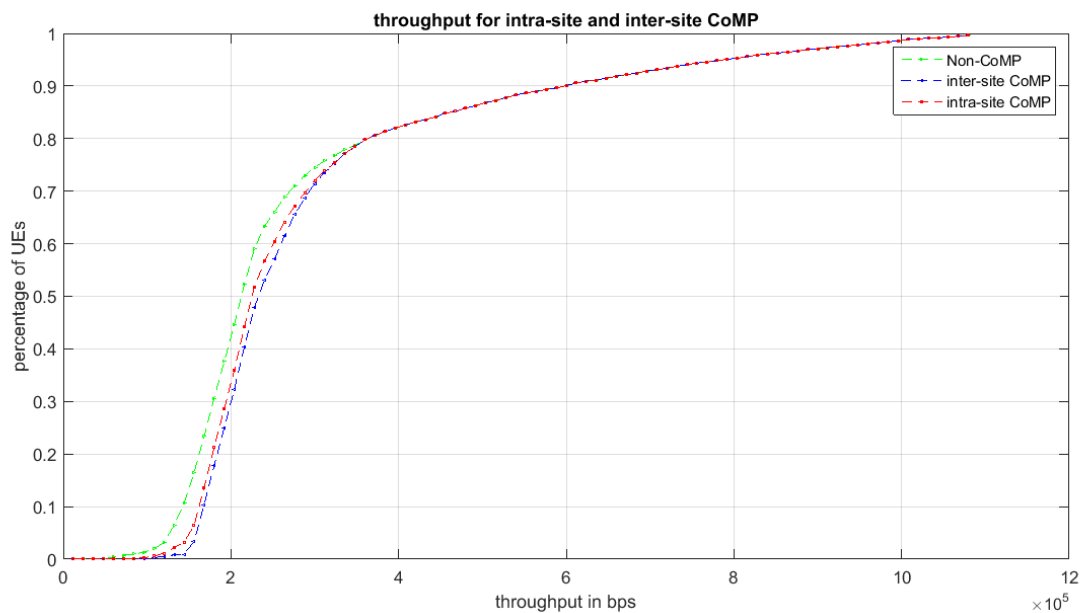


Figure 19 throughput for different network scenarios.

Figure 19 depict the UEs' throughput with 10 dB CoMP threshold for the CoMP systems and the non-CoMP system with a uniform distribution of users in each cell. For the CoMP transmission only cell edge (5%ile) UEs were considered. The result from the simulation shows that low throughput users have achieved a gain but higher throughput users have achieved no or low gain for both inter-site and intra-site CoMP systems with no enhancement on the peak throughput. This is because CoMP is a technique that makes a tradeoff between high and low throughput UEs. It allocates more RBs to the cell edge users to improve their performance.

Figure 20 shows the throughput for the cell-edge and average users for the three systems. The figure shows that both the inter-site and intra-site perform equivalently in-terms of throughput. The actual gain for the cell-edge and average users for both CoMP systems is shown in figure 21. The figure shows that at the cell-edge there is an 18% gain for the inter-site CoMP and a gain of 14% for intra-site CoMP. For the average user there is a 10% gain for the inter-site CoMP and a 6% gain for the intra-site CoMP.

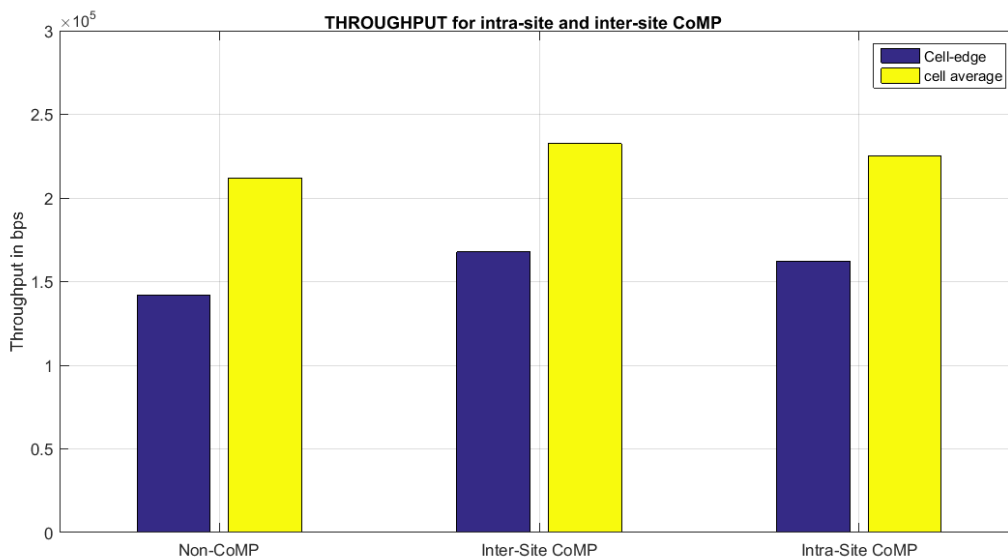


Figure 20 cell-edge and average user throughput for non-CoMP, inter-site and intra-site CoMP systems.

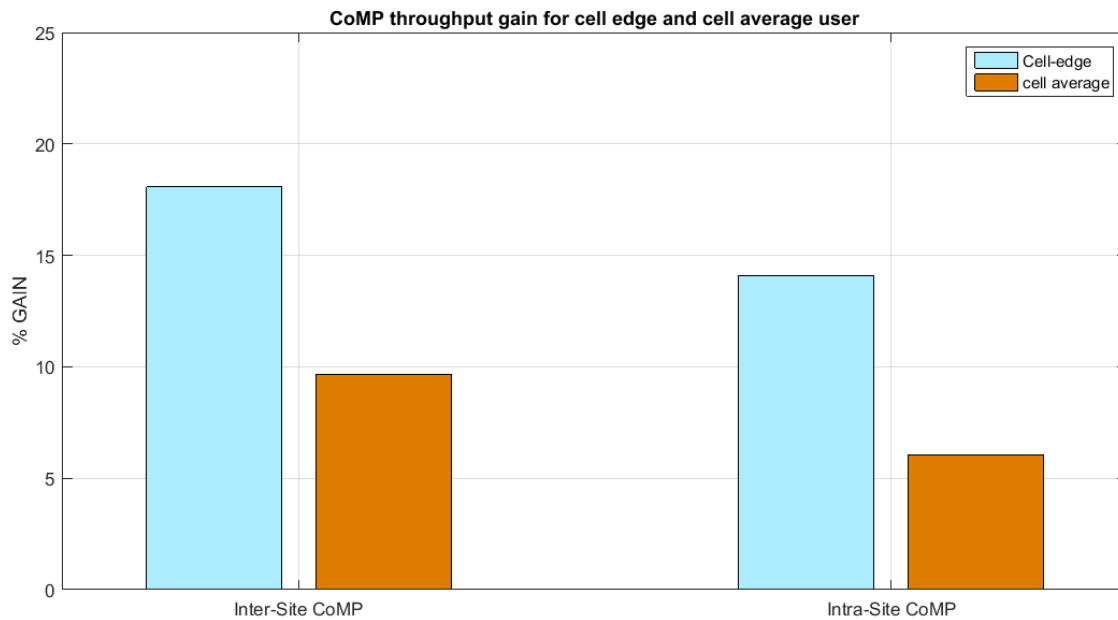


Figure 21 Throughput gain for inter-site and intra-site CoMP systems.

From figure 21 it is clear both CoMP systems can achieve a throughput improvement to the existing non-CoMP system. Therefore, in the AA LTE for the selected area, CoMP can efficiently mitigate the ICI and improves the coverage and throughput for both systems.



Chapter 6

6. Conclusion

This thesis investigated the improvement that can be achieved in the current LTE network in Addis Ababa by incorporating CoMP JT in the downlink to the system. In the thesis, the outcomes from the CoMP system simulation on the selected area in the AA LTE system shows a significant improvement in SINR and throughput. This illustrates the deployment value of CoMP. In general, CoMP under intra-site and inter-site scenarios were simulated and analyzed.

The simulation results show CoMP brings major gain on cell edge UE and cell average UE in SINR and throughput. The two CoMP schemes – intra-site and inter-site CoMP - were observed and inter-site CoMP always has a better performance than intra-site CoMP. The throughput gain for inter-site CoMP can reach 20% while for intra-site CoMP it can reach 15%.

From the results it is apparent CoMP joint transmission is worthy for deployment and can improve the coverage for cell edge users. Also the results show that inter-site CoMP is better in performance compared to intra-site CoMP though it has other drawbacks. Inter-site CoMP is affected by the backhaul and synchronization requirement due to the different location of the transmission points unlike intra-site CoMP where the transmission points are located at the same place.

In addition, CoMP in intra-site scenario offers over 14% throughput gain on cell edge UEs which is a large improvement. In terms of the coverage by applying CoMP around 2dB SINR improvement can be achieved for the average user. Therefore, in the current LTE



network where the backhaul delay can reach more than 20ms applying intra-site CoMP will be recommended.

Future work should include studying the effect of the backhaul on the CoMP system. Moreover, as backhaul is the limiting factor in the performance of CoMP and in the current simulation an ideal backhaul was assumed, in the future the simulation with non-ideal backhaul is better for study so that the evaluation result can be close to the reality.

In addition, in future work for the propagation modeling the more accurate ray-tracing can be used since it could not be used due to the lack of a detailed digital map of AA. Hence, further study can be made by using a detailed digital map of AA and incorporating the ray-tracing propagation model.

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