



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

**Investigation and Optimization of Electrical Tilt and  
Azimuth for Addis Ababa LTE Network**

**By**

**Taddege Assefa**

**Advisor**

**Dr. Beneyam Berhanu Haile**

A thesis submitted to the School of Electrical and Computer Engineering in Partial Fulfillment of the requirements for The Degree of Master of Science in Telecommunication Engineering (Telecommunication Networks Engineering Track)

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**By: Taddege Assefa Beyene**

**Approved by Board of Examiners**

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Chairperson

---

Signature

Dr. Beneyam Berhanu Haile

Adviser

---

Signature

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Examiner

---

Signature

---

Examiner

---

Signature

## Declaration

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

Taddege Assefa Beyene

Name

---

Signature

Place: **Addis Ababa University, Ethiopia**

Submission date: 3<sup>rd</sup> November 2018

This master thesis has been submitted for examination with my approval as a university adviser.

Dr. Beneyam Berhanu Haile

Adviser

---

Signature

# Abstract

Demand for mobile broadband connectivity is significantly increasing and mobile network operators are continuously improving their network by introducing new technologies to accommodate the demand. After mobile network is operational for the first time, to maximize network performance, it is common to perform further optimization of initially planned and configured network parameters. One important category of such network parameters that incur significant network performance impact is antenna parameters that mainly include antenna tilt and azimuth. Optimization of antenna tilt and azimuth plays a major role in optimization of coverage, capacity, load balancing and interference of mobile networks. Long Term Evolution (LTE) network is operational in some parts of Addis Ababa since 2015. This thesis work reviews Addis Ababa LTE network, deployed antenna solutions and ethio telecom antenna optimization practices. The work continues by evaluating the performance of this LTE network from electrical down tilt and azimuth steering perspective. Based on observed performance, the tilt and azimuth parameters are also optimized by applying educated trial and error approach. The performance evaluation and optimization of the network are performed through Signal-to-Interference-Plus-Noise-Ratio (SINR) and throughput parameters obtained using WinProp based network simulation backed by Matlab. Results show that, by optimizing electrical tilt, SINR and throughput can be improved by 12.5% and 4.4% respectively. On the other hand, there is negligible performance gain by optimizing the azimuth.

**Key words-** LTE, Electrical Tilt, Azimuth Steering, SINR, Throughput, Network simulation, Addis Ababa

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## Abbreviations

2G	2 <sup>nd</sup> Generation
3D	3-Dimensional
3G	3 <sup>rd</sup> Generation
4G	4 <sup>th</sup> Generation
3GPP	3 <sup>rd</sup> Generation Partnership Project
AC	Admission Control
ACK	Acknowledgement
ADSL	Asymmetric Digital Subscriber Line
BBU	Baseband Unit
BSC	Base Station Controller
CAPEX	Capital Expenditure
CCO	Coverage and Capacity Optimization
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CMC	Connection Mobility Control
CP	Cyclic Prefix
CPRI	Common Public Radio Interface
CQI	Channel Quality Indicator
DFT	Discrete Fourier Transform
DL	Downlink
eNB	evolved NodeB
EPC	Evolved Packet Core

E-UTRA	Evolved UMTS Terrestrial Radio Access
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FFT	Fast Fourier Transform
GGSN	Gateway GPRS Support Node
GSM	Global System for Mobile Communications
HARQ	Hybrid Automatic Repeat Request
HII	High Interference Indicator
HO	Handover
ICIC	Inter-Cell Interference Coordination
IDFT	Inverse Discrete Fourier Transform
IFFT	Inverse Fast Fourier Transform
IMT-A	International Mobile Telecommunications-Advanced
IP	Internet Protocol
ISI	Inter Symbol Interference
LHCP	Left Hand Circular Polarization
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MAC	Media Access Control
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MME	Mobility Management Entity
MU-MIMO	Multi User MIMO
NACK	Non Acknowledgement
NAS	Non Access Stratum

NE	Network Element
NMS	Network Management System
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OI	Overload Indicator
OPEX	Operational Expenditure
OVSF	Orthogonal Variable Spreading Factor
PAPR	Peak to Average Power Ratio
PM	Performance Management
PDCP	Packet Data Convergence Protocol
PRB	Physical Resource Block
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
QPSK	Quadratic Phase Shift Keying
RB	Radio Bearer
RAT	Radio Access Technology
RET	Remote Electrical Tilt
RF	Radio Frequency
RHCP	Right Hand Circular Polarization
RLC	Radio Link Control
RNC	Radio Network Controller
RNTP	Relative Narrowband Transmit Power
RRH	Radio Remote Head
RRM	Radio Resource Management

RRU	Remote Radio Unit
SAE	System Architecture Evolution
SC-FDMA	Single Carrier-Frequency Division Multiple Access
SFC	Space Frequency Coding
SGSN	Serving GPRS Support Node
SM	Spatial Multiplexing
SINR	Signal to Interference plus Noise Ratio
SNR	Signal to Noise Ratio
SRS	Sounding Reference Signal
SU MIMO	Single User MIMO
TDMA	Time Division Multiple Access
TMA	Tower Mounted Amplifier
TTI	Transmission Time Interval
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
UL	Uplink
VET	Variable Electrical Tilt
WCDMA	Wideband Code Division Multiple Access
WiFi	Wireless Fidelity
WiMAX	Worldwide Inter-operability for Microwave Access

# Chapter 1: Introduction

## 1.1. Background

Long Term Evolution (LTE), also marketed as 4<sup>th</sup> generation (4G), standardization has been launched in November 2004 by the Third Generation Partnership Project (3GPP) [1]. Release 8 was frozen in December 2008 and this was the basis for first wave of LTE equipment. The specifications of the LTE project are formally known as the Evolved UMTS Terrestrial Radio Access (E-UTRA) and Evolved UMTS Terrestrial Radio Access Network (E-UTRAN).

LTE radio interface is based on Orthogonal Frequency Division Multiple Access (OFDMA) [1]. LTE employs flexible transmission bandwidth from 1.4MHz to 20MHz to utilize operators' available spectrum. It also admits higher peak data rates and more users per cell as well as lower control plane latency than previously deployed third generation (3G) technologies. Moreover, the core network architecture of LTE, also known as System Architecture Evolution (SAE), is simplified.

LTE is further developed to meet the requirements set for International Mobile Telecommunications-Advanced (IMT-A) technologies and is called LTE-Advanced (LTE-A). LTE-A is standardized by 3GPP since Release 10 including the technology components carrier aggregation, advanced multi-antennas, relays and coordinated multipoint transmission/receptions.

Number of LTE commercial networks and subscriptions has reached 681 and 3.2 billion by the end of quarter 1 of 2018, respectively [2]. The number of subscriptions accounts for 38.5% of total global mobile subscriptions. It is also forecasted that LTE will account for more than 50% of all global mobile subscriptions by 2020 and more than 60% by 2022.

Although Ethiopian incumbent operator ethio telecom is now the largest mobile operator in Africa in terms of subscriptions, with 65.7 million as of September 2018 [3], LTE network share is small and is deployed in selected hot spot areas of Addis Ababa. As the demand for mobile broadband services is also increasing in the country [4], it is inevitable to expand the LTE network to reach the potential customers in different parts of the country. There is high mobile data usage, especially in Addis Ababa, which can cause capacity challenge in the near future.

Even if ethio telecom utmost effort is appreciated to expand the cellular network infrastructure to achieve more capacity and coverage throughout the country, there are still undeniable quality, capacity and coverage problems that persistently remained challenging. While working to expand, optimization of existing Addis Ababa LTE network is an important task to maximize its coverage, capacity and quality.

Optimization of antenna parameters has an important role to achieve optimal capacity and coverage performance in LTE and beyond (LTE-A). Tilt and azimuth are examples of main parameters found in one antenna.

Antenna tilt is defined as the angle of the antenna main lobe and the horizon. Positive and negative angles are also referred to as downtilt and up-tilt respectively [2]. Antenna downtilt can be adjusted mechanically and/or electrically. In electrical downtilt, phases of antenna elements are adjusted so that desired tilt angle is obtained by tilting main, side and back lobes uniformly [3] – contrary to mechanical downtilt. Azimuth angle is the compass bearing, relative to true (geographic) north, of a point on the horizon directly beneath an observed object. With the development of modern base station antennas, these parameters are controllable parameters which (when properly optimized) can increase the quality and capacity of the radio network. For that reason, real LTE network is adopted for optimization of antenna electrical down tilt and azimuth parameters simulations and investigations.

## 1.2. Related Works

So far many researchers have conducted a research on optimization of radio access networks based on antenna adjustments for different radio access technologies. Short literature survey of selected papers is presented below.

Hampel et al. [5] and Garcia-Lozana et al. [6] have found that fixing antenna down tilt angle is the best solution in terms of interference and load distribution when the user distribution or traffic is uniform and equal path loss conditions apply across the network. However, when the user distribution is non-uniform and terrain renders varied signal propagation across the network, intelligent tilt adjustment can improve both coverage and capacity in cellular networks. Pettersen et al. [7] confirm that adjusting antenna tilt angles to adapt to current geographical load distribution gives capacity gains in Universal Mobile Telecommunications System (UMTS) networks and show that the amount of capacity gain is proportional to the imbalance in the load distribution across the network.

Osman et al. [8] compared mechanical and electrical down tilt performance of LTE. System performance was investigated using snapshot simulator with 3-dimensional (3D) antenna modeling. The results show that electrical down tilt provides better performance in case of interference limited system, while performance difference is insignificant for noise limited cases.

The same authors in [9] have evaluated the impact of various antenna parameters to the down-link performance of LTE networks. Accordingly results showed that interference limited 3GPP case 1 (short inter site distance) is sensitive to changes in antenna parameters while noise limited 3GPP case 3 is not so sensitive to impact of antenna properties like horizontal and vertical half-power beam widths, coverage and capacity

(5% tile of SINR CDF, 50% tile of SINR CDF) optimization criteria may lead to a bit different parameter selections.

Osman et al. [10] have also conducted a research on self-optimization of remote electrical tilt from the perspective of Coverage and Capacity Optimization (CCO). Using LTE snapshot simulator they modeled propagation and uneven user distribution in three dimensions for realistic macro-cellular network scenario. Results show that remote electrical tilt (RET) optimization may provide significant performance improvement in case of suboptimal network planning or reuse of 3G network planning. However, it doesn't consider optimization of antenna azimuth.

In [29] LTE mobile network performance was evaluated with antenna tilt considering real radiation patterns. It proposed system level simulation of two real antennas to evaluate the results in terms of coverage and capacity for varying degrees of tilt and results show 32% and 50% respectively. However, considering only two antennas doesn't represent performance of a large network.

### **1.3. Statement of the problem**

In the last decade, ethio telecom has deployed UMTS and LTE as a replacement of and/or expansion over the existing Global System for Mobile Communications (GSM) infrastructure. Consequently, number of network elements has been increased and resulted network management and optimization complexity.

Regardless of ethio telecom network expansion and optimization efforts to accommodate growing mobile data demand, impactful coverage, capacity and quality challenges are still existing. Causes of the challenges vary due to changed environment, insertion or deletion of a base station, or malfunctioning of base stations or no optimal parameter selection in the network planning phase. Furthermore, unwanted coverage and capacity availability might cause waste of network resources. For instance, construction boom has

been observed in Addis Ababa which could significantly affect mobile network performance unless considered during network planning and implementation phase. This has been officially identified challenge experienced by ethio telecom [30]. The network performance can be improved by playing on selected antenna parameters as these parameters have significant impact on the overall radio access network. However, continuous optimization actions are not being performed unless complaints from different customers are not raised.

As the data demand will continue increasing, these challenges will be more problematic unless appropriate optimization and expansion actions are taken timely. One key network performance playing ground are antenna parameters as these parameters have significant impact on the network coverage, capacity and quality performance.

## **1.4. Thesis objectives**

### **1.4.1. General objective**

The main objective of the thesis is to investigate and optimize antenna tilt and azimuth for LTE network, particularly for the Addis Ababa deployment scenario.

### **1.4.2. Specific objectives**

The specific objectives of the thesis are to:

- Assess antenna and Radio Frequency (RF) optimization practices in ethio telecom
- Review antenna optimization techniques.
- Investigate antenna tilt and azimuth optimization techniques
- Performance evaluation and optimization of antenna tilt and azimuth for Addis Ababa LTE network.

## 1.5. Methodology

To realize the completion of this thesis work, the following methodology will be used. Firstly, assessment of current Ethio telecom antenna and radio frequency (RF) optimization practices via interview of the optimization team and reading relevant documents will be conducted. Survey of literatures on antenna optimization techniques will be done. Secondly, revision of antenna optimization techniques will follow. Then, tilt and azimuth optimization techniques will be investigated. At last, to check optimality of tilt and azimuth parameters for current live LTE network of Addis Ababa and optimize them using educated trial and error approach. WinProp network simulation software based system level network simulation are performed. Matlab is also used for plotting figures and result presentations. The overall methodology is shown in Figure 1.1.

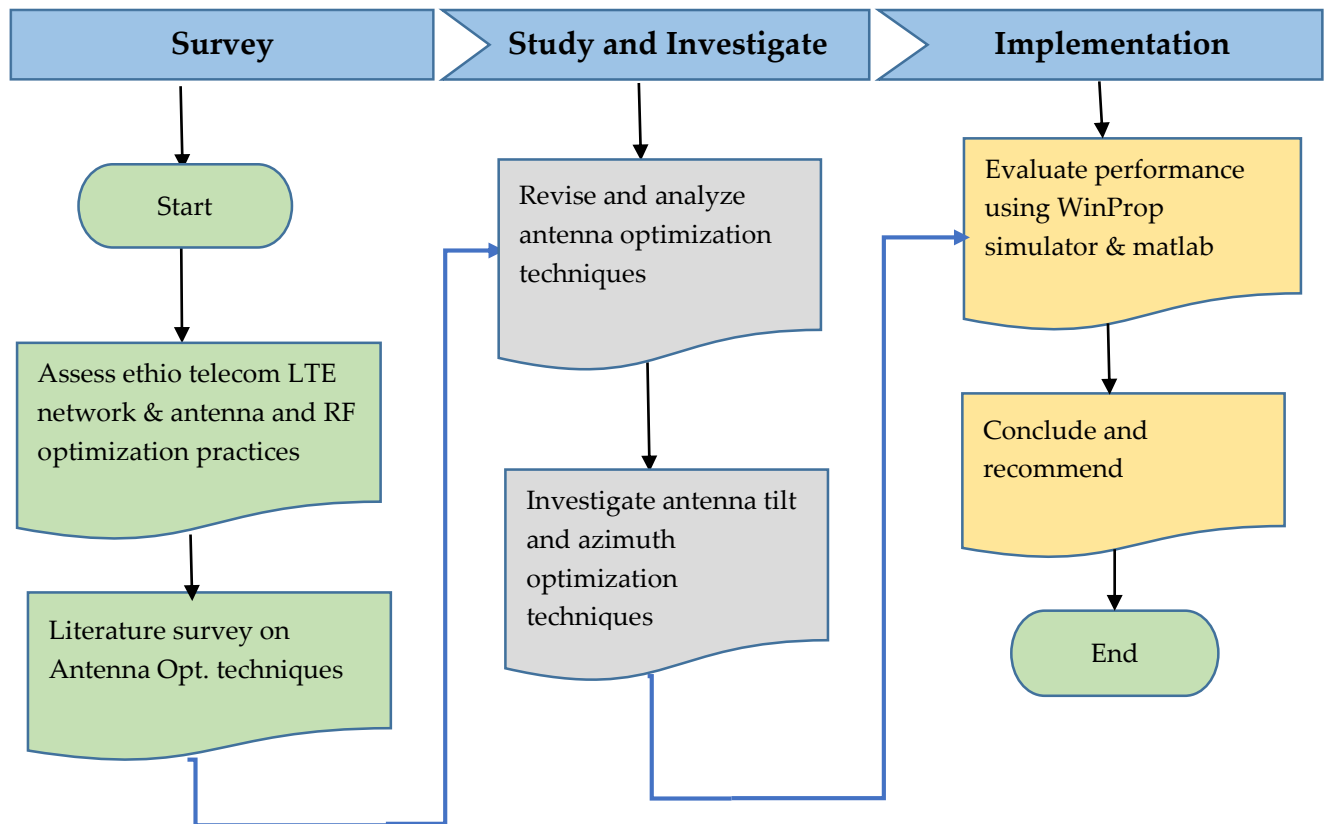


Figure 1.51: Research Methodology

## **1.6. Scopes and limitations**

### **1.6.1. Scope**

The study is limited to the optimization of antenna electrical tilt and azimuth parameters. The network evaluation and optimization is also performed for Addis Ababa LTE network consisting of three-sectored 34 evolved NodeBs (eNBs), i.e. 102 cells located around Bole area.

### **1.6.2. Limitations**

Since the WinProp simulation software is mainly used for planning of radio network, flexibility of simulation work has been limited. Furthermore, uniform traffic and static simulation assumption are considered and thus the evaluation and optimization does not include impacts of traffic non-uniformity and network dynamism.

## **1.7. Contributions**

Antenna parameter selection and optimization techniques are key in improving the coverage and capacity performances of a cellular network so that due attention should be given. These techniques are very important as an operator can address coverage and capacity issues of their cellular networks and consequently improve customer experience without requiring additional investment. Review of Addis Ababa LTE network & applied antenna solutions ethio telecom antenna optimization process is one of the key contributions in this work. This thesis work also contributes by providing insight on the impact of antenna parameters on network performance. In general, by optimizing electrical tilt, SINR and throughput can be improved by 12.5% and 4.4% respectively. However, there is negligible performance gain obtained from azimuth parameter adjustment for the existing network setting.

## **1.8. Thesis outline**

The thesis work is organized into six chapters. The first chapter deals with the introduction to this thesis. It consists of the general background, related literatures, statement of the problem, objective of the thesis, methodologies used, scope and limitations and contributions of the study. Basics of LTE technology, including LTE overview, system architecture, LTE air interface, and radio resource management are discussed in Chapter 2. Chapter 3 explains base station antenna parameters which consists of the background, antenna parameters, modeling of antenna radiation pattern, electrical and mechanical tilt and azimuth steering.

Chapter 4 describes the network to be studied including overview of the Addis Ababa LTE network, deployed antenna solutions, network model used for the simulation and assumptions considered. The final results are presented and comparisons made in Chapter 5 of this thesis. Finally, Chapter 6 concludes and gives insight for future works.

# Chapter 2: Long Term Evolution

## 2.1. Introduction

Long Term Evolution, commercialized as 4G LTE, is a family of 3GPP standards in which the radio interface is based on OFDMA in the downlink (DL) and Single Carrier – Frequency Division Multiple Access (SC-FDMA) in the uplink (UL) [1]. The work on the evolution of the 3G mobile system is aimed at enhancing service provisioning and reducing cost. 3GPP concluded a set of targets and requirements for Long Term Evolution in Release 8, on the basis of the LTE feasibility study [11], and the LTE requirements document [12], such as:

- LTE admits higher peak data rates and more users per cell as well as lower control plane latency than previously deployed 3G technologies.
- Radio technology is based on OFDMA and it applies sophisticated scheduling and multi-antenna methods.
- Also, LTE network architecture is simplified.

LTE is specifically designed for packet data communications, where the focus of the technology is high spectral efficiency, high peak data rates, low latency, and frequency flexibility [24].

GSM and UMTS are the predecessors of the LTE and are referred to as second generation (2G) and third generation (3G) technologies, respectively. GSM was developed as a circuit switched network where radio services are configured at the user's request and resources remain allocated until terminated by the network controller. This kind of operation is convenient for supporting voice calls. Later, GSM was enhanced to support low data rate services with packet switching capability but data rates were limited by GSM's air interface, time division multiple access (TDMA). In TDMA, each user is assigned to a

particular channel (frequency band) and time slot which serves to limit capacity as the channel spacing is only 200 kHz.

UMTS uses code division multiple access (CDMA) as its air interface. In CDMA, active users transmit simultaneously over the allocated bandwidth, typically 5 MHz. Signals are separated from each other by the use of orthogonal variable spreading factor (OVSF) spreading codes. The advantage of OVSF codes is that resources can be allocated asymmetrically among the active users. UMTS supports both circuit and packet switched services for voice calls and data sessions respectively. Due to its larger bandwidth and superior spectral efficiency, UMTS can support higher data rates than GSM.

Unlike GSM and UMTS, LTE is a purely packet switched network in which both voice and data services are carried by Internet Protocol (IP). LTE uses OFDMA in which the spectrum is divided into resource blocks that are composed of twelve 15 kHz subcarriers. By dividing the spectrum this way, complicated equalizers are no longer necessary to mitigate frequency selective fading. LTE supports higher order modulation schemes up to 64-QAM along with bandwidth allocations starting from 1.4 MHz up to 20 MHz. In addition, LTE makes use of Multiple Input Multiple Output (MIMO) so that very high theoretical data rates can be achieved (75 Mbps in the uplink and 300 Mbps in the downlink for Release 8) [24].

Second and third generation cellular networks consist of an interface to the public telephone or IP network, a controller (BSC for GSM and RNC for UMTS) that allocates radio resources among the users, a base station (referred to as BTS in GSM and Node B in UMTS) that transmits and receives signals to and from the users, and user devices (MS for GSM and UE for UMTS). The LTE access network is similar with the exception that the BSC/RNC functionality has been shared between the evolved Node B (eNB) and the Mobility Management Entity (MME), which is the core part of the system called Evolved

Packet Core (EPC). The flatter architecture reduces the time required to establish data services resulting in lower latency. The architecture is shown in Figure 2.1 below.

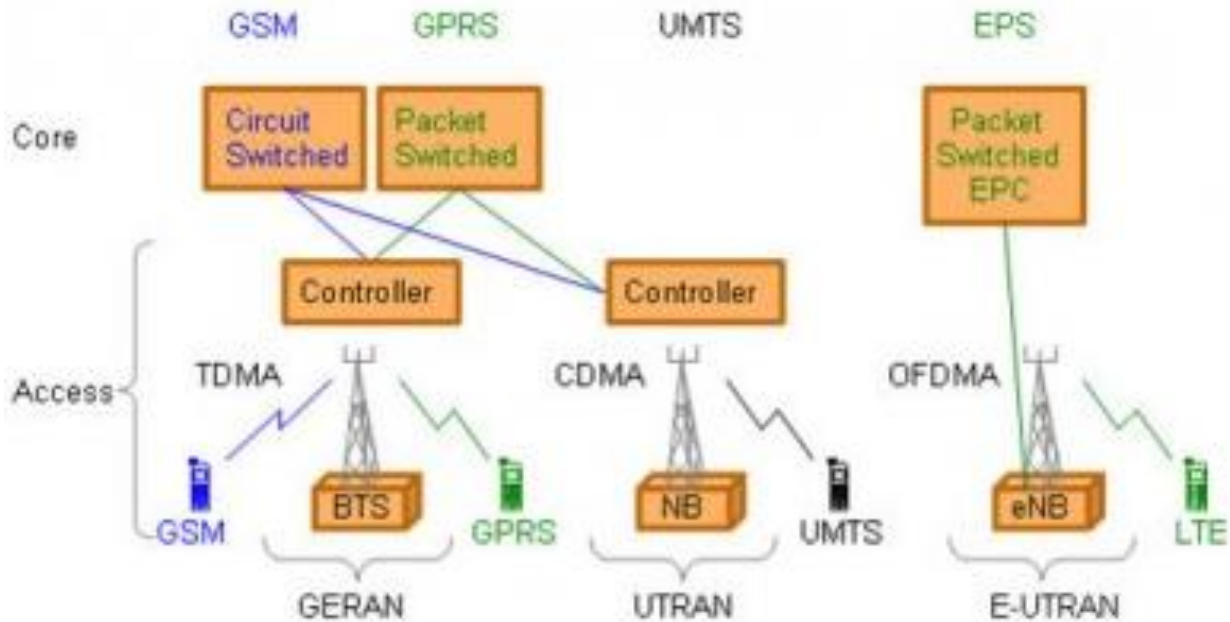


Figure 2.1: Network Architecture Evolution from GSM to LTE [1]

## 2.2. LTE System architecture

System Architecture Evolution, standardized by 3GPP, increases data plane efficiency and minimizes the number of nodes with respect to the second and third generation systems. Intermediate nodes such as the Radio Network Controller (RNC), the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN) are removed and replaced by the SAE Gateway (GW), to minimize inter-node data traffic delays.

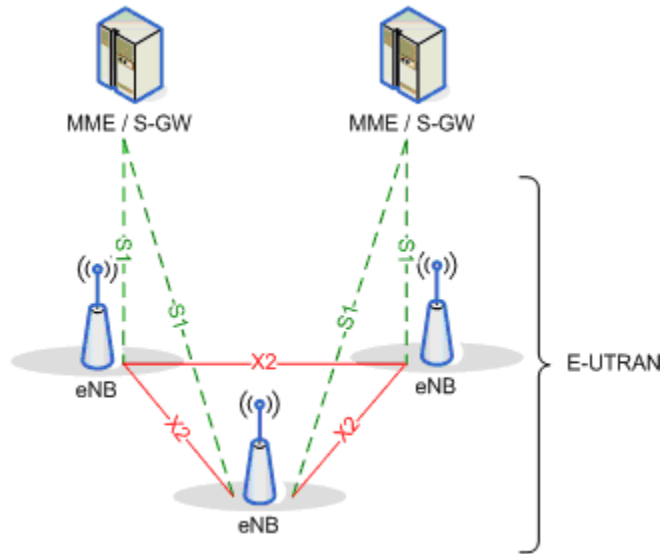


Figure 2.2: LTE RAN Architecture [13]

In SAE, the radio access part known as E-UTRAN, comprises a single type of network element referred to as eNBs and are able to communicate with each other using a new logical inter-eNB interface, called X2 as shown in Figure 2.2. Thus, the eNB has more control functions than a 3G Node B. The S1 interface connects eNBs to mobility management entities and gateways.

Since an LTE network is all-IP, previous transcoding delays are avoided. The eNB incorporates the radio protocol terminations in the user plane shown in Figure 2.3 (PDCP /RLC / MAC / PHY) and the control plane shown in Figure 2.4 (PDCP / RRC / RLC / MAC / PHY) towards the UE. The Non Access Stratum (NAS) is the only radio control protocol layer that is terminated in the MME.

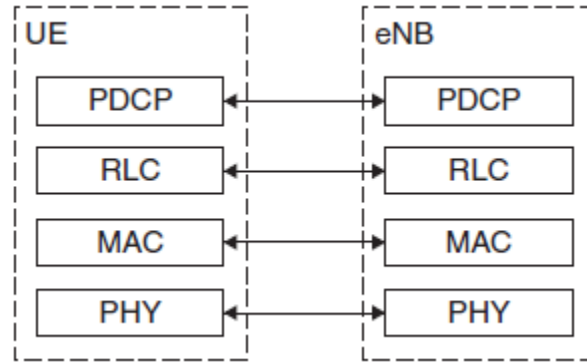


Figure 2.3: User Plane Protocol Stack [14]

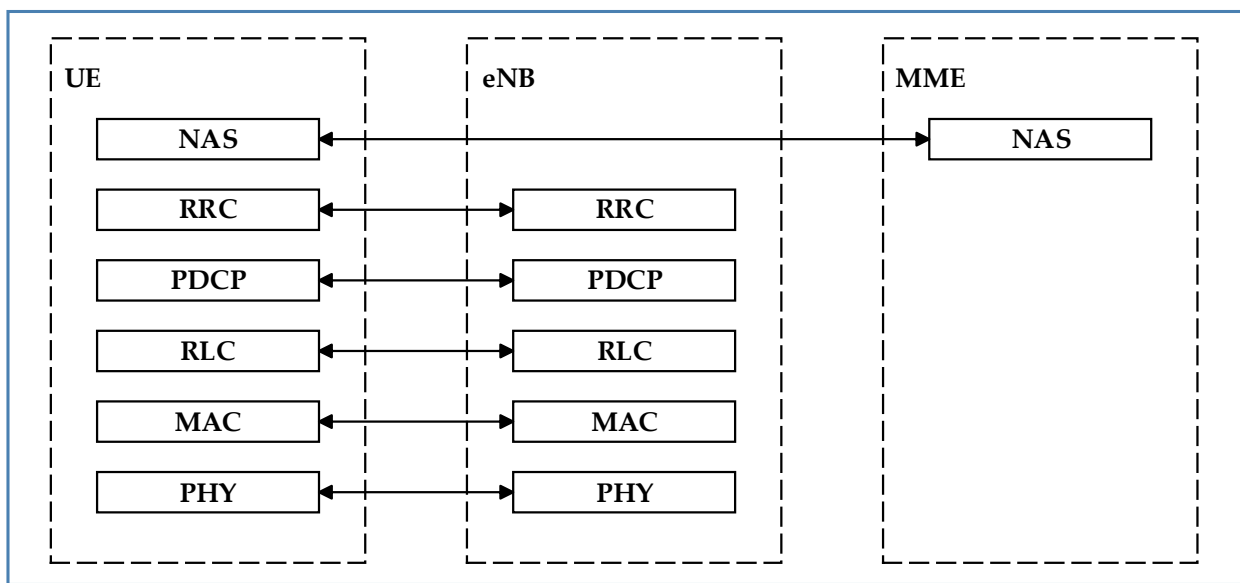


Figure 2.4: Control Plane Protocol Stack [13, 14]

## 2.3. Overview of LTE Air Interface

One of the main difference between LTE and 3G is the use of multiple transmission schemes in the air interface in LTE. LTE is designed to be based on OFDMA in the downlink, while the uplink air interface is based on SC-FDMA. The transmission scheme details are given in [14, 15] and 3GPP specifications.

### 2.3.1. Multiple Access Technology in Downlink: OFDMA

Orthogonal Frequency Division Multiple Access is a variant of Orthogonal Frequency

Division Multiplexing (OFDM) [24]. It performs well in frequency selective fading channels and provides a feasible and affordable solution with its low-complexity in the implementation as well as allows high spectral efficiency by means of compatibility with advanced receiver and antenna technologies. Hence, it is chosen for the DL of E-UTRAN as selected before in wireless technologies, such as WiFi, WiMAX; and wired technologies, for example, ADSL and ADSL2+.

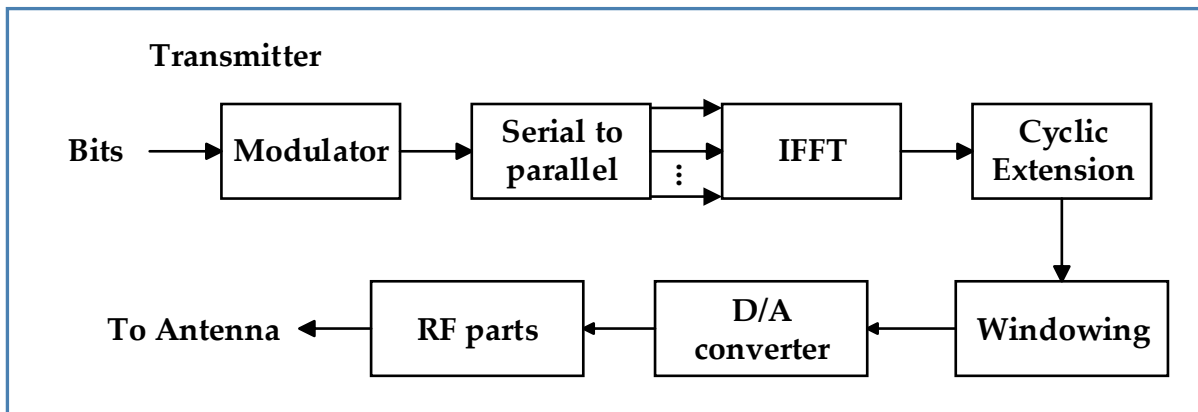


Figure 2.5: OFDMA Transmitter with Windowing [15]

The idea of OFDMA is based on the use of narrow, mutually orthogonal subcarriers. At the transmitter side, a group of subcarriers is allocated to each user depending on its data rate. Each physical resource block (PRB), which consists of twelve subcarriers in LTE, is modulated with a conventional modulation scheme (e.g., QPSK, 16QAM, or 64QAM). An Inverse Fast Fourier Transform (IFFT) block is used to move the modulated signal from frequency domain representation to time domain representation after the serial to parallel conversion. A Cyclic Prefix (CP), that is longer than the channel impulse response is inserted between the symbols by the transmitter to avoid Inter-Symbol Interference (ISI). As the OFDMA transmitter may cause spreading of the spectrum due to imperfections, filtering is carried out for shaping the spectral mask (i.e., windowing).

### 2.3.2. Multiple Access Technology in Uplink: SC-FDMA

SC-FDMA is used as an uplink transmission scheme due to having a low Peak-to-Average Power Ratio (PAPR), efficient frequency-domain equalization at the receiver side and more flexible frequency allocation with respect to OFDM [14, 15, 23].

In SC-FDMA, data symbols in the time domain are moved into the frequency domain by using Discrete Fourier Transform (DFT). After the mapping of resources in the frequency domain, the data symbols are converted to time domain symbols by using IFFT. Similar to OFDMA system, the CP is inserted periodically but after a block of symbols as the symbol rate is faster in SC-FDMA such that ISI between blocks is avoided and the receiver complexity is reduced.

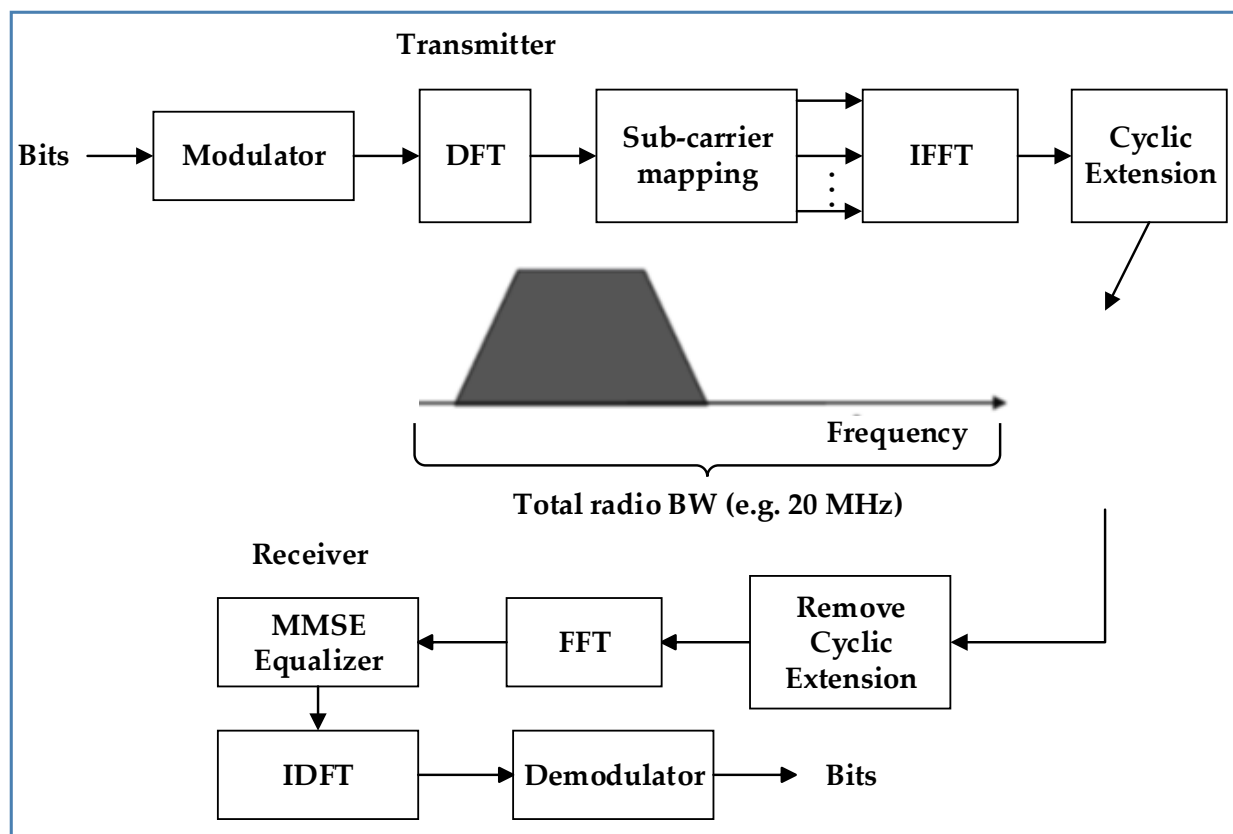


Figure 2.6: SC-FDMA transmitter and receiver [15]

At the receiver side, the cyclic extension is removed and FFT is applied respectively as shown in Figure 2.6. Since the CP is not added after every symbol, ISI may occur between

the symbols of the same block. Hence, the receiver runs the equalizer for each block of symbols.

### **2.3.3. Multiple Antenna Techniques**

In modern wireless communication systems, multi-element antenna arrays have been adopted for reliable communications and higher data rates compared to Single Input Single Output (SISO) systems. The major drawback in the deployment of the Multiple Input Multiple Output (MIMO) systems is the increased hardware complexity and the cost due to expensive RF chains such as low noise amplifiers, analog to digital converters. On the other hand, the increasing demand for higher data rates and the reducing capital expenditures (CAPEX) make MIMO technology more favorable from the operator's point of view. Therefore, the first release of LTE standards covers up to 4 antennas whereas LTE-A supports up to 8 antennas. Figure 2.7 shows the basic modes in multiple antenna systems.

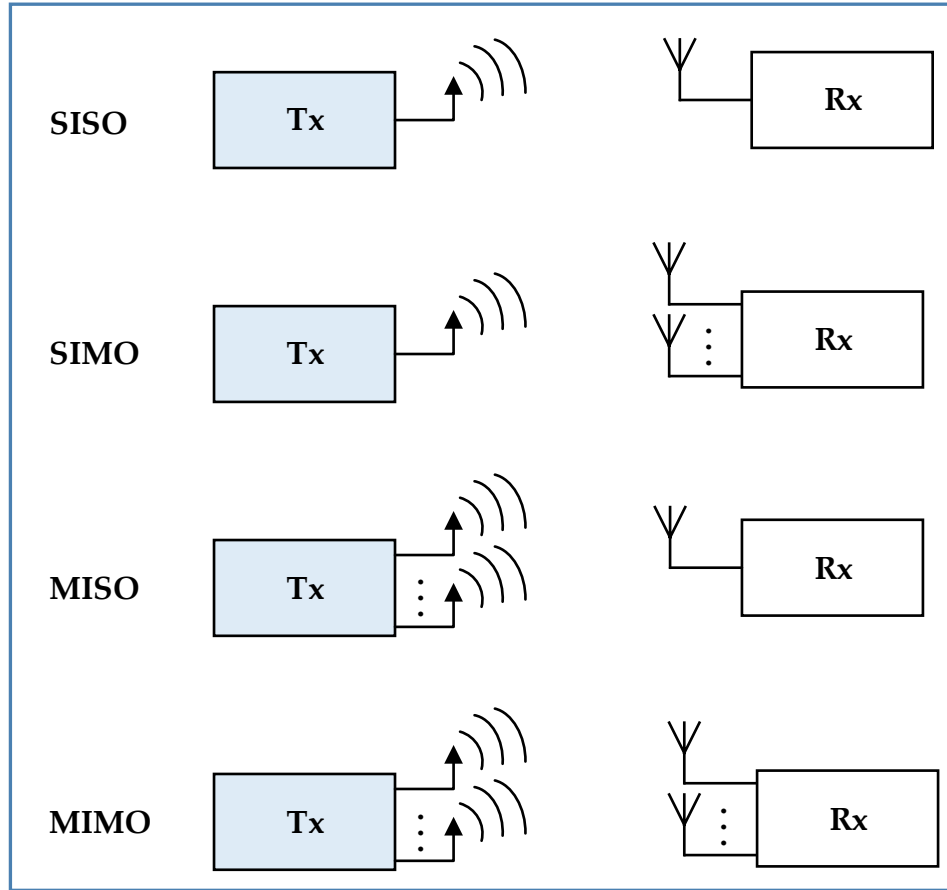


Figure 2.7: Basic modes in multiple antenna systems

MIMO technology employs various techniques: Spatial Multiplexing (SM) so that multiple data streams are transmitted and received, for instance, Single User (SU) – MIMO and Multi User (MU) – MIMO schemes; and transmit diversity in which a single data stream is multiplexed by space time/frequency codes. MIMO SM is a more effective way to increase the user throughput in higher Signal Noise Ratio (SNR) conditions, while MIMO Space Frequency Coding (SFC) performs better in lower SNR conditions [16]. Hence, MIMO mode switching is applied to maximize throughput in LTE DL.

## 2.4. Radio Resource Management in LTE

The Radio Resource Management (RRM) in LTE covers the management and optimization of the radio resource utilization and the network quality. Some of the

important features in RRM, for which requirements are given in [17], are briefly discussed in this section to introduce LTE RRM basics.

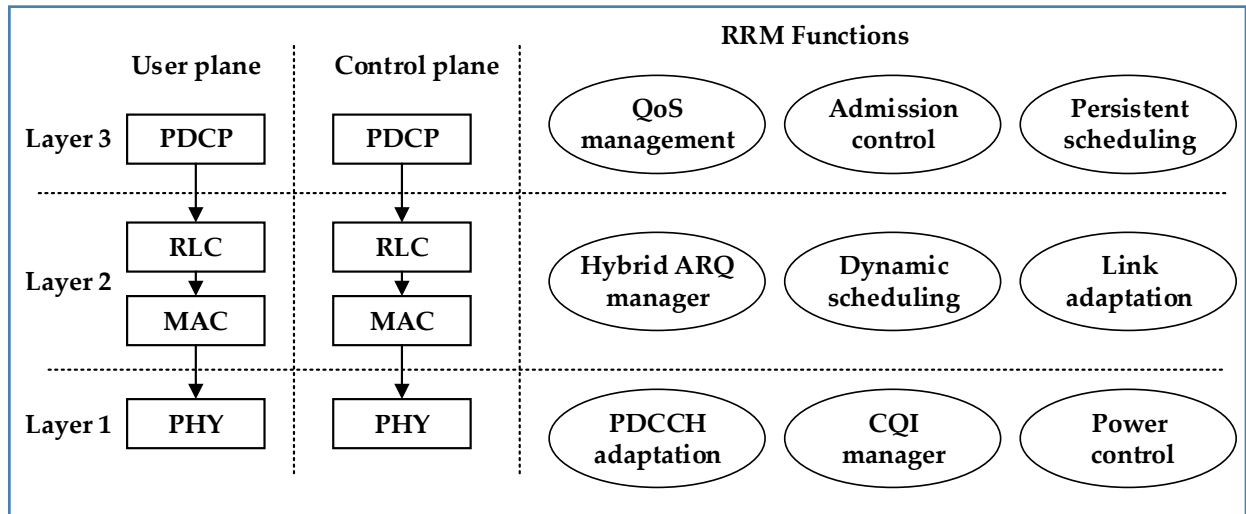


Figure 2.8: Mapping of the primary RRM functionalities [15]

### 2.4.1. Dynamic Scheduling

As can be seen in Figure 2.11, dynamic scheduling is one of the RRM functions of layer 2 and is responsible for the assignment of available uplink and downlink resources in time and frequency domains every Transmission Time Interval (TTI) by allocating PRBs.

The dynamic scheduler takes the advantage of slow and fast fading such that users under better channel conditions are prioritized in scheduling (i.e., channel aware scheduling). Larger bandwidths provide higher benefits in the frequency domain scheduling because effective coherence bandwidth is less than the system bandwidth [15].

In LTE, each cell has its own scheduler and the UE follows the scheduling commands from its serving cell. Scheduling decisions in the uplink and the downlink can be made independently because the downlink scheduling and the uplink scheduling are separated.

### 2.4.2. Link adaptation

Link adaptation is a basic function of the air interface for efficient data transfer. In the link adaptation of LTE, data rate is dynamically adjusted for each user by changing the type of Modulation and Coding Scheme (MCS) based on channel conditions such that system capacity and coverage performance is improved [23].

In the downlink, the eNB decides whether a higher or lower level MCS will be used according to the Channel Quality Indicator (CQI). The CQI is an indication of the data rate, which can be supported by the downlink channel, with respect to SINR and the characteristics of receiver.

Outer loop link adaptation is used to compensate for the CQI measurement errors. It adds a CQI offset to the CQI reports of each UE. Corrected CQI reports are used by the link adaptation for further processing. The CQI offset is controlled by the acknowledgement (ACK) and negative acknowledgement (NACK) responses, provided by the DL Hybrid Automatic Repeat Request (HARQ) mechanism, for the initial transmission of each transport block.

In the uplink, the eNB can directly estimate uplink data rates by channel sounding i.e., using Sounding Reference Signals (SRS) and also controls which modulation and coding schemes can be used in the UL.

The following modulation and coding schemes are defined in [18]: QPSK, 16QAM and 64QAM in both uplink and downlink directions. However, 64QAM is not mandatory in the UL except for the UEs with the highest category. The number of applicable modulation and coding schemes also depends on the type of channel used as shown in Table 2.1.

Table 2.1: Allowed modulation and coding schemes per physical channel

Physical channel	MCS
PDSCH, PMCH	QPSK, 16QAM, 64QAM
PBCH	QPSK
PDCCH (PCFICH, PHICH)	QPSK
PUSCH	QPSK, 16QAM, 64QAM
PUCCH	BPSK and/or QPSK

Since LTE aims to achieve high peak data rates, it is necessary to use multiple antennas at both terminal and eNB as a basic part of the specifications. However, performances of MIMO modes differ from each other under different SINR conditions, hence MIMO adaptation that can be applied only in the DL switches between transmit diversity and spatial multiplexing modes as well as single TX mode.

### 2.4.3. Power Control and Inter Cell Interference Coordination

In the downlink, the power level can be controlled based on performance indicators, for instance, the indicator of Relative Narrowband Transmit Power (RNTP) per PRB which is signaled to neighboring eNBs through the X2 interface, while in the uplink, terminals use combined open-loop and closed loop power control [18]. In addition, a standardized Inter-Cell Interference Coordination (ICIC) mechanism can alleviate the inter-cell interference in the UL by modifying power settings based on the interference indicators exchanged over the X2, i.e., High Interference Indicator (HII) and Overload Indicator (OI).

### 2.4.4. Admission Control

Admission control (AC) is one of the RRM functions in layer 3 as shown in Figure 2. 11. AC is responsible for cell level admission or rejection of the requests for establishment of Radio Bearers (RBs), that include, a paging event, handover (HO) request, or a call establishment request. It decides on each request based on the current cell load and the expected effect of a new bearer on existing connections.

### **2.4.5. Connection Mobility Control**

Connection Mobility Control (CMC) deals with the management of radio resources in relation to idle and connected mode mobility [13]. In LTE, cell reselection and handover algorithms are controlled by a setting of parameters (e.g., thresholds and hysteresis values) which determines when the UE should select a new cell or initiate a handover. In active mobility, the handover decision is taken based on the measurements performed by the UE and eNB. A target cell is selected by the E-UTRAN not by the UE and the core network is only involved when the handover is successful. Packets are forwarded from the source cell to target cell in order to provide lossless handover. Moreover, key performance indicators (e.g., neighboring cell load), and policies defined by operator can be taken into account in the eNB for selecting the target cell.

# Chapter 3: Modeling of Base Station Antenna Parameters

## 3.1. Introduction

Base station technology finds itself in a continuous evolution process [22]. Figure 3.1 shows the key technological milestones. It depicts that at the start of the evolution process, there has been a clear tendency towards the integration of electronic components into antennas. The first active components near to an antenna were “tower-mounted amplifiers” (TMAs) which amplified the receiving signals of the antenna and bypassed the transmitting signals by means of low-loss filter structures. The acceptance of such electronics near to the antennas is driven by higher reliability figures for the electronic components. The same acceptance problem has prevented for a long time the use of remote radios near to antennas, comprising the receiving as well as the transmitting parts. However, today’s reliability is high enough, and the advantage of power saving has forced the breakthrough of the use of Remote Radio Heads (RRHs) beside the use of TMAs in the fields.

The deployed Addis Ababa LTE network employs the RRH using optical cable referred to as the Common Public Radio Interface (CPRI) to connect the Baseband Unit (BBU) to the Radio Remote Unit (RRU) which is mounted near to the antenna.

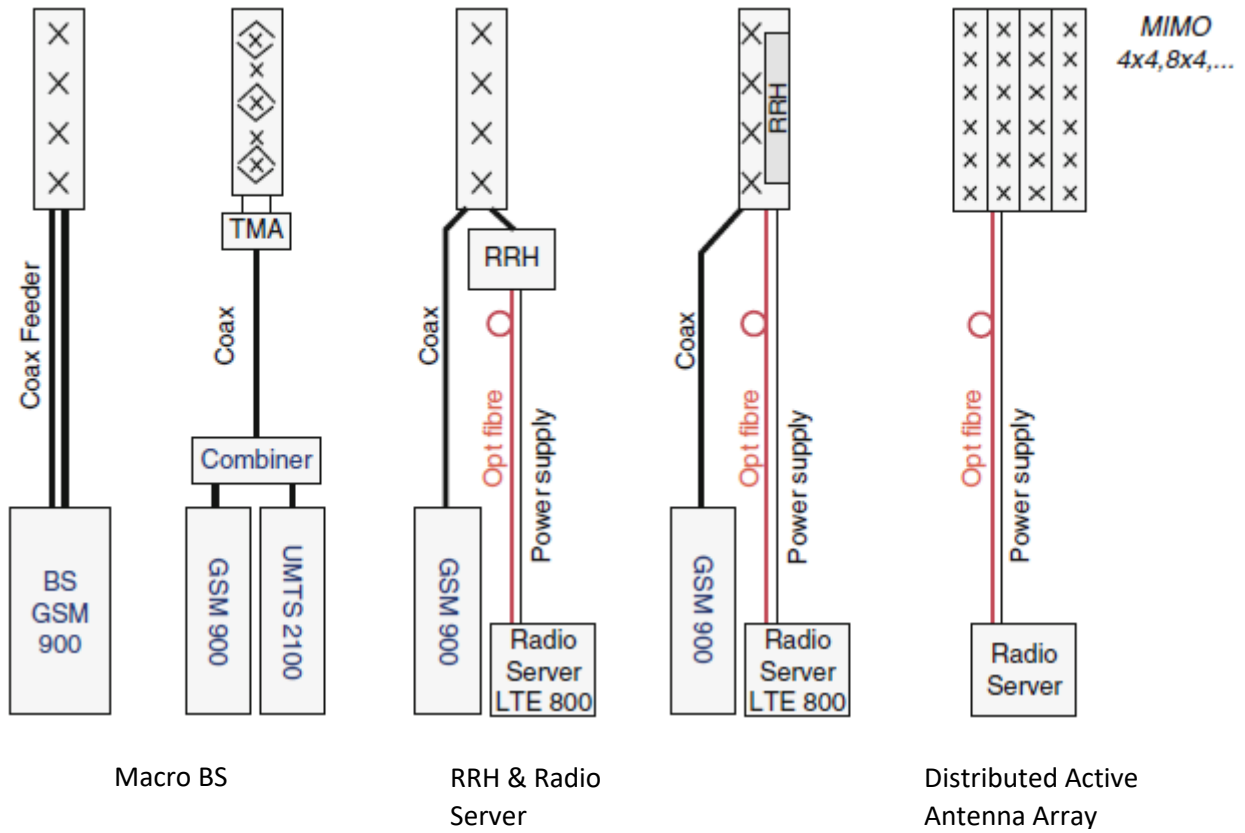
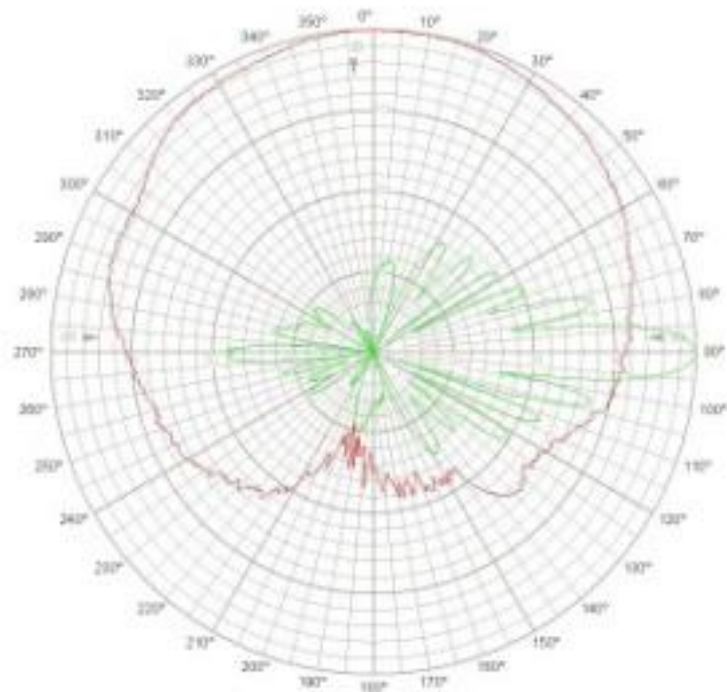


Figure 3.1: Technology evolution of base station antenna systems [22]

Dipole and monopole antennas are the most widely used ones for wireless mobile communication systems [20, and 21 and 22]. An array of dipole elements is widely used at the base station of a cellular radio network because of the array's broadband characteristics and simple construction.



(a)



(b)

Figure 3.2: Base station antenna (a) and radiation pattern (b)

Base station antennas with parameters such as electrical tilt and azimuth will become an integral part of LTE base station platforms for providing better system performance and radio network capacity. Figure 3.2 shows the base station antenna(a) and radiation pattern(b).

In this thesis work, real antenna files of the existing antenna solutions are used to prepare the antenna pattern for each electrical tilt using the AMan software package of the WinProp simulation tool.

## 3.2. Antenna parameters

Although there are various antenna types and geometries, all antennas can be described by a small set of main parameters. In this section, those fundamental parameters based on [20, 21] are briefly described.

- **Far-field:** It is the region away from an antenna where the radiated wave takes the form of a plane wave. The criterion, which is commonly used, is  $2D^2/\lambda$  where  $D$  is the maximum linear transmission of the antenna, and  $\lambda$  is the operating wavelength.
- **Directivity:** The ratio of the radiation intensity  $U$  in a given direction from the antenna to the radiation intensity averaged over all directions. The directivity depends on the shape of the radiation pattern. The average radiation intensity is equal to the total power radiated  $P_{\text{rad}}$  by the antenna divided by  $4\pi$ .

$$D = \frac{4\pi U}{P_{\text{rad}}} \quad (1)$$

- **Efficiency:** Power in the antenna may be dissipated due to conductor loss or dielectric loss. Hence, antenna efficiency  $\eta$  can be defined as the ratio of total power radiated  $P_{\text{rad}}$  by the antenna to the input power  $P_{\text{in}}$  of the antenna.

$$\eta = \frac{P_{\text{rad}}}{P_{\text{in}}} \quad (2)$$

- **Gain:** Antenna gain is the product of efficiency and directivity, but the loss due to conductor or dielectric loss reduces the power density radiated in a given direction.

$$D = \frac{4\pi U}{P_{\text{in}}} \quad (3)$$

The efficiency and gain characteristics of the antenna are strongly influenced by the frequency of operation [21].

- **Half-Power (3dB) Beamwidth:** This term defines the aperture of the antenna. The HPBW is defined by the points in the horizontal and vertical diagram, which show where the radiated power has reached a -3 dB level with respect to the main radiation direction. These points are also called 3 dB points.

- **Input Impedance:** It is defined as the impedance presented by an antenna at its terminals or the ratio of the voltage to the current at a pair of terminals or the ratio of the appropriate components of the electric to magnetic field at a point.
- **Bandwidth:** Bandwidth is defined as the range of frequencies within which the performance of the antenna conforms to a specified standard.
- **Polarization:** Polarization of an antenna refers to the polarization of the electric field vector of the radiated wave. Linear (vertical or horizontal), and circular, i.e., Right Hand Circular Polarization (RHCP) and Left Hand Circular Polarization (LHCP), are the most typical antenna polarizations. Antennas can also be designed to operate with two polarizations, e.g., X polarization widely used in base station antennas.
- **Antenna azimuth:** It is defined as the direction, in degrees referenced to true north, that an antenna must be pointed [9, 10]. The angular distance is measured in a clockwise direction.
- **Antenna tilt:** It is defined as the angle of the main beam of the antenna below the horizontal plane. Positive and negative angles are also referred to as downtilt and uptilt respectively [23, 26]. Antenna downtilt can be adjusted mechanically and/or electrically as shown in Figures 3.3 and 3.4 respectively.

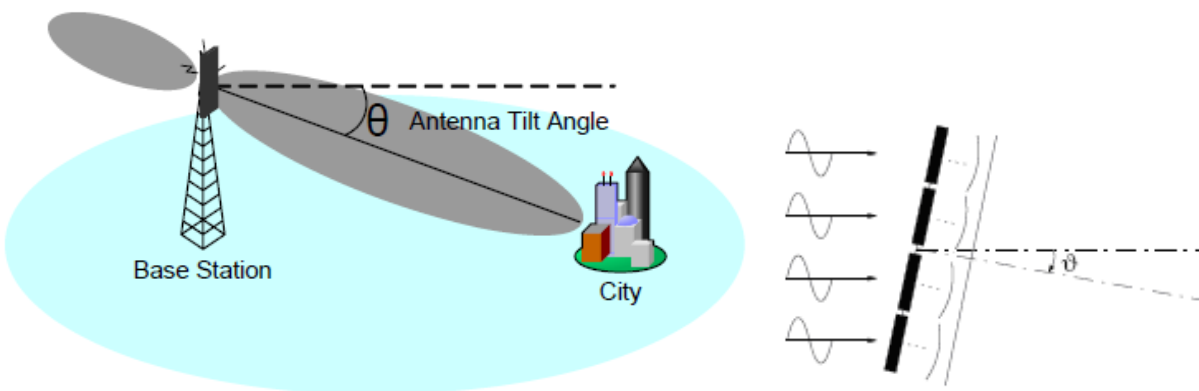


Figure 3.3: Mechanical tilt [23]

There are different existing techniques for electrical tilt such as RET, variable electrical-tilt (VET) and fixed electrical tilt. Usage of RET antennas removes the need for tower

climb and base station site visits by controlling electrical tilt angle by Network Management System (NMS) so that operational cost is saved. In addition, mechanical downtilt is also needed because the electrical tilt range is narrower than the mechanical tilt range.

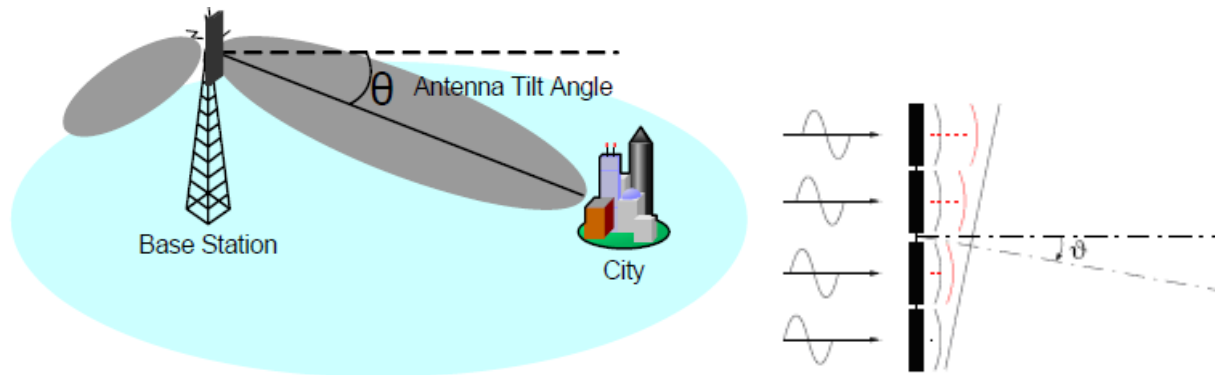


Figure 3.4: Electrical tilt [23]

### 3.3. Modeling of antenna parameters

#### 3.3.1. Antenna radiation pattern

In 3GPP LTE simulations, two formulas are applied for computing horizontal and vertical radiation patterns

$$A_h(\phi) = -\min\left[12\left(\frac{\phi}{\phi_{3dB}}\right)^2, A_m\right] \quad (4)$$

$$A_v(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, SLA_v\right] \quad (5)$$

where  $A_m$  is the front to back attenuation, and  $SLA_v$  is the side lobe attenuation.

It needs to be considered that antenna characteristics, e.g., the patterns which are shown in Figures 3.5 and 3.6 [9], are typically measured in an anechoic chamber, whereas in real world deployment there are the significant impacts of scattering in the near field of the antenna (e.g., mast, mountings, other objects in the vicinity, such as roof-top, etc.) and diffraction. These near-field scatterers and diffractions are not accounted for by the propagation models; therefore, they need to be conceptually included in an effective antenna pattern. A basic property of such an effective antenna pattern would be the

attenuation of nulls, reduction in the front-to-back attenuation ( $A_m$ ) and the side lobe attenuation ( $SLA_v$ ) as shown in Figures 3.5 and 3.6 respectively. It is also visible that the design of the narrow vertical beam in a practical antenna leads to more severe and strong side lobes than we encountered in case of a wider horizontal pattern. In the figures, real (blue color) is to mean the simulated one.

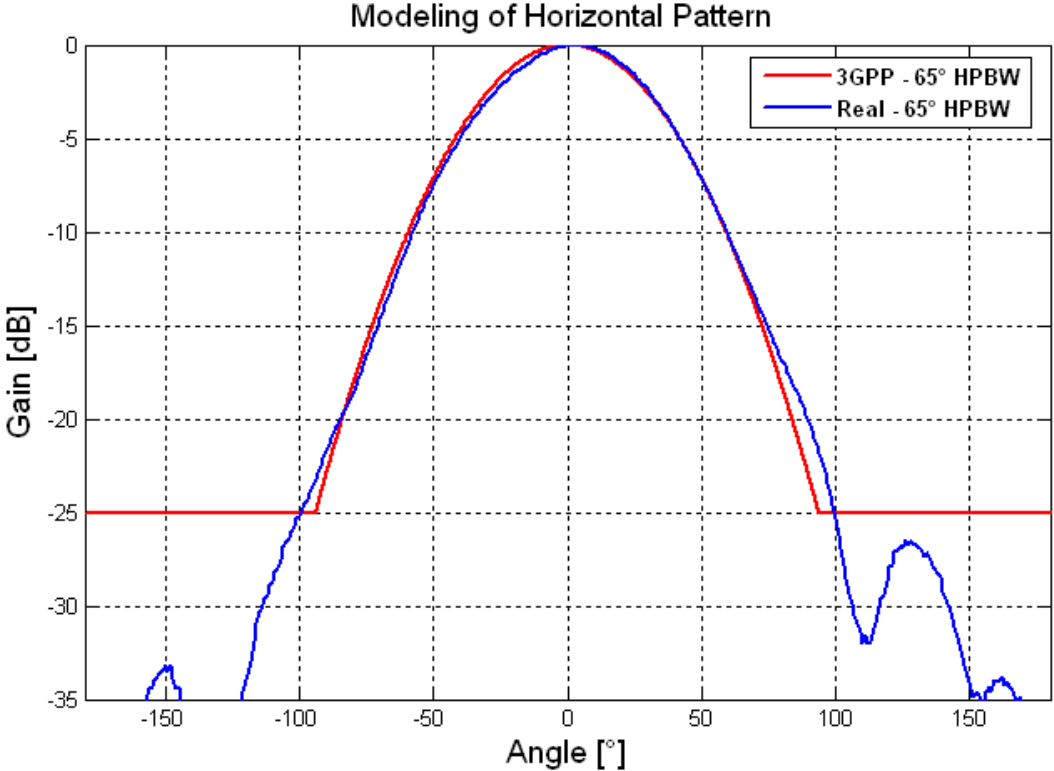


Figure 3.5: Modelling of horizontal pattern

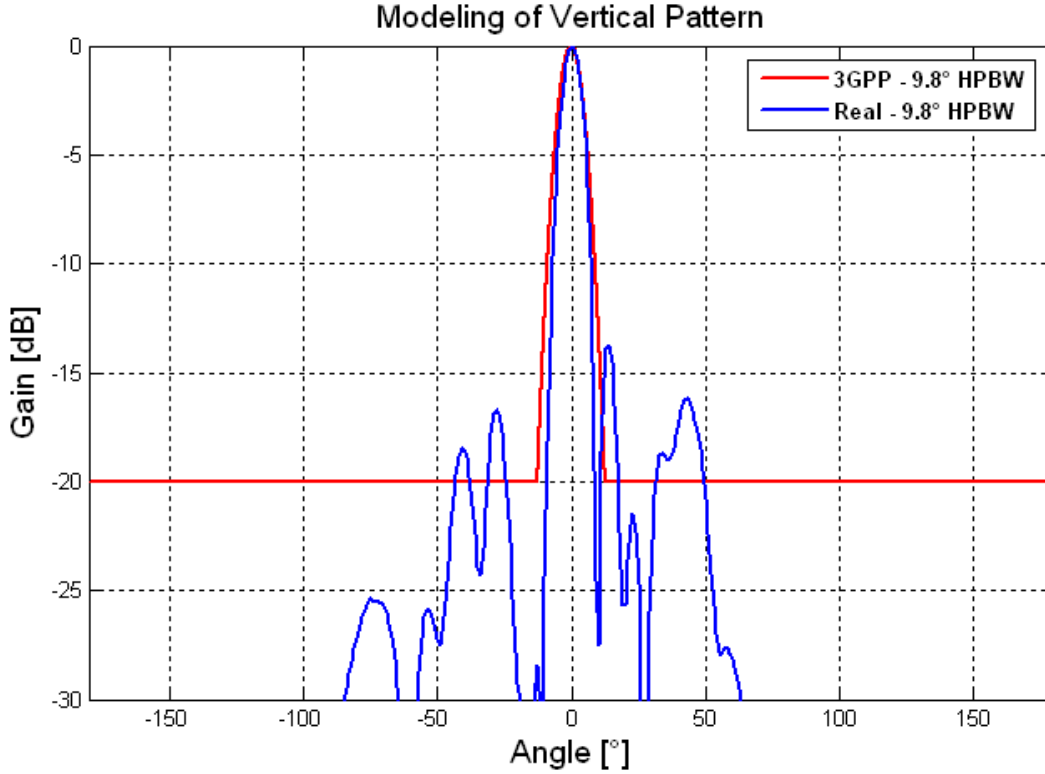


Figure 3.6: Modeling of vertical pattern

To extract the 3D loss pattern from the two previous equations, the following formula was utilized.

$$A(\theta, \phi) = -\min\{-[A_H(\phi) + A_v(\theta)], A_m\} \quad (6)$$

However, in this study, taking an antenna file, the antenna radiation pattern was prepared by drawing the horizontal and vertical pattern and then taking the 3D pattern by extrapolating the two patterns on the AMan software module of the WinProp simulator.

### 3.3.2. Modeling of Electrical and mechanical tilt

Referring to Figure 3.7, the angle  $w(i, k)$  between the line of sight from eNB antenna to the UE antenna and the horizontal plane, in radians, is given by the following formula

$$w(i, k) = \arctan\left(\frac{h(i,k)}{d(i,k)}\right) \quad (7)$$

where  $d(i, k)$  is the distance between the user  $k$  and cell  $i$  and  $h(i, k)$  is the height difference between the antenna of user  $k$  and the antenna of eNB $i$ . The angle  $\theta(i, k)$  between the line of sight and the center of the main lobe, in the vertical plane, is given as the following

$$\theta(i, k) = w(i, k) - \theta(i) \quad (8)$$

where  $\theta(i)$  is the electrical downtilt angle of eNB $i$  in radians.

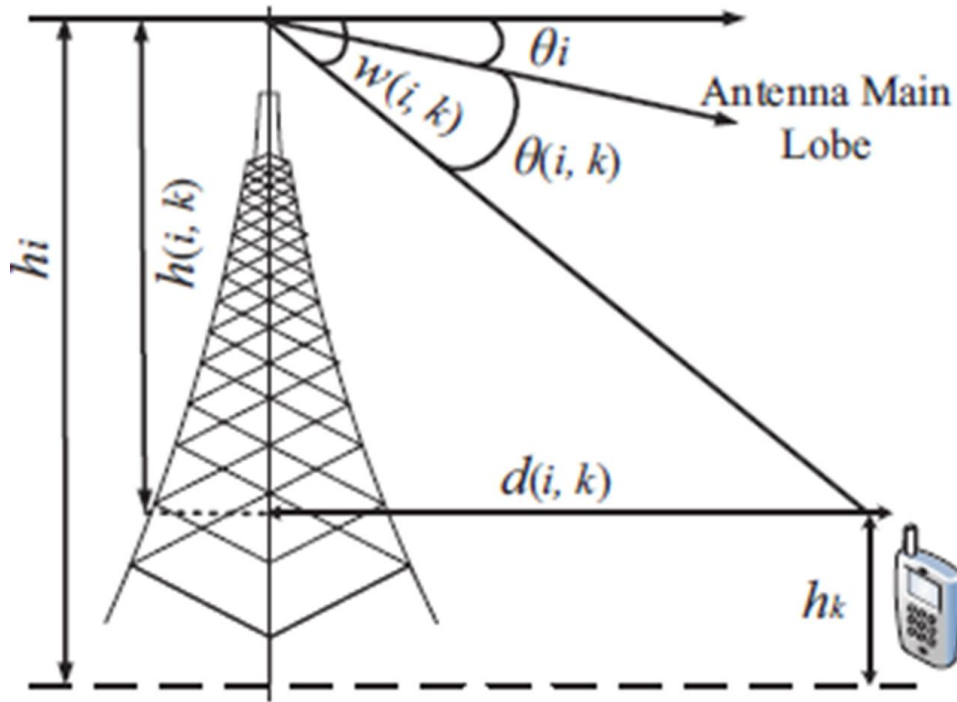


Figure 3.7: Layout of eNB antenna parameters in the vertical plane

### 3.3.3. Modeling of azimuth steering

Referring to Figure 3.8, the angle  $\psi(i, k)$  between the line of sight and the true north is dependent on the location of the user in the x-y coordinates and it is modeled in the horizontal plane as the following.

$$\psi(i, k) = \arctan\left(\frac{\Delta y(i, k)}{\Delta x(i, k)}\right) \quad (9)$$

The angle  $\varphi(i, k)$  between the line of sight and the center of the main lobe, in the horizontal plane, can be deduced as the following.

$$\phi(i, k) = \psi(i, k) + \phi(i) \quad (10)$$

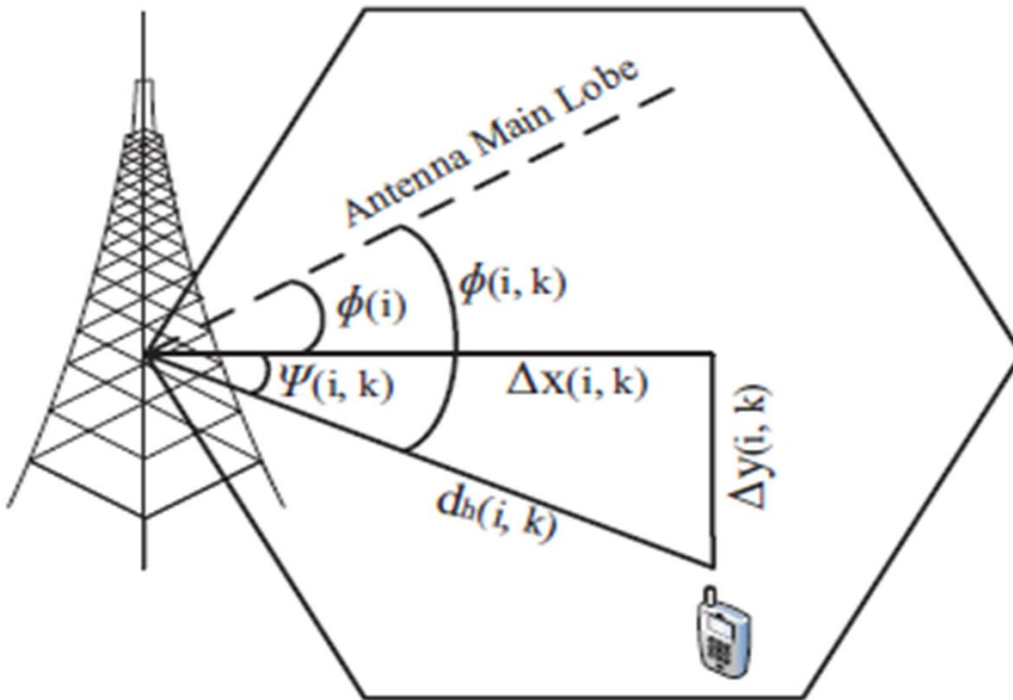


Figure 3.8: Layout of eNB antenna parameters in the vertical plane

# Chapter 4. LTE Network Simulation Modeling and Assumptions

## 4.1. Overview of Addis Ababa LTE Network

There are 331 eNBs deployed in selected hotspot areas of Addis Ababa. The network capacity is planned to serve for 400,000 subscribers. The site configuration is single carrier (L111).

### 4.1.1. Frequency usage

The LTE network is assigned to the frequency range between 1851.5-1871.5 MHz. The frequency band is shared with the GSM1800. The band usage is depicted in the table below.

Table 4.1: Addis Ababa LTE Network Frequency Usage

Technology	Downlink (MHz)	Uplink (MHz)
GSM1800	1842.5-1851.5	1747.5-1756.5
LTE	1851.5-1871.5	1756.5-1776.5
GSM1800	1871.5-1880	1776.5-1785

### 4.1.2. Antenna solutions

Two types of antenna solutions exist in Addis Ababa LTE network.

1. **Green field solution:** this solution is when the antennas are mounted on towers. In such type of scenario, the antennas operate on dual mode, i.e., there are two 1710-2200 MHz. one of them is 1800 MHz band which is used for both GSM1800 and LTE re-farmed. The other one is for 2100 MHz band on which UMTS is operating.

The two antenna ports with the specified range of frequencies along with the physical snapshot of the deployment is shown in Figure 4.1.

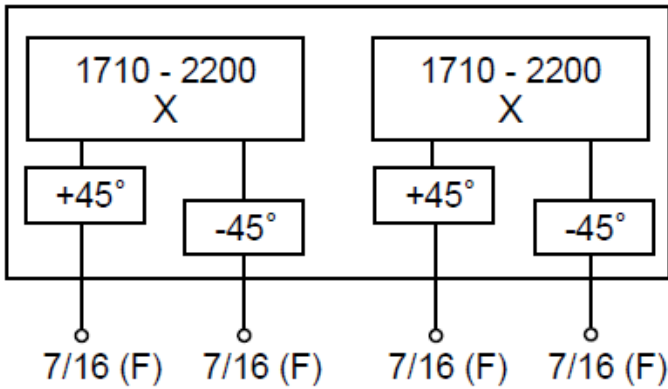


Figure 4.1: Green field dual band antenna

2. **Rooftop solution:** here the antennas are installed on top of buildings. In this kind of solution, each sector uses a single antenna. GSM900 operates on 790-960 MHz range. There are also two 1710-2180 MHz range frequencies on which GSM1800 and LTE share the 1800 MHz band and UMTS operates on the other 2100 MHz band.

Figure 4.2 shows the triband antenna ports and a picture of one of this type of antenna mounted on top of a building.

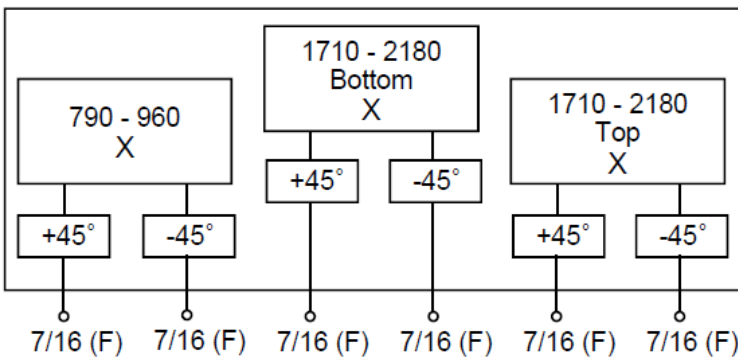


Figure 4.2: Rooftop triband antenna

### 4.1.3. Ethio telecom antenna optimization practices

Ethio telecom has GSM900, GSM1800, UMTS2100, and LTE1800 technologies deployed in Addis Ababa. Since the LTE1800 is working in the GSM1800 spectrum they use the shared antenna, antenna parameter optimization is difficult as it may affect the other

technology for any antenna adjustment. As per the experts working on the optimization teams, the antenna optimization is performed by priority of received service complaints.

## 4.2. Optimization Approach

The optimization is done in such a way that the network is simulated using existing system configuration including the antenna parameters of the LTE radio access network. Then, the antenna parameters, specifically the electrical down tilt and the azimuth angle are iteratively changed and simulated so that best network performance in terms of SINR and throughput is obtained. The general optimization approach is shown in Figure 4.3.

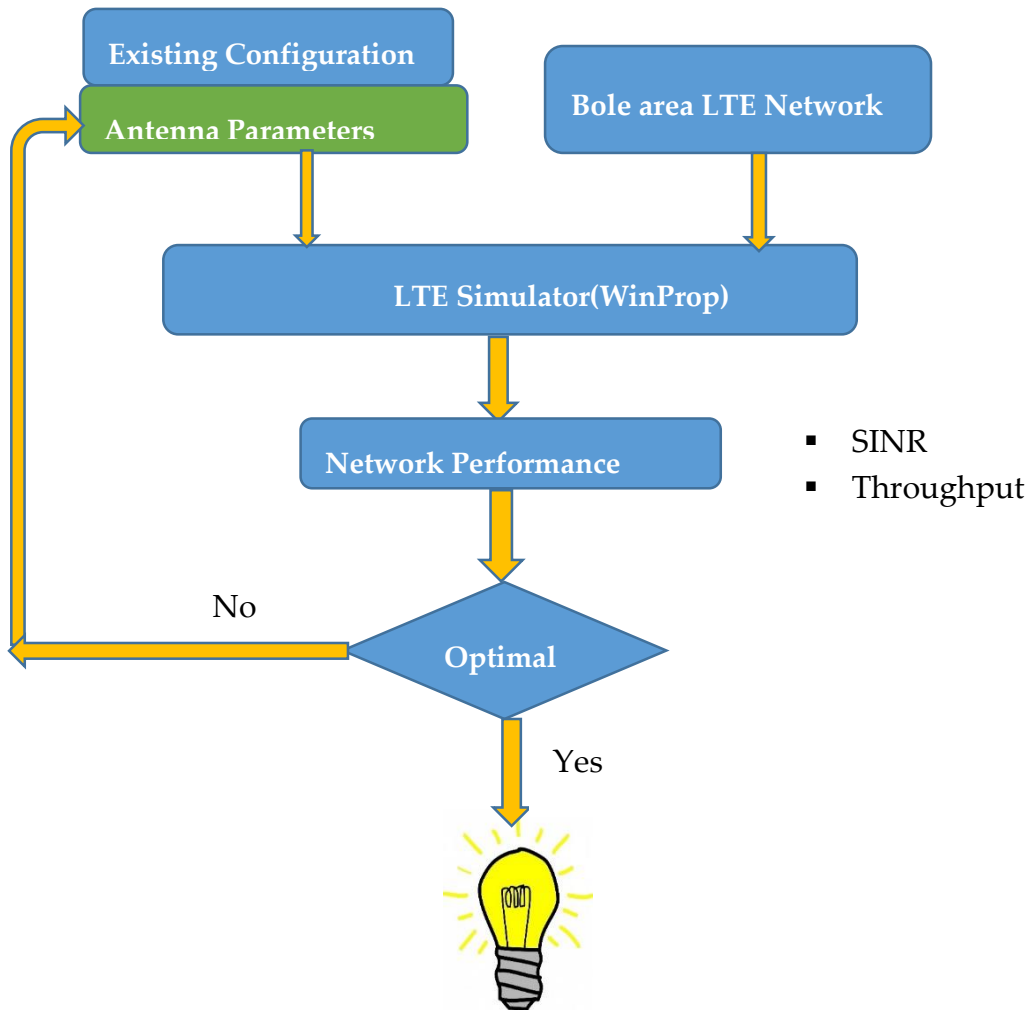


Figure 4.3: Optimization approach

### 4.3. Network Simulation Assumption

As mentioned in section 4.1, there are 331 eNBs serving Addis Ababa LTE coverage area. For reasonable view of the network, 34 eNBs (102 cells) geographically located around Bole area are considered for this study. The site layout is shown in Figure 4.4.

The simulation tool used for this study is the WinProp simulation tool. This tool is commercial and has been used in different research activities by senior researchers and academicians [31, 32]. The details about the tool is found in [33, 34]. It has various modules such as the AMan (Antenna Manager) tool used for developing the antenna pattern of a practical antenna. In this study the antenna pattern is developed using AMan software module for each tilt of the antenna in both the horizontal and vertical planes and then convert them to a 3D pattern by extrapolating the pattern in both planes.

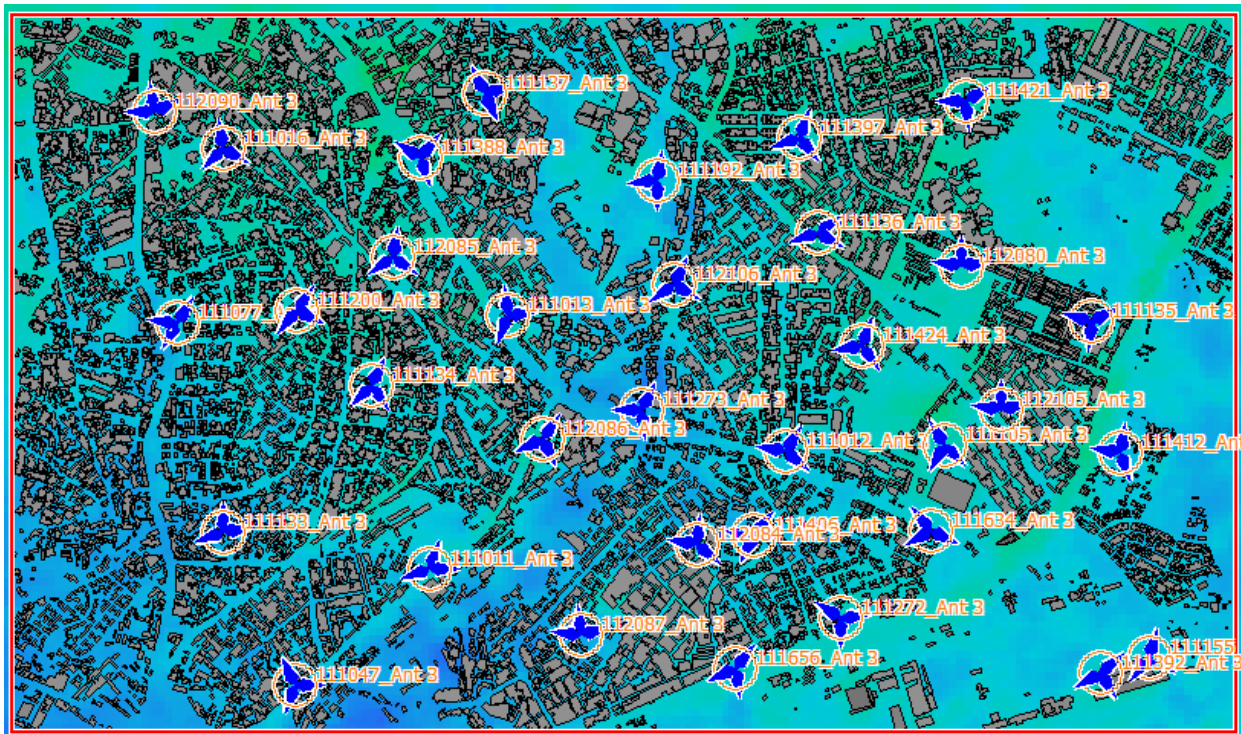


Figure 4.4: Selected 34 eNBs layout around Bole area

The propagation model adopted for the network simulation is the dominant path loss model. This model is used for modeling the propagation because it can be applied for urban scenario while majorly it concentrates only on the dominant paths and does not calculate the paths with small energy contributions. Hence, it doesn't consider all the details of the database, requiring less time to pre-process it. The accuracy of the model in very complex environments (with high shadowing of the direct ray) is higher than other models like ray tracing.

Basic simulation parameters are shown in Table 4.2 below.

Table 4.2: Basic simulation parameters/assumptions

<b>Parameters</b>	<b>Values</b>
Number of eNBs	34(102 cells)
Air interface	LTE FDD
Carrier frequency/bandwidth	1800/20 MHz
Simulation	System level simulator (WinProp)
Transmitter power	43 dBm
Antenna vendor	Huawei
UE distribution	uniform

The configuration of some of the important parameters of the network in the study is shown in Table 4.2. The focus of the study is on antenna electrical down tilt and azimuth angle parameters depicted in the second and third column of Table 4.3.

Table 4.3: Partial site parameter configuration

Antennapattern	Azimuth	Downtilt	Frequency	Gain	Height	Latitude	Longitude	Name	Number	Power	ower Mod	Power Uni	Carrier
D:\Antenna pattern\1880_3D_03T_left.apb	20	1	1880	17.4	17	993457.9	474692.9	111011_Ar	1	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_06T_left.apb	90	0	1880	17.4	17	993457.9	474692.9	111011_Ar	2	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_04T_left.apb	250	6	1880	17.4	17	993457.9	474692.9	111011_Ar	3	43	PA Power	dBm	50
D:\Antenna pattern\1850_3D_05T_top.apb	30	4	1850	17.1	27	993949.6	476174.1	111012_Ar	4	43	PA Power	dBm	50
D:\Antenna pattern\1850_3D_03T_top.apb	130	4	1850	17.1	27	993949.6	476174.1	111012_Ar	5	43	PA Power	dBm	50
D:\Antenna pattern\1850_3D_04T_top.apb	280	4	1850	17.1	27	993949.6	476174.1	111012_Ar	6	43	PA Power	dBm	50
D:\Antenna pattern\1850_3D_05T_top.apb	355	4	1850	17.1	38.5	994516.3	475017.9	111013_Ar	7	43	PA Power	dBm	50
D:\Antenna pattern\1850_3D_01T_top.apb	85	10	1850	17.1	38.5	994516.3	475017.9	111013_Ar	8	43	PA Power	dBm	50
D:\Antenna pattern\1850_3D_01T_top.apb	200	10	1850	17.1	38.5	994516.3	475017.9	111013_Ar	9	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_04T_left.apb	350	0	1880	17.4	24	995216.9	473830.9	111016_Ar	10	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_04T_left.apb	120	1	1880	17.4	24	995216.9	473830.9	111016_Ar	11	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_05T_left.apb	225	8	1880	17.4	24	995216.9	473830.9	111016_Ar	12	43	PA Power	dBm	50
D:\Antenna pattern\1850_3D_02T_top.apb	90	8	1850	17.1	22	992973.3	474130.5	111047_Ar	13	43	PA Power	dBm	50
D:\Antenna pattern\1850_3D_04T_top.apb	200	6	1850	17.1	22	992973.3	474130.5	111047_Ar	14	43	PA Power	dBm	50
D:\Antenna pattern\1850_3D_03T_top.apb	335	6	1850	17.1	22	992973.3	474130.5	111047_Ar	15	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_01T_left.apb	30	2	1880	17.4	36	994484.9	473636.8	111077_Ar	16	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_07T_left.apb	210	3	1880	17.4	36	994484.9	473636.8	111077_Ar	17	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_00T_left.apb	275	4	1880	17.4	36	994484.9	473636.8	111077_Ar	18	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_08T_left.apb	330	2	1880	17.4	33	993974	476838.5	111105_Ar	19	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_05T_left.apb	135	5	1880	17.4	33	993974	476838.5	111105_Ar	20	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_05T_left.apb	210	2	1880	17.4	33	993974	476838.5	111105_Ar	21	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_01T_left.apb	0	2	1880	17.4	24	993610.7	473829.8	111133_Ar	22	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_02T_left.apb	80	3	1880	17.4	24	993610.7	473829.8	111133_Ar	23	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_04T_left.apb	250	8	1880	17.4	24	993610.7	473829.8	111133_Ar	24	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_00T_left.apb	25	4	1880	17.4	26	994227.7	474450.7	111134_Ar	25	43	PA Power	dBm	50
D:\Antenna pattern\1880_3D_00T_left.apb	145	7	1880	17.4	26	994227.7	474450.7	111134_Ar	26	43	PA Power	dBm	50

## Chapter 5: Simulation Results and Performance Comparison

This chapter presents our study results using WinProp radio network simulation tool for system level network simulation, backed up with matlab for plotting results.

### 5.1. Simulation Results of Existing Network

Network performance is usually measured in terms of throughput and SINR metrics. Throughput is defined as the measure of quality expressed as the data transfer rate of useful and non-redundant information [25]. SINR is also another metrics used in telecommunications to measure quality of a network.

SINR can be calculated by the following formula.

$$SINR = \frac{P_{signal}}{P_{signal} + P_{interference}} \quad (5.1)$$

Where  $P_{signal}$  is the power of desired signals and  $P_{interference}$  is the power of the interfering signals. Changing antenna parameters such as tilt and azimuth can increase  $P_{signal}$  and reduce  $P_{interference}$  so that SINR can be improved.

According to the network model and the existing parameter configuration of the considered cells, the performance of the network in terms of throughput and SINR CDF is shown in Figure 5.1 and Figure 5.2 respectively.

The existing network configuration depicted in Figure 5.1 shows that the maximum achievable throughput is 45 Mbps. The probability of achieving below 15 Mbps throughput is about 75%. It also indicates that about 80% probable throughput is less than 20 Mbps.

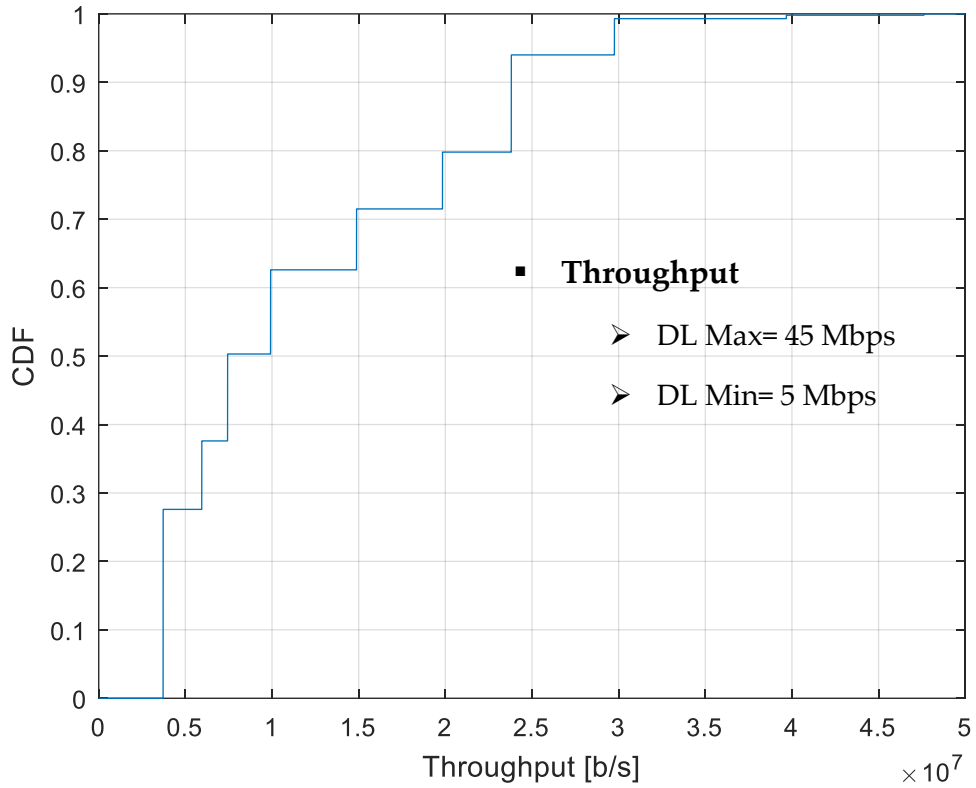


Figure 5.1: Existing network DL throughput CDF

On the other hand, the SINR CDF for the existing network configuration as shown in Figure 5.2 shows that it is possible to achieve up to 16 dB. The probability that the SINR is less than 10 dB is 95%.

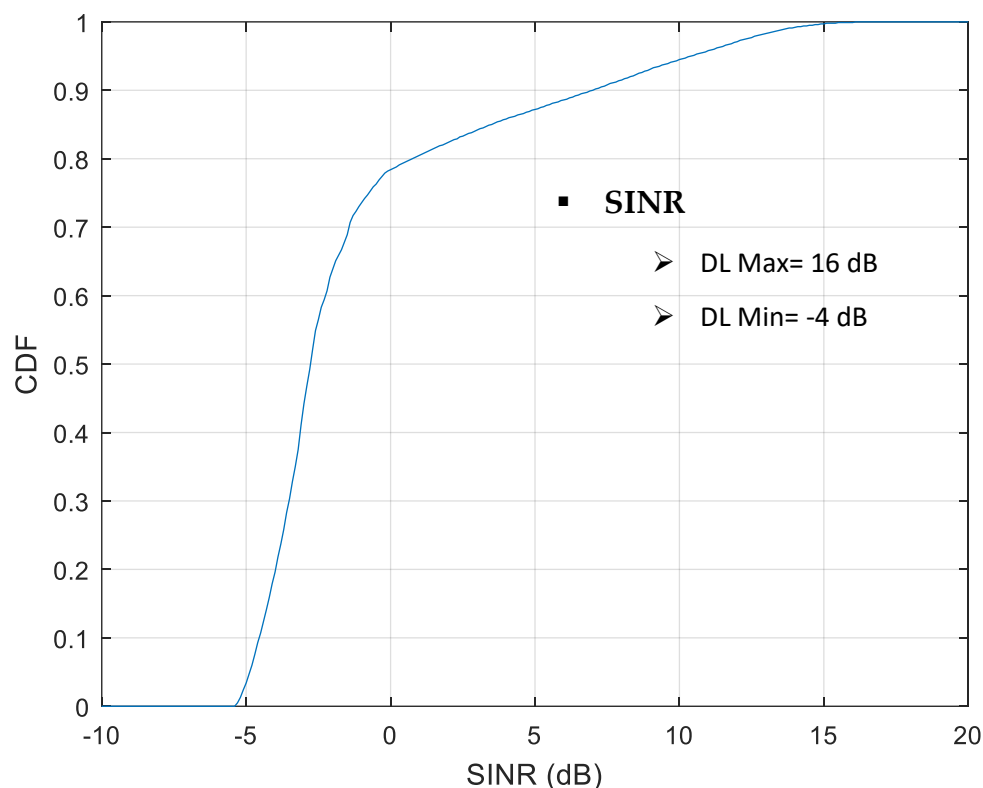


Figure 5.2: Existing network SINR CDF performance

## 5.2. Simulation Results for Electrical Tilt Adjustment

From a network map that shows the existing cell throughput and SINR, the worst areas are iteratively simulated for performance improvement for electrical down tilt in steps of two below and above the existing parameter setting. Accordingly, the adjustment shown as shown in Table 5.1 shows the tilt setting best network performance improvement.

Table 5.1: Electrical down tilt adjustment

Site	112090			111016			111077			111133			111047		
Antenna	Ant 1	Ant 2	Ant 3	Ant 1	Ant 2	Ant 3	Ant 1	Ant 2	Ant 3	Ant 1	Ant 2	Ant 3	Ant 1	Ant 2	Ant 3
Existing EDT	2	2	0	5	5	7	3	7	0	1	2	4	2	4	3
New EDT	2	4	1	4	5	5	4	5	0	3	2	1	3	5	3

After the electrical tilt is set as shown in Table 5.1, a maximum of 47 Mbps throughput can be achieved. Figure 5.3 shows the throughput CDF and it depicts the probability that throughput can be achieved less than 10 Mbps is 80%. It also shows that below 20 Mbps is achieved with probability of 90%.

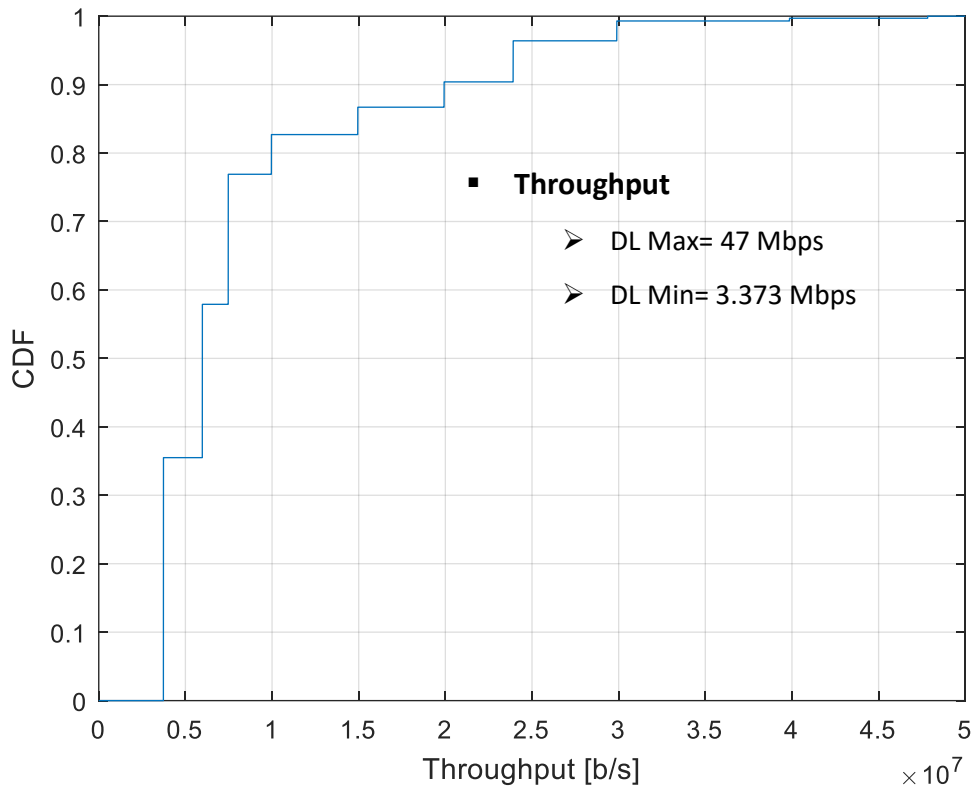


Figure 5.3: Throughput CDF after electrical down tilt

Figure 5.4 shows the SINR CDF after the adjustment of the electrical tilt as in Table 5.1. Hence, it indicates that a maximum of 18 dB can be achieved. The probability that SINR is below 5 dB is about 75%. Furthermore, it shows that nearly 92% of the SINR is less than 10 dB.

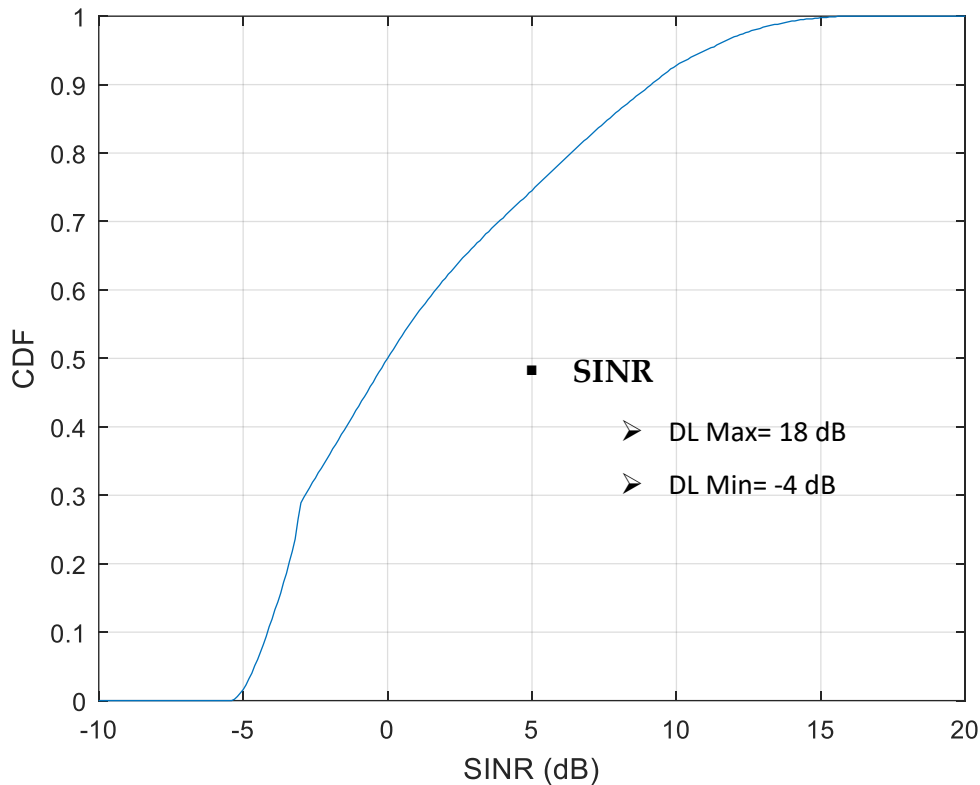


Figure 5.4: SINR CDF after electrical down tilt

### 5.3. Performance Comparison

Figure 5.5 shows the throughput performance for both the existing and after electrical tilt adjustment is done to get optimal values. The blue line shows the existing throughput performance as shown in section 5.1 while the red line shows the throughput plot after the electrical tilt adjustment.

It shows throughput performance gain. For example, the probability of achieving less than 10 Mbps is 50% in the existing network configuration whereas it is 80% after the electrical tilt angle adjustment. Furthermore, the probability of achieving less than 20 Mbps throughput for the existing and electrical tilt angle adjusted network is 80% and 90% respectively.

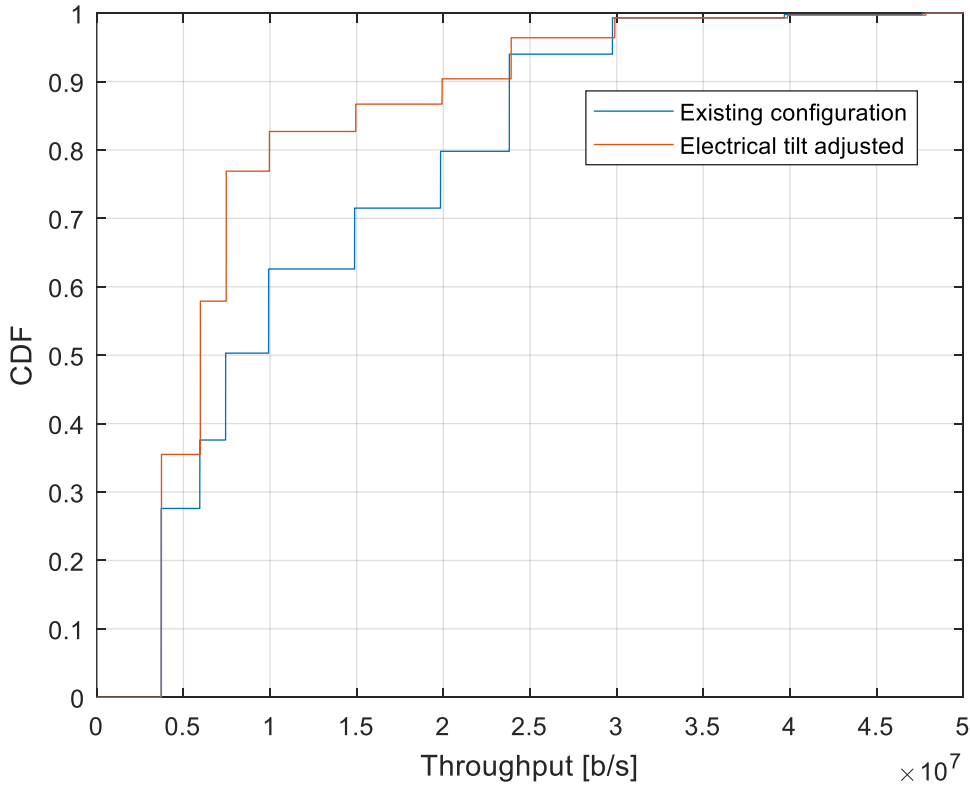


Figure 5.5: Throughput performance comparison

On the other hand, the SINR performance plot shown in Figure 5.6 compares the performance for both the existing network configuration and after electrical tilt has been adjusted.

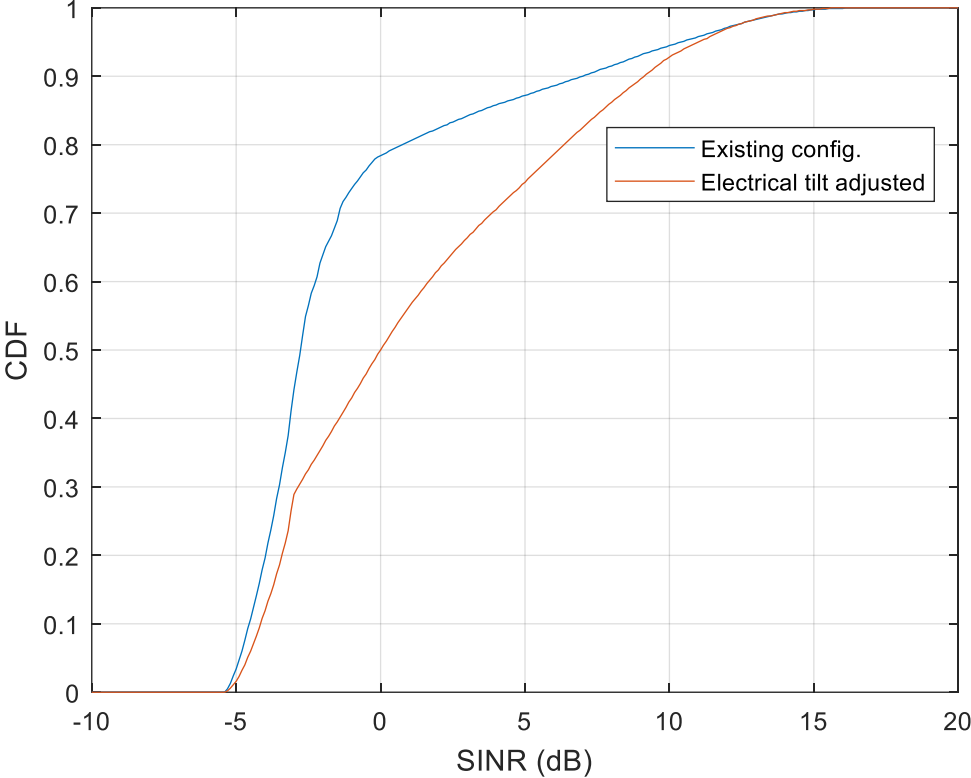


Figure 5.6: SINR performance comparison

Figure 5.7 shows the throughput gain percentile. At the 10 %tile, there is no significant improvement. It shows better improvement at the 50<sup>th</sup> %tile whereas there is best throughput gain at 90 percentile compared to 10 and 50 percentiles.

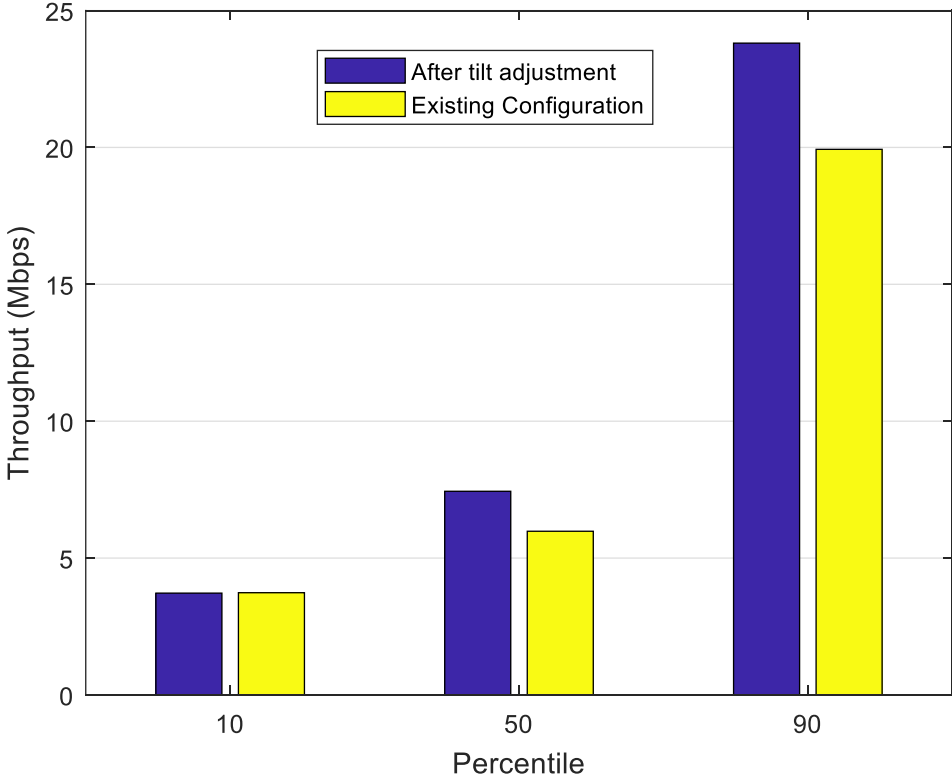


Figure 5.7: Throughput percentile; 10%, 50% and 90%

The SINR percentile shown in Figure 5.8 shows a loss where as there is a good gain at 90 percentiles. The loss for the 10 %tile and 50 %tile is due to the fact that the SINR had negative values.

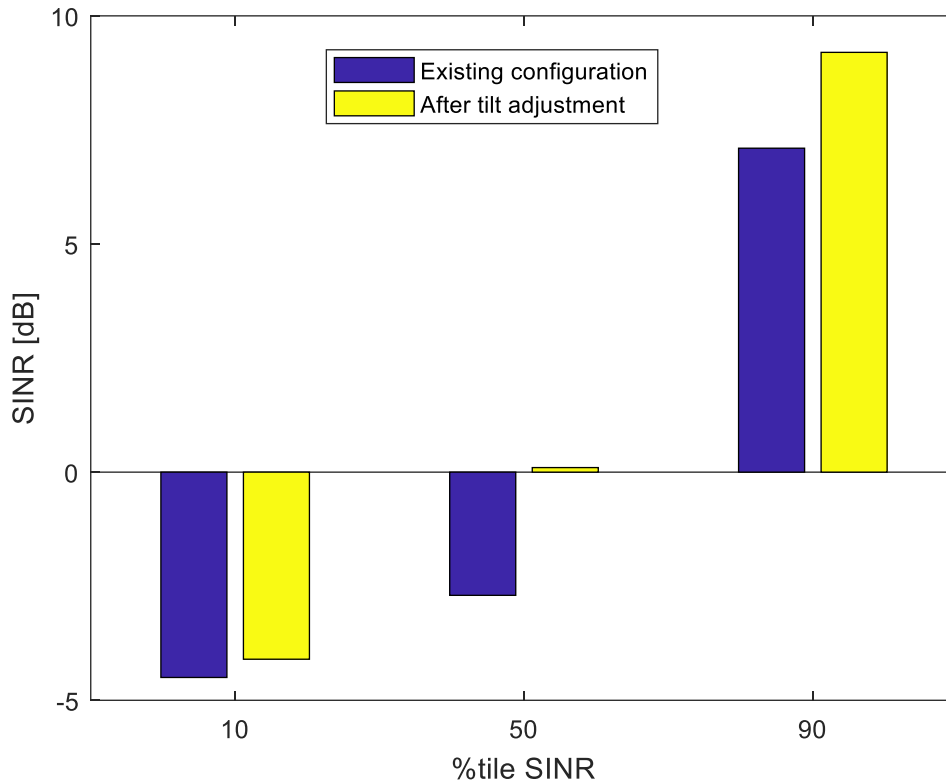


Figure 5.8: SINR percentile; 10%, 50%, 90%

As can be seen from Figures 5.1 and 5.3, with the electrical tilt adjustment as stated in Table 5.1, the maximum throughput is improved from 45 Mbps to 47 Mbps. Similarly, the SINR performance is improved from maximum SINR of 16 dB to a maximum of 18 dB.

There is no performance gain obtained from in the simulated network for various azimuth angle alterations. Simulation results depict the same throughput and SINR CDF as shown in Figure 5.1 and Figure 5.2 respectively, which are the existing network setting simulation results.

## **Chapter 6: Conclusion and Future works**

### **6.1. Conclusions**

In this thesis work, we have reviewed Addis Ababa LTE network and deployed antenna solutions as well as ethio telecom optimization practices. Moreover, antenna electrical down tilt and azimuth angle parameters have been studied to investigate their impact on LTE network performance, particularly for an Addis Ababa LTE deployment scenario. Furthermore, tilt and azimuth optimization is performed using educated trial and error approach.

Results show that antenna electrical down tilt can be further optimized to improve network performance. It is found that, by optimizing antenna tilt, throughput and SINR can be improved by 4.4% and 12.5% respectively with respect to existing configuration.

The trial and error optimization effort for antenna azimuth has no significant performance gain compared to already existing setting.

Such kind of antenna optimization are of paramount advantage for the operator for it does not require additional investments while improving network performance and in turn satisfying customers.

### **6.2. Future works**

Recommended study areas in relation to antenna parameter optimization are listed as follows:

- Study these parameters based on dynamic simulators since in reality the traffic and environment are changing
- Study of the future of antenna technology such as active antenna

- Full or partial automation of antenna optimization process applying various self-optimization techniques

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