ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
AFRICAN RAILWAY CENTER OF EXCELLENCE

Optimization of LTE Network for Addis Ababa Light Railway

A Thesis in Electrical Engineering for Railway System

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A Thesis
Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled "Optimization of LTE Network for Addis Ababa Light Railway" presented by Kefyalew Biru Flatie, a candidate for the Degree of Master of Science and hereby certify that it is worthy of acceptance.

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Declaration

I certify that research work titled “Optimization of LTE Network for Addis Ababa Light Railway” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/referred.

Kefyalew Biru Flatie

Dedication

This paper is dedicated to families who lost their child due to lack of money for medical treatment.

Abstract

To meet railway communication demand, conventional railway mobile communication systems including Global System for Mobile Communication-Railway and Terrestrial Trunked Radio have been challenged in terms of capacity, coverage and quality. To address the capacity, coverage and quality challenges, Long Term Evolution (LTE) has been emerged as an alternative important wireless technology for railway.

Addis Ababa Light Rail Transit Service (AALRTS) has been operational since September 2015 serving an average of 130,000 users daily with its two lines extended from east to west (Line 1) and north to south (Line 2) of Addis Ababa. To AALRTS communication demand, LTE network has been planned and deployed at 400 MHz carrier frequency. The network consists of 4 sites of 9 LTE cells operating with 3MHz bandwidth and planned antenna and other configurations. Although the network provides quality service for current rail voice/data service in most parts of both rail lines, there are coverage challenge in some parts of the lines and it needs to be enhanced for the increasing multimedia service demand.

The objective of this thesis is to quantitatively articulate aforementioned coverage challenge of the LTE network for AALRTS and then to perform optimization campaign to address the challenge. To articulate the coverage challenge, data is collected using drive test around challenged parts of the rail lines beside data obtained from management system of the network. Drive test is undertaken using Huawei EP680 LTE terminal and obtained data is analyzed using Matlab. Optimization is performed for antenna parameters of existing network cells and location of a newly added cell using search method from potential values. For the optimization, network simulation is performed using WinProp network simulation tool and for propagation computation deterministic dominant path model is applied. For performance analysis, signal-to-interference-plus-noise-ratio (SINR) is used as a key metric.

Drive test result shows that 17% and 6% parts of Lines 1 and 2 SINR results are less than $7dB$, respectively. Independent and combined antenna height and power optimization provides significant coverage improvement while antenna tilt and azimuth optimization present negligible performance gains. Furthermore, adding a new LTE cell and optimizing its location presents excellent SINR improvement.

Key Words: *LTE, Railway, Coverage, Capacity, Quality, Optimization, Drive Test, Antenna Parameters*

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Acronyms

AALRTS	Addis Ababa Light Rail Transit Service
AMC	Adaptive Modulation and Coding
ATA	Antenna Tilt Angle
BBU	Baseband Unit
BLER	Block Error Rates
BPS	Bits Per Second
BS	Base Station
C/I	Carrier/Interference
CCTV	Close Circuit Television
CDF	Cumulative Distribution Function
CN	Core Network
CoMP	Coordinated Multi-Point
COST	Cooperation in Science and Technology
CP	Cyclic Prefix
CQI	Channel Quality Indicator
DL	Down Link
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
eNB	Evolved Node B
EPC	Evolved Packet Core
ETSI	European Telecommunications Standard Institute
GGSN	Gateway GPRS Support Node
GSM-R	Global System for Mobile Communication – Railway
GW	Gateway
HSPA	High-Speed Packet Access
Hz	Hertz
ICIC	Inter-Cell Interference Coordination
IP	Internet Protocol
IRC	Interference Rejection Combining
ISI	Inter-Symbol Interference
IVS	Intelligent Video Surveillance
KPI	Key Performance Indicator

LTE	Long Term Evolution
Mbps	Megabits per second
MCS	Modulation and Coding Scheme
MHz	MegaHertz
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MVR	Multi-Vendor Radio Access Network
NAS	Non-Access Stratum
NLOS	None Line of Sight
NMS	Network Management System
OFDM	Orthogonal Frequency Division Multiplex
OFDMA	Orthogonal Frequency Division Multiple Access
OMC	Operation and Maintenance Client
P-GW	PDN Gateway
PDN	Packet Data Network
PDSCH	Physical Downlink Shared Channel
PF	Proportional Fairness
PMI	Precoding Matrix Indicator
PRB	Physical Resource Block
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Key
RB	Resource Block
RF	Radio Frequency
RI	Rank Indicator
RMS	Root Mean Square
RNC	Radio Network Controller
RR	Round Robin
RRM	Radio Resource Management
RRU	Remote Radio Unit
RS	Reference Signal

RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
S-GW	Serving Gateway
SAE	System Architecture Evolution
SC-FDMA	Single Carrie Frequency Division Multiple Access
SFBC	Space-Frequency Block Coding
SGSN	Serving GPRS Support Node
SINR	Signal to Interference plus Noise Ratio
SISO	Single Input Single Output
SON	Self Optimizing Network
TDD	Time Division Duplexing
TDMA	Time Division Multiple Access
TETRA	Terrestrial Trunked Radio
UE	User Equipment
UL	Up Link
UMTS	Universal Mobile Telecommunications System
UTM	Universal Transverse Mercator

Contents

List of Tables

List of Figures

Chapter 1 Introduction

1.1 Background and Motivation

In modern railway, communication network is inevitable element. Data service demand for railway signaling, operation, and to provide travel comfort by offering more quality services to passengers through real-time multimedia is abruptly increasing in Light Railway. Quality of Service (QoS) demand is beyond the existing technologies such as Global System for Mobile Communication – Railway (GSM-R) and Terrestrial Trunked Radio (TETRA), which are European Telecommunications Standard Institute (ETSI) standards.

GSM-R offers only circuit-switched transmission. This transmission mode is less efficient than packet-switched. The lack of packet-switched transmissoin leads to very low utilization of the network. GSM-R has insufficient capacity, that is a small number of channels available for user transmission. This is a consequence of the combined effect of the circuit-switched transmission paradigm and the reduced band of radio spectrum assigned. The other shortcoming of GSM-R is its very limited support for data communication. TETRA is a technology that was designed specifically for the private mobile radio market, with public safety feature at the fore [1]. TETRA has important advantages in comparison with GSM-R in spectrum efficiency, coverage, cost, public safety and mission critical features. In TETRA the access mode is Time Division Multiple Access (TDMA) with four slots per carrier and the user data is $7.2kbps$ per time slot, i.e., $28.8kbps$ per carrier. Even it provides strong speech communications its data rate is insufficient.

LTE network is the new emerging wireless system for Railway. LTE network resolves the above problems by introducing new features. LTE is entirely based on packet-switching for the transport of data of all services, including speech. Hence, LTE is more flexible in managing available network resource. The most important objective of LTE is a significante increase in the speed of data. The network architecture is simplified and reduces packet delay. It uses advanced radio interface to give higher throughput over its radio access [2].

	GSM-R	TETRA	LTE
Operation Voice Support	Yes	Yes	VoLTE
Data Support	$<$10kbps	$<$28.8kbps	$>$10Mbps
All IP	No	No	Yes
Call Setup Time	1 to 5s	250ms	100ms
Available Frequency	900MHz	400MHz	400MHz
Maturity	End by 2025	Mature	Emerging

Table 1.1: Comparison of Existing Radio Communication Technology [3]

AALRTS wireless communication system is an LTE network, which is deployed by Huawei Technologies. The LTE network consists of 4 sites of 9 LTE cells along the two lines of AALRTS, as shown in Figure 1.1. It provides wireless voice and data services for dispatchers, train drivers, maintenance personnel, field workers, operators, depot watchers, network management and ticket system (under process).

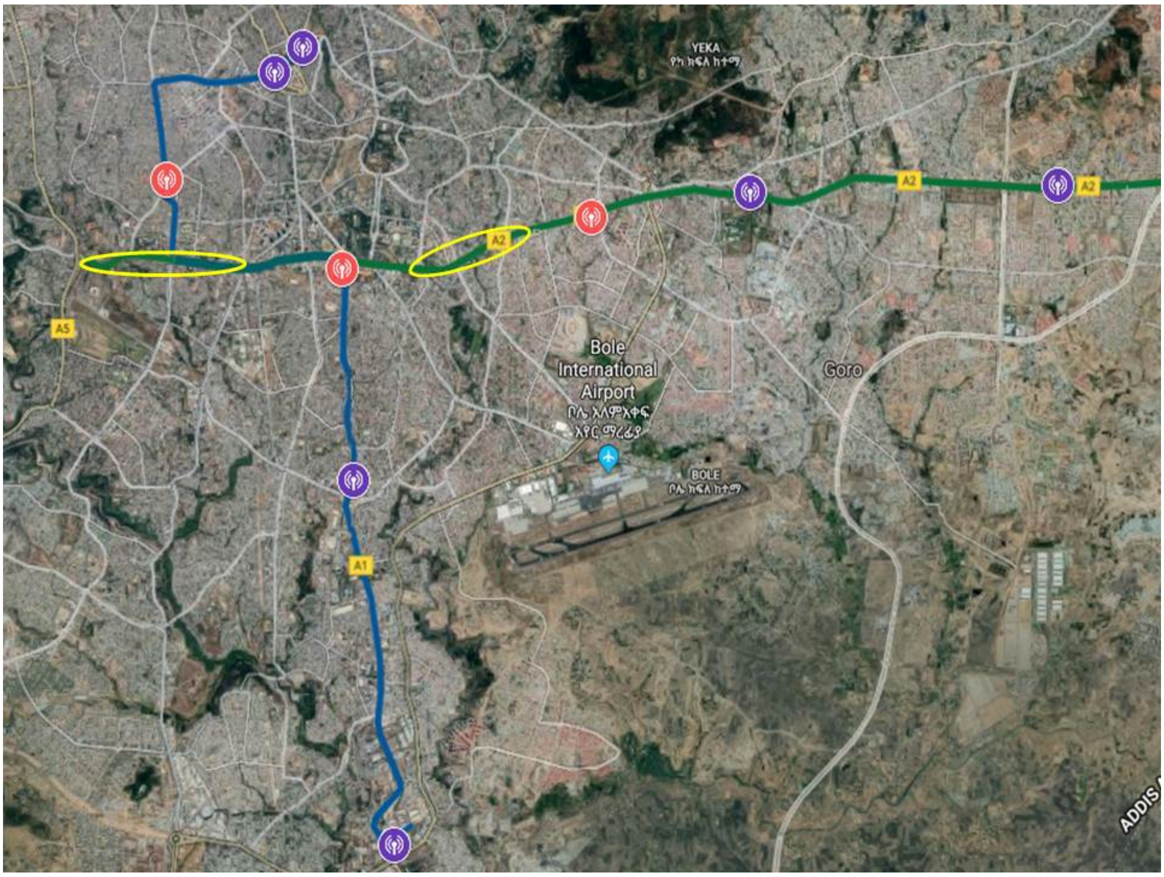

Figure 1.1: AALRTS LTE Network Cells

1.2 Problem Statement

Light Railway transport operation requires high QoS communication system. However, LTE network faces coverage challenges in Light Railway due to abrupt construction changes in a city and failure to work according to the network plan. AALRTS LTE network is one of the victims of the aforementioned challenge.

The coverage challenges in some area along the east to west line (Line 1) and in the common line of AALRTS are shown in Figure 1.1. According to AALRTS LTE Network Management System (NMS) software tool; the average Block Error Rates (BLER) of the red cells in Figure 1.1 is 22.5% which is higher than the acceptable value (10%). This value confirms that the marked sites are under coverage challenge.

AALRTS staff are forced to use a public mobile phone on the sites which leads to extra cost to the staff and the company. Furthermore, it is difficult to use the public mobile phone for emergency and group calls. Its also difficult to trust the public mobile phone number during transfer and receive a company work order; you can not make a staff accountable for not responding a call to his private number. Hence, optimization of the LTE network is advisable action to resolve the coverage problem at hand.

1.3 Objective

1.3.1 General Objective

The general objective of this paper is to articulate Light Railway LTE network coverage challenges and propose mitigation techniques. The specific objectives are described below.

1.3.2 Specific Objective

1. Identify and articulate area coverage challenges of AALRTS LTE network
2. Study and analyze practical optimization approaches that are able to address coverage challenges cost effectively
3. Perform optimization of LTE network of AALRTS using antenna optimization approach
4. Perform optimization of LTE network of AALRTS by adding new site
5. Analyze performance of the optimization approaches

1.4 Scope and Limitation of Thesis

The main focus of this thesis is the optimization of an LTE network for a light railway to overcome area coverage challenges. The LTE network optimization method will be a simulation using WinProp tool and Matlab plot. The LTE terminal, which will be applied during the drive/walk test to collect actual antenna parameters' values, does not support to collect continuous information. Therefore, the data to be collected during the drive/walk test will be discrete values. The channel model of the simulation will be the dominant path model which neglects the other losses like fading.

1.5 Related Literature Review

In the references [2][4], the drawbacks of the existing railway communication technologies are discussed in detail. In these references, the advantages of LTE in railway communication technologies clearly shown. The reference [5], presented major short-comings of GSM-R which are a motivation for research on alternative technologies for railway communication, low network resource utilization, insufficient capacity and support only most basic data services. LTE address these short-comings, and it can be a valid alternative to GSM-R.

In reference [6], a study conducted to investigate the effect of antenna parameters in an optimization. In this international journal, antenna parameters power, azimuth, tilt, and horizontal beam-width optimized separately and in combination. The percentage improvement of Signal to Interference plus Noise Ratio (SINR) value for each parameter and combination of parameters plotted and listed in a table.

The reference [7], provides guidelines on LTE network optimization. To meet customer requirements for high-quality networks LTE network must be optimized during and after project implementation. In this literature, the network optimization process divided into two phases; single site verification and Radio Frequency (RF) (or cluster) optimization. Single site verification ensures each site properly installed and parameters correctly configured. RF optimization controls pilot pollution while optimizing signal coverage. In this work, the selected checklists for RF optimization are RSRP, SINR, and measured handover success rates.

Reference [8], described the causes of coverage problem and the significance of optimization. Incorrect network planning, position of actual Evolved Node B (eNB) deviation, actual parameters differ from planned parameters, change in the environment in the coverage area, add new coverage requirements and service increment are the causes of coverage problem. The coverage problem defined by the Key Performance Indicator (KPI) such as RSRP, RSRQ and SINR. In this literature, the coverage optimization flow includes preparation, data collection, KPI requirement check, problem analysis, and adjustment implementation.

In reference [9], the two User Equipment (UE) measuremets RSRP and RSRQ range for best QoS are described. RSRP measurement results categorized in three ranges. If RSRP $> -75dBm$ excellent QoS, $-95dBm <$ RSRP $\leq -75dBm$ a slight degradation of QoS and RSRP $\leq -95dBm$ the QoS become unacceptable and throughput tends to decline. RSRQ values higher than $-9dB$ guarantee the best subscriber experience, the range between -9 and $-12dB$ neutral with a slight degradation of QoS, and with RSRQ less than $-12dB$ significant declines of throughput.

1.6 Methodology

The methodology of this work is described using a flowchart in Figure 1.2. The individual parts of the flowchart explained as follows.

Thesis Idea: The author, while working maintenance in AALRTS wireless communication system, experienced weakness in radio signal which made the communication between coworkers challenging in some areas. This caught his attention and drove him to solve the challenge in his company and for similar problems that may occur in such Light Railway LTE networks.

Data Collection: Network plan, network structure design, site distribution, site information and engineering parameters of the LTE network collected from Ethiopian Railways Corporation, AALRTS.

Actual Parameter Value Collection: The antenna parameters of the actual network were collected from the design documents as well as from the existing configuration using LTE NMS. The KPIs collected through a drive/walk test using an LTE terminal and NMS of the existing network.

Identify Optimization Techniques: Antenna parameter and adding new site optimization techniques studied. The fundamental antenna parameter optimization techniques are an adjustment of antenna height, tilt, azimuth, and power.

Simulation: The preferable methodology in this paper is a simulation and emulation method with a quantitative approach. With the help of WinProp simulation tool and Matlab plot; the network simulated using the existing parameters and optimized parameters of the LTE network. The simulation results analyzed using Cumulative Distribution Function (CDF) plot. Then the suitable parameter optimization which can solve the coverage challenge identified. In addition to the antenna parameter optimization; adding new site optimization also performed.

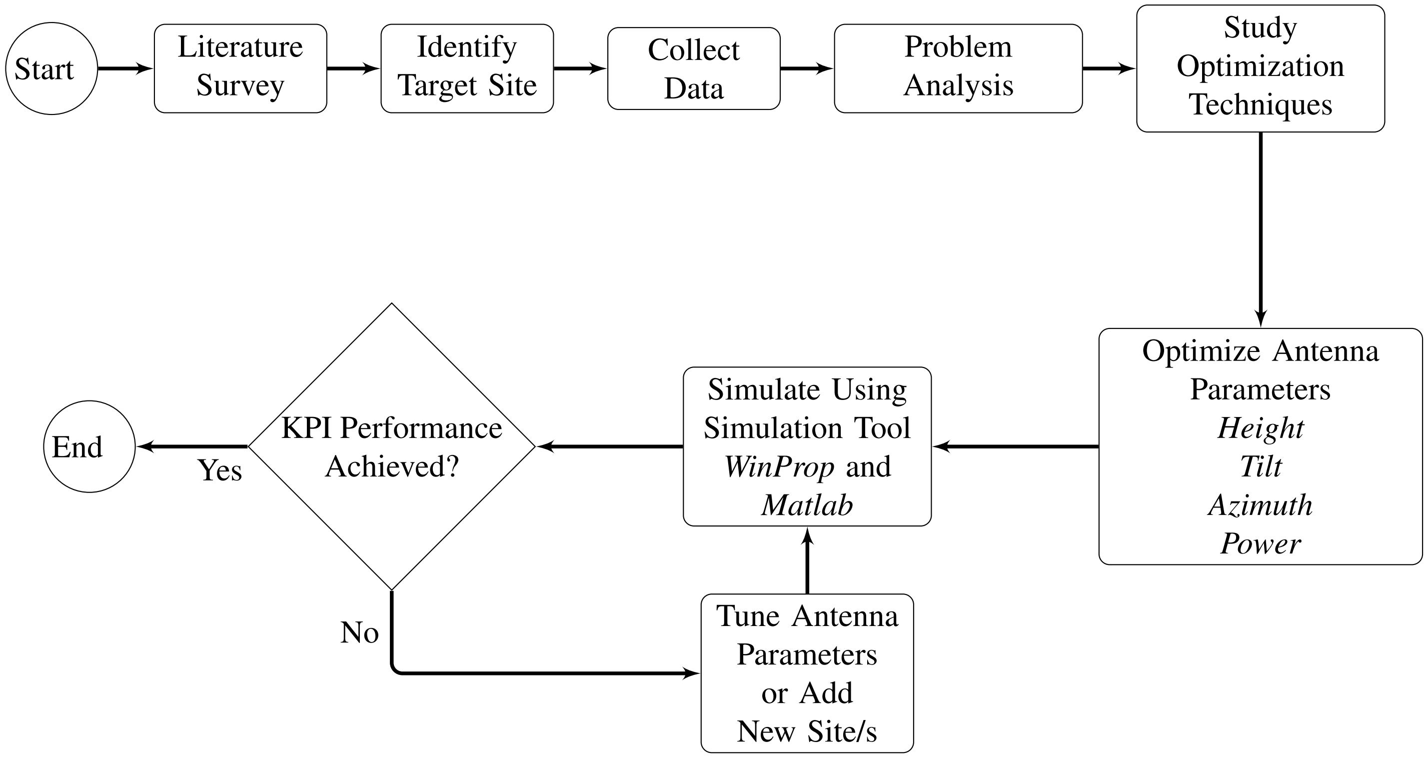

Figure 1.2: Applied Methodology

1.7 Outline of Thesis

Outlines of the remaining parts of the thesis are presented as follows.

- Chapter 2: In this chapter the LTE network architecture, radio interface and resource management, network planning, performance and LTE for the railway highlighted
- Chapter 3: Optimization of LTE network approaches, QoS measurement KPI and methods discussed in detail
- Chapter 4: Addis Ababa Light Railway and LTE network as well as the network configuration and existing network challenges described
- Chapter 5: System model, optimization methods and simulation model identified
- Chapter 6: Results and discussion of the existing network, antenna and new site optimization are analyzed
- Chapter 7: Based on the results found in the optimization process conclusion has been made

Chapter 2 Overview of LTE

LTE technology has been developed by the Third-Generation Partnership Project (3GPP) as an improvement to the current Universal Mobile Telecommunications System (UMTS) is sometimes called 3.9G or Super 3G [10].

The wireless capacity requirement, cost of wireless data delivery and the capacity gap between the wireline and wireless broadband are some of the driving forces to LTE development. The initial target of the LTE was to improve the spectral efficiency, data rate and minimize time latency. The reference for the performance comparison was HSPA. Other requirements are improving terminal power efficiency, flexible frequency allocation and support high mobility [11].

LTE offers flexible bandwidth options ranging from 1.4 to 20 MegaHertz (MHz) using Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink and Single Carrie Frequency Division Multiple Access (SC-FDMA) in the uplink [12]. The uplink user frequency resource allocation is continuous to enable single carrier transmission while in downlink frequency resource blocks can be allocated to the user from different parts of the spectrum. The uplink single carrier solution is designed to allow efficient terminal power amplifier design, which is relevant for the terminal battery life. In LTE user transmissions can be divided in frequency and time that gives better orthogonality between users, less interference and better network capacity can be achieved.

2.1 LTE Network Architecture

The LTE network architecture is illustrated in Figure 2.1. The data are exchanged between the UE and the base station (eNB) through the air interface. The eNB is part of the Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) where all the functions and network services are conducted. Whether it is voice packets or data packets, the eNB will process the data and route it accordingly [13].

In LTE System Architecture there are three main components, namely the user equipment (UE), the E-UTRAN and the Evolved Packet Core (EPC). The E-UTRAN handles the radio communications between the mobile and the evolved packet core and just has one component, the evolved Node B (eNB). Each eNB is a base station that controls the mobiles in one or more cells. A mobile communicates with just one base station and one cell at a time, so there is no equivalent of the soft handover state from UMTS.

The eNB has two main functions. Firstly, the eNB sends radio transmissions to all its mobiles on the Down Link (DL) and receives transmissions from them on the Up Link (UL), using the analogue and digital signal processing functions of the LTE air interface. Secondly, the eNB controls the low-level operation of all its mobiles, by sending them signaling messages such as handover commands that relate to those radio transmissions [14]. The network architecture elements are [13]:

User Equipment (UE): This is the user device that is connected to the LTE network via the RF channel through the BS that is part of the eNB subsystem.

Evolved Node B (eNB): The eNB functionalities include Radio Resource Management (RRM) for both UL and DL), Internet Protocol (IP) header compression and encryption of user data, routing of user data, selection of MME, paging, measurements, scheduling, and broadcasting.

Mobility Management Entity (MME): This portion of the network is responsible for Non-Access Stratum (NAS) signaling and security, tracking UE, handover selection with other MMEs, authentica-

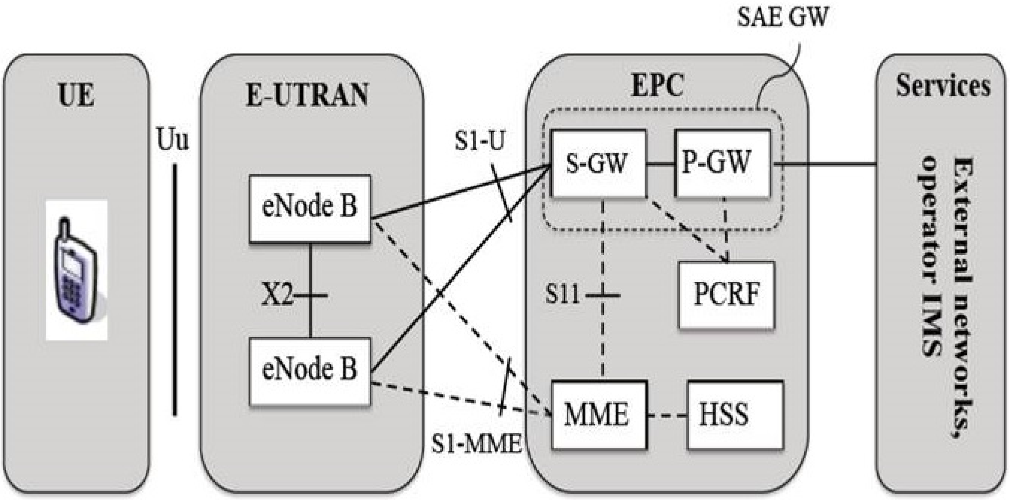

Figure 2.1: LTE System Architecture [11]

tion, bearer management, CN node signaling, and Packet Data Network (PDN) service and selection. The MME is connected to the S-GW via an S11 interface.

Serving Gateway (S-GW): This gateway handles eNB handovers, packet data routing, QoS, user UL/DL billing, lawful interception, and transport level packet marking. The S-GW is connected to the PDN gateway via an S5 interface.

PDN Gateway (P-GW): This gateway is connected to the outside global network (Internet). This stage is responsible for IP address allocation, per-user packet filtering, and service level charging, gating, and rate enforcement.

Evolved Packet Core (EPC): It includes the MME, the S-GW as well as the P-GW.

System Architecture Evolution (SAE), 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), for the reduction of inter-node data traffic delays [15].

In SAE, the central control functions of the RNC are distributed between the evolved Node B (eNB) and the Mobility Management Entity (MME) as eNBs are able to communicate with each other using a new logical inter-eNB interface, called $X2$ as shown in Figure 2.1.

One LTE target was to improve the network scalability and minimize the end-to –end latency by reducing the number of network elements. eNB includes almost all algorithms that are located in Radio Network Controller (RNC) in WCDMA/HSPA architecture. The core network is streamlined by separating the user and control planes [11].

2.2 LTE Radio Interface and Resource Management

2.2.1 Multiple Access Techniques

One of the main changes in LTE compared to 3G is the use of multiple transmission schemes in the air interface. LTE is designed to be based on OFDMA in the downlink, whereas the uplink air interface is based on SC-FDMA.

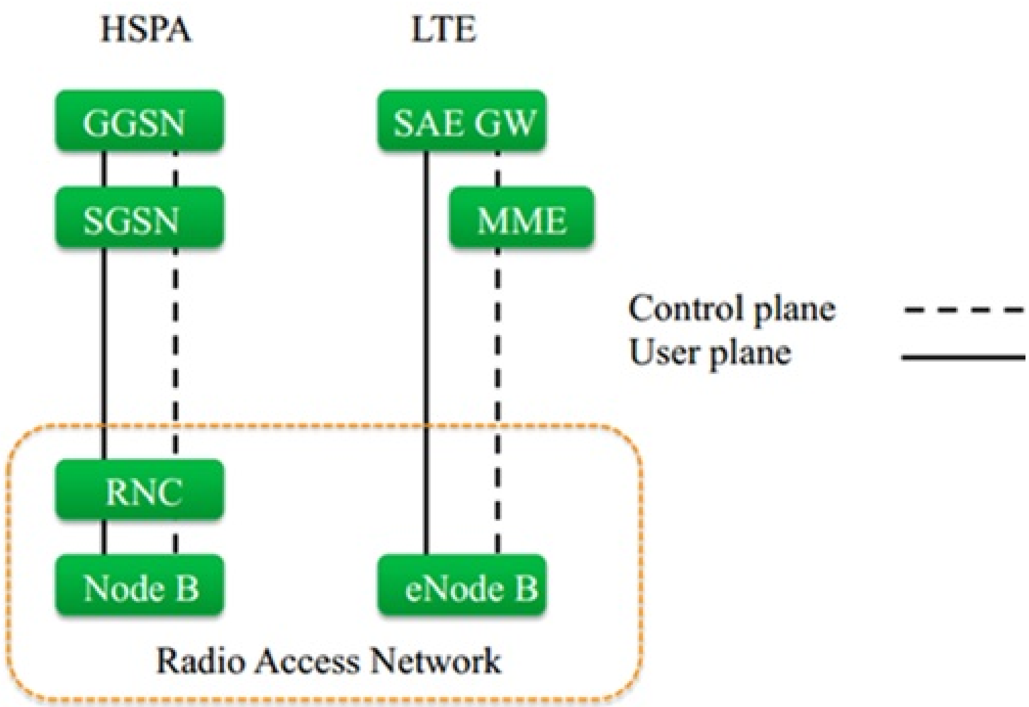

Figure 2.2: System Architecture Comparison of HSPA and LTE [11]

Down Link: OFDMA

Orthogonal Frequency Multiple Access divides spectrum into large number of tightly packed narrow subcarriers. At the peak of each subcarrier, all other subcarriers have amplitude zero, hence avoids subcarrier interference. Orthogonal Frequency Division Multiplex (OFDM) subcarriers have a frequency response resulting in overlap in the frequency domain. However, this overlap does not cause interference due to the orthoganality of the subcarriers [11]. In OFDM Systems, the multiple user signals are separated in the time and/or frequency domains. The subcarriers and the OFDM symbol period are the finest allocation units in in the frequency and time domain, respectively. Hence, multiple users are allocated different slots in the time and frequency domain, i.e., different groups of subcarriers and/ or OFDM symbols are used for transmitting the signals to/from multiple users. For instance, it illustrates in Figure 2.4 wherein the subcarriers in an OFDM symbol are represented by arrows and the lines shown at different times represent the different OFDM symbols. Have considered 5 users and have shown how resources can be allocated by using the different subcarriers and OFDM symbols [17]. Orthogonal Frequency Multiple Access 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. Each Physical Resource Block (PRB), which consists of twelve subcarriers in LTE, is modulated with a conventional modulation scheme (e.g., Quadrature Phase Shift Key (QPSK), Quadrature Amplitude Modulation (QAM) (16-QAM, or 64-QAM)). 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. To avoid Inter-Symbol Interference (ISI), the transmitter inserts a Cyclic Prefix (CP), which is longer than the channel impulse response, between the symbols. Since the OFDMA transmitter may cause spreading of the spectrum due to imperfections, filtering is carried out for shaping the spectral mask (i.e., windowing) [15].

High data rate transmission in a multipath environment leads to inter symbol interference (ISI). OFDM is a powerful way to solve the problem. Instead of sending the information as a single stream, an OFDM transmitter divides the information into several parallel sub-streams, and sends each substream on a different frequency known as a sub-carrier. If the total data rate stays the same, then the

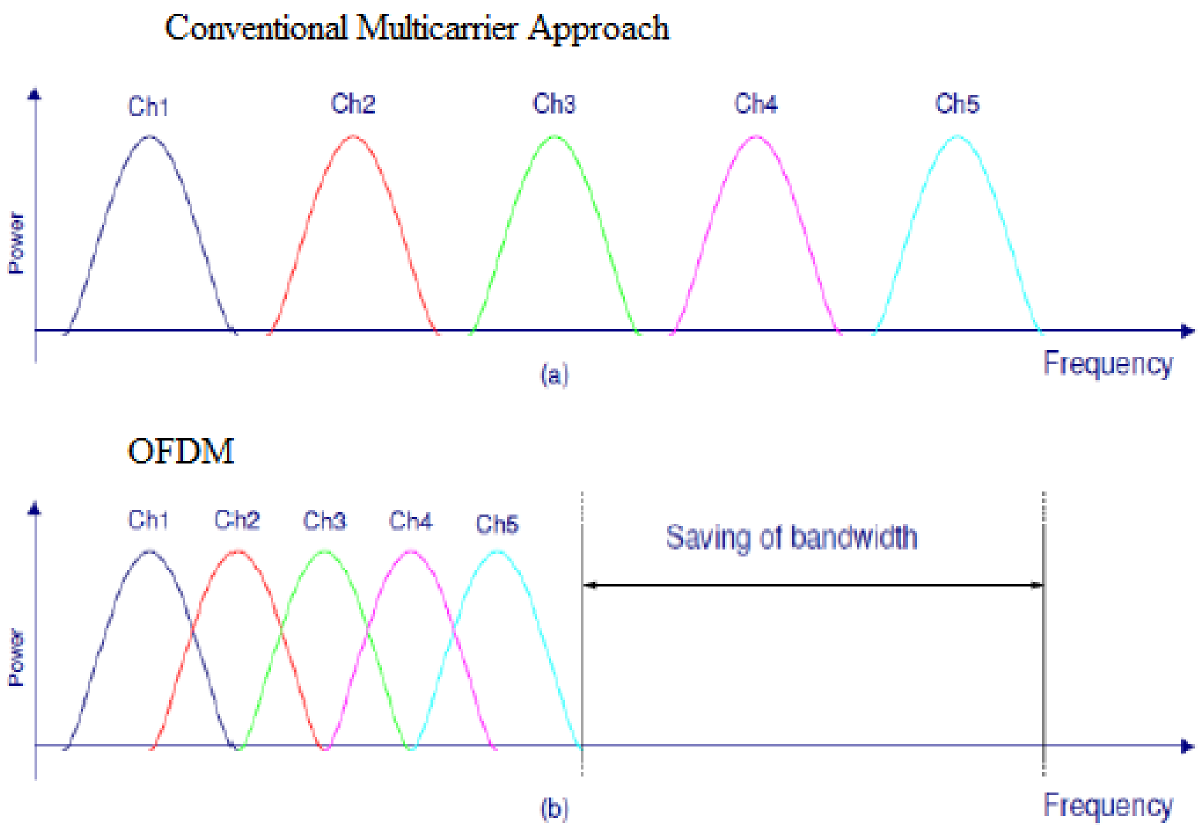

Figure 2.3: Conventional Multicarrier and OFDM [16]

data rate on each sub-carrier is less than before, so the symbol duration is longer. This reduces the amount of ISI, and reduces the error rate [14].

Up Link: SC-FDMA

The 3GPP decided to use SC-FDMA as an uplink transmission scheme due to have 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 [15]. The uplink user frequency resource allocation is continuous to enable single carrier transmission while in downlink frequency resource blocks can be allocated to the user from different parts of the spectrum. The uplink single carrier solution is designed to allow efficient terminal power amplifier design, which is relevant for the terminal battery life [11].

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 Inverse Fast Fourier Transform (IFFT). As in OFDMA system, Cyclic Prefix is inserted periodically but after a block of symbols as the symbol rate is faster in SC-FDMA so that Inter Symbol Interference between blocks is avoided and the receiver complexity is reduced [15].

2.2.2 Multiple Antenna System

Multiple Input Multiple Output (MIMO) systems are one of the major enabling technologies for LTE. They will allow higher data rate transmission through the use of multiple antennas at the receiver/-transmitter. Let the number of transmitting antennas be M_T and the number of receiving antennas be

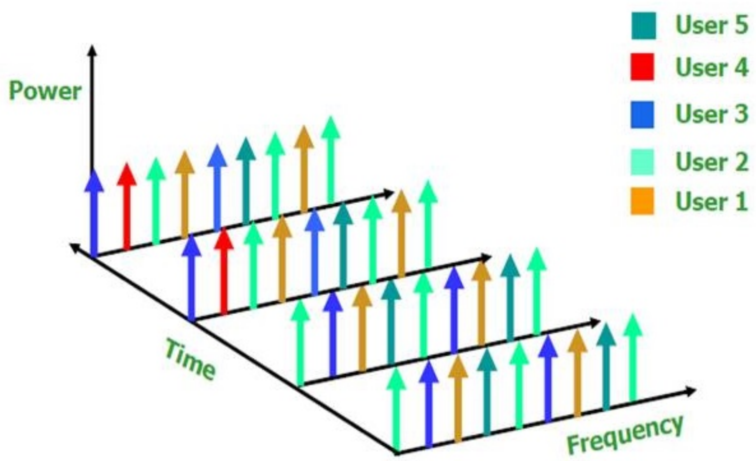

Figure 2.4: Allocation of Resources to Users in an OFDM System [17]

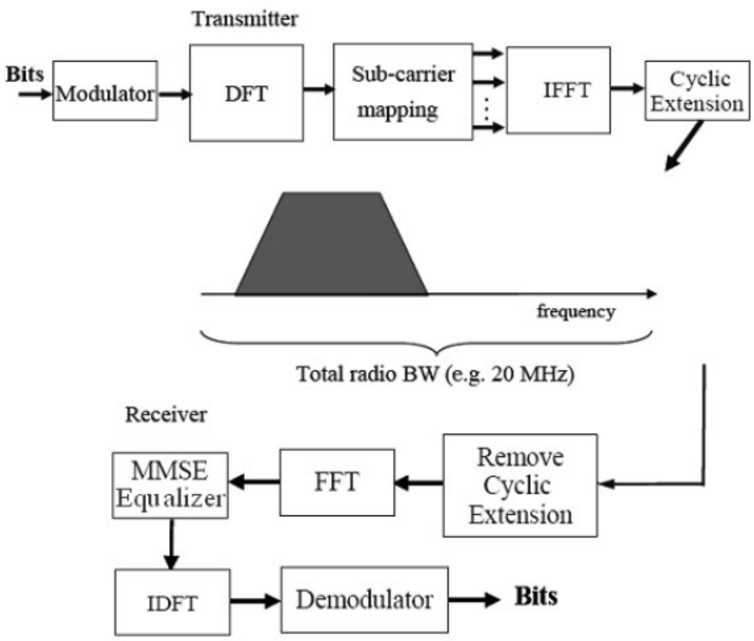

Figure 2.5: SC-FDMA Transmitter and Receiver [15]

N_R where $N_R \geq M_T$.

In a Single Input Single Output (SISO) – used in current cellular systems 3G and 3.5G – the maximum channel capacity is given by the Shannon-Hartley relationship [13]:

$$C \approx B \times \log_2 (1 + SNR_{avg}) \tag{2.1}$$

Where C is the channel capacity in Bits Per Second (BPS), B is the channel bandwidth in Hertz (Hz), and SNR_{avg} is the average signal to noise ratio at the receiver. In the SISO case, $M_T = N_R = 1$. In a MIMO case, the channel capacity becomes:

$$C \approx B \times \log_2 (1 + M_T \times N_R \times SNR_{avg}) \tag{2.2}$$

thus obtaining an $M_T N_R$ fold increase in the average SNR, increasing channel capacity. If $N_R \geq M_T$, we can send different signals within the same bandwidth and still decode them correctly at their corresponding receivers. For each channel (transmitter-receiver), its capacity will be given as:

$$C_{Single-CH} \approx B \times \log_2 (1 + \frac{N_R}{M_T} \times SNR_{avg}) \tag{2.3}$$

In the same bandwidth, we will have M_T dedicated channels (M_T transmitting antennas), resulting in an M_T-fold increase in capacity:

$$C \approx M_T B \times \log_2 (1 + \frac{N_R}{M_T} \times SNR_{avg}) \quad (2.4)$$

Hence, with respect to the transmitting antennas we obtain a linear increase in the system capacity.

2.2.3 Radio Resource Scheduling

Scheduling is the process of dynamically allocating the physical resources among the UEs based on some set of rules, i.e. scheduling algorithm. Before the eNB can assign the modulation technique and coding rate to an UE, based on the transmission channel condition, it must be assigned radio resource blocks [18].

Resource Scheduling Algorithms

In radio resource scheduling there are a number of algorithms. Proportional Fairness (PF): In this algorithm the priority for each user at each resource block is calculated firstly and then the user with maximum priority is assigned the Resource Block (RB) and the algorithm continues to assign the RB to user with next priority [18]. Soft Frequency Reuse Based: The designed frequency scheduler runs in a way that the cell edge users have the greater probability to use the frequency band with higher power and the cell center users have the higher probability of using frequency band with lower power [18]. Round Robin (RR): In RR scheduling the terminals are assigned the resource blocks in turn (one after another) without considering Channel Quality Indicator (CQI) [19]. Based on Maximum Interference: In this algorithm, the user with worst CQI is ranked up on the top and scheduled to utilize the physical resource blocks for the specific time [18]. Best CQI: The resource blocks assigned by the Best CQI to the user will have the highest CQI on that RB. The Modulation and Coding Scheme (MCS) must feedback the CQI to the eNB to perform the Best CQI.

2.2.4 Link Adaptation

Link adaptation is about adapting the channel conditions and changing system parameters based on actual channel quality. The LTE standards enables link adaptations that can help us make use of the spectrum more efficiently [20]. To enable dynamic changes to MCSs and for proper operation of MIMO schemes, the LTE standard provides mechanisms that enable information regarding the channel characteristics to be measured by the UE. This information is then fed back to the eNB to help with scheduling and link adaptation.

In LTE, link adaptation is based on Adaptive Modulation and Coding (AMC). AMC can adapt modulation scheme and coding rate in the following way. Modulation Scheme: if the SINR sufficiently high, higher order modulation schemes with higher spectral efficiency like 64-QAM are used. In the case of poor SINR a lower-order modulation scheme like QPSK, which is more robust against transmission errors but has a lower spectral efficiency, is used. Code Rate: for a given modulation scheme, an appropriate code rate can be chosen depending on the channel quality. The better the channel quality, the higher the code rate is used and of course the higher the data rate [21].

At the mobile receiver, three types of channel-state report are generated and transmitted to the eNB. 1) The CQI, a measure of DL radio channel quality that specifies the best modulation constellation and coding rate to match the link quality. 2) The Precoding Matrix Indicator (PMI), a measure that indicates the best set of precoding matrices for use in closed-loop single-and multi-user spatial multiplexing modes of the LTE standard. 3) The Rank Indicator (RI), which signals the number of useful transmission layers that can be used by the transmitter in spatial multiplexing modes [20].

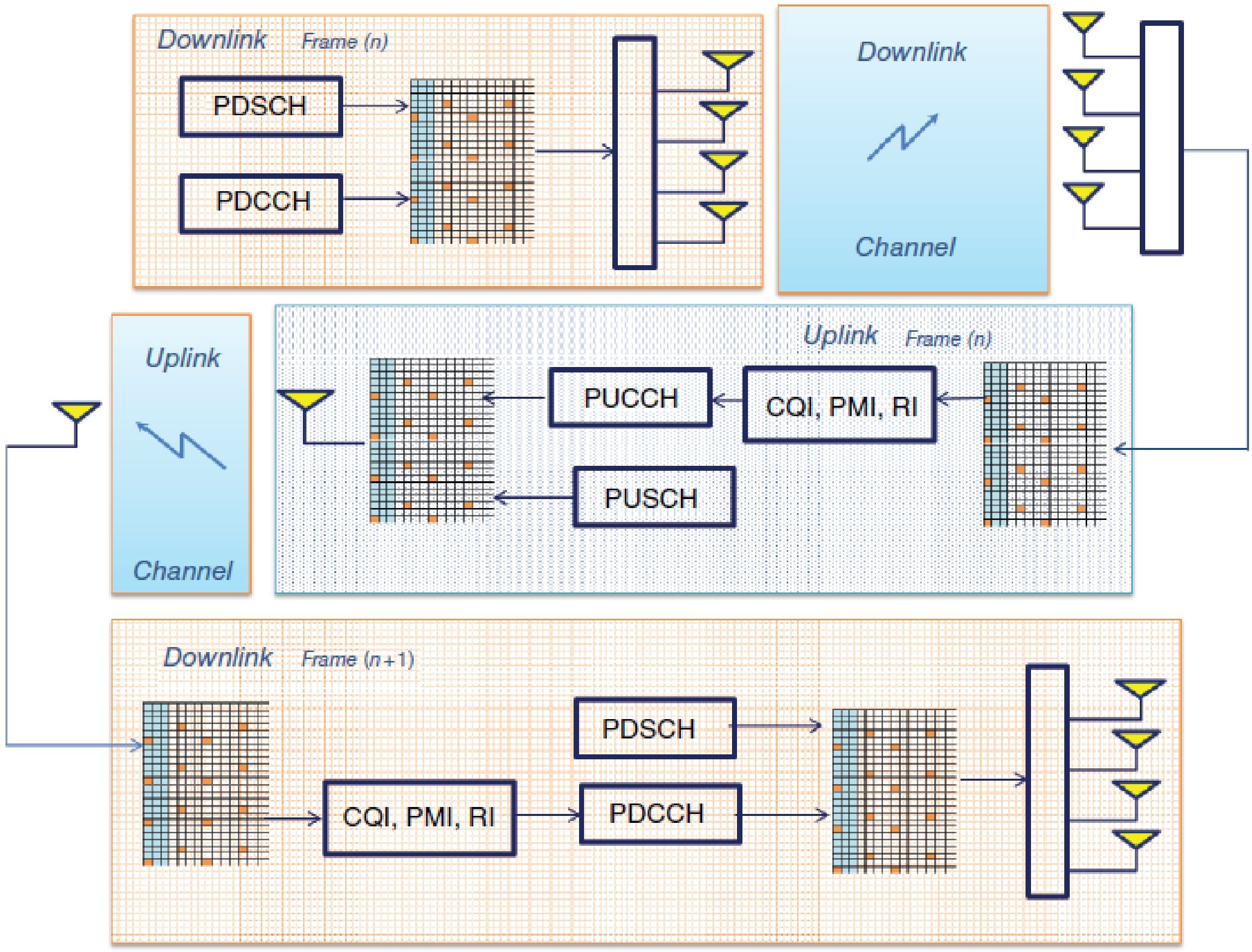

Figure 2.6: Sequence of DL and UL Operations Involved in Link Adaptations [20]

2.3 LTE Network Planning

In wireless communications, a multi-path channel is the one that describes the medium between the UE and the eNB. Path loss models are important in the RF planning phase to be able to predict coverage and link budget among other important performance parameters. These models are based on the frequency band, type of deployment area (urban, rural, suburban, etc.), and type of application.

The planning of wireless communication networks in urban scenarios is based on accurate propagation models for the prediction of the path loss between fixed base station (eNB) antennas and mobile terminals. Many different approaches have been investigated during the last years to obtain accurate and fast propagation models. Today either statistical/empirical models or ray-optical models are used [23].

Empirical Propagation Models: They are based on the direct ray between transmitter and receiver [23]. In urban scenarios, this ray passes over the rooftops and is not always dominant as it is highly attenuated. Ray-optical Propagation Models: up to hundreds of rays are computed for each receiver [23]. The contribution of all rays is superposed to obtain the received power. In most cases, only 2 or 3 rays are contributing more than 95% of the energy. The computation and processing time is very long. During processing the database is divided into tiles and segments and the visibility between these tiles and segments is determined. As databases consist of a large number of tiles and segments, this process can take a considerable amount of time. A new model is required to overcome the disadvantages of both models, the Dominant Path Model, which discussed in Chapter five. Three models that will be used in LTE are discussed below.

CQI Index	Modulation	SINR Estimate (dB
1	QPSK	-6.7
2		-4.7
3		-2.3
4		0.2
5		2.4
6		4.3
7	16-QAM	5.9
8		8.1
9		10.3
10	64-QAM	11.7
11		14.1
12		16.3
13		18.7
14		21.0
15		22.7

Table 2.1: Lookup Table for Mapping SINR Estimate to Modulation Scheme [20]

Minimum Instantaneous DL SNR Values (dB)	Modulation Scheme
1.7	QPSK
3.7	
4.5	
7.2	16-QAM
9.5	
10.7	
14.8	64-QAM
16.1	

Table 2.2: DL SNR Values and Modulation Scheme Mapping for LTE [22]

Okumura-Hata

The Okumura-Hata model is a widely used wireless cellular propagation model that can predict channel behavior in the 150–2200 MHz range. It covers distances from 1 to 20 km. The model has three environment formulas [13]:

- Typical Urban

$$L_{P(urban)} = 69.55 + 26.16\log(f_c) + (44.9 - 6.55\log(h_{Bs})\log(d)) - 13.82\log(h_{Bs}) - a(h_{UE}) \quad dB \tag{2.5}$$

where f_c is the carrier frequency $400 \leq f_c \leq 2200$ MHz, $h_{BS} \in [30, 200]$ m and $h_{UE} \in [1, 10]$ m are the base station and mobile station heights, respectively, $d \in [1, 20]$ km is the distance between the Base Station (BS) and UE, and $a(h_{UE})$ is the UE antenna height correction factor. For $fc \geq 400$ MHz, $a(h_{UE)}$ given by

$$a(h_{UE}) = \begin{cases} 3.2[\log(11.75h_{UE})]^2 - 4.97, & Denseurban; \\ [1.1\log(f_c) - o.7]h_{UE} - [1.56\log(f_c) - 0.8], & Urban \end{cases} \tag{2.6}$$

- Typical Suburban

$$L_{P(suburban)} = L_{P(urban)} - 2[\log(\frac{f_c}{28}) - 5.4] \quad dB \tag{2.7}$$

- Rural

$$L_{P(rural)} = L_{P(urban)} + 18.33\log(f_c) - 4.78(\log(f_c))^2 - 40.94 \quad dB \tag{2.8}$$

COST 231

Cooperation in Science and Technology (COST)-231 is one of the models anticipated to be used for LTE channel prediction. It covers frequencies from 800 to 2000 MHz, and distances from the BS starting at 20 m and up to 5 km. It is widely used in Europe for the GSM 1800-MHz system. The model is valid for $h_{BS} \in [4, 50]$ m and $h_{UE} \in [1, 3]$ m. The path loss formula is given by [13]:

$$L_P = 32.4 + 20\log(d) + 20\log(f_c) + L_{rts} + L_m \quad dB \tag{2.9}$$

where L_{rts} and L_m are the rooftop to street diffraction and scatter factor and multiscreen loss, respectively. The formulas for these two factors are given by

$$L_{rts} = 10\log(f_c) + 20\log(h_r - h_{UE}) + L_\phi - 10\log(W) - 16.9 \quad dB \tag{2.10}$$

$$L_m = L_{Bs2B} + K_a + K_d\log(d) + K_f\log(f_c) - 9\log(b) \quad dB \tag{2.11}$$

where, h_r is the average building height, W is the street width, b is the distance between adjacent buildings, L_ϕ is the loss due to the incident angle relative to the street, and L_BS2B is the loss factor due to the difference between the BS and average building height. The various relationships are given by (all in dB)

$$L_\phi = \begin{cases} -10 + 0.354\phi, & 0 \leq \phi \leq 35°; \\ 2.5 + 0.075(\phi - 35), & 35 \leq \phi \leq 55°; \\ 4 - 0.114(\phi - 55), & 0 \leq \phi \leq 35°. \end{cases} \tag{2.12}$$

$$L_{BS2B} = \begin{cases} -18\log(11 + h_{BS} - h_r), & h_{BS} \geq h_r; \\ 0, & h_{BS} < h_r. \end{cases} \tag{2.13}$$

$$K_a = \begin{cases} 54, & h_{BS} > h_r; \\ 54 - 0.8h_{BS}, & d \geq 500m, h_{BS} \leq h_r; \\ 54 - 0.8h_{BS}(\frac{d}{500}), & d < 500m, h_{BS} \leq h_r. \end{cases} \tag{2.14}$$

$$K_d = \begin{cases} 18, & h_{BS} < h_r; \\ 18 - \frac{15(h_{BS}-h_r)}{h_{UE}-h_r}, & h_{BS} \geq h_r. \end{cases} \tag{2.15}$$

$$K_f = \begin{cases} 4 + 0.7(\frac{f_c}{925} - 1), & midsize\ city/suburban; \\ 4 + 1.5(\frac{f_c}{925} - 1), & metro\ area. \end{cases} \tag{2.16}$$

IMT-2000

International Mobile Telecommunications (IMT-2000) is the standard that includes the system requirements for 3G-based cellular systems from which UMTS is derived. This standard has the following several propagating environment models for outdoor and indoor channels [13].

Indoor environment: this model covers indoor scenarios with small cells and low transmit power levels. It is suitable for Root Mean Square (RMS) delay spread values of 35–460 nsec. It uses a log-normal shadowing with a 12-dB standard deviation. The path loss is given by [13]:

$$L_{P(indoor)} = 37 + 30\log(d) + 18.3n[\frac{n+2}{n+1} - 0.46] \quad dB \tag{2.17}$$

where d is the distance between the transmitter and receiver stations, and n is the number of floors.

Pedestrian and outdoor-to-indoor environment: the model uses small cells, with low transmit power levels, and RMS delay spread of 100–800 nsec. It covers only None Line of Sight (NLOS) scenarios, and utilizes a log-normal shadowing with a 10-dB standard deviation. The path loss is given by

$$L_{P(ped-out2in)} = 40\log(d) + 30\log(f_c) + 49 \quad dB \tag{2.18}$$

Vehicular environment: the model covers large cells and higher transmit power levels, with an RMS delay spread of 4–12 μsec. A log-normal shadowing with a 10-dB standard deviation is used. The path loss formula is given by

$$L_{P(vehicle)} = 40(1 - 4 \times 10^{-2}\Delta h_{BS})\log(d) - 18\log(\Delta h_{BS}) + 21\log(f_c) + 80 \quad dB \tag{2.19}$$

where Δh_{BS} is the BS antenna height measured from the average rooftop level of the vehicle in meters.

2.4 LTE Performance

Enhanced Air Interface Allows Increased Data Rate

LTE is built on an all-new radio access network based on OFDMA technology. Specified in 3GPP Release 8, the air interface for LTE combines OFDMA-based modulation and multiple access scheme for the downlink, together with SC-FDMA for the uplink. The result of these radio interface features is significantly improved radio performance, yielding up to five times the average throughput of HSPA. Downlink peak data rates are extended up to a theoretical maximum of 300 Megabits per second (Mbps) per 20 MHz of spectrum. Similarly, LTE theoretical uplink rates can reach 75 Mbps per 20 MHz of spectrum, with theoretical support for at least 200 active users [24] per cell in 5 MHz.

Higher Spectral Efficiency

LTE's greater spectral efficiency allows operators to support increased numbers of customers within their existing and future spectrum allocations, with a reduced cost of delivery per bit.

Flexible Radio Planning

LTE can deliver optimum performance in a cell size of up to 5 km. It is still capable of delivering effective performance in cell sizes of up to 30 km radius, with more limited performance available in cell sizes up to 100 km radius [24].

Reduced Latency

By reducing round-trip times to 10ms or even less (compared with 40–50ms for HSPA), LTE delivers a more responsive user experience. This permits interactive, real-time services such as high-quality audio/videoconferencing and multi-player gaming.

An all-IP Environment

One of the most significant features of LTE is its transition to a 'flat', all-IP based core network with a simplified architecture and open interfaces. Indeed, much of 3GPP's standardisation work targets the conversion of existing core network architecture to an all-IP system. Within 3GPP, this initiative has been referred to as SAE – now EPC. SAE/EPC enables more flexible service provisioning plus simplified interworking with fixed and non-3GPP mobile networks.

Co-existence with Legacy Standards and Systems

LTE users should be able to make voice calls from their terminal and have access to basic data services even when they are in areas without LTE coverage. LTE therefore allows smooth, seamless service handover in areas of HSPA, WCDMA or GSM/GPRS/EDGE coverage. Furthermore, LTE/SAE supports not only intra-system and inter-system handovers, but inter-domain handovers between packet switched and circuit switched sessions.

Extra Cost Reduction Capabilities

The introduction of features such as a Multi-Vendor Radio Access Network (MVR) or Self Optimizing Network (SON) should help to reduce operating expense and provide the potential to realize lower costs per bit.

Summary of LTE Benefits

1. LTE is based on packet-switched transmission i.e.,
    - It is more flexible in managing available network resources
    - Increases network utilization and reduces waste of limited network resources

2. Reduce packet delay:
    - Achieved by simplifying the network architecture
3. Higher throughput over its radio access - advanced radio interface
    - Advanced Multiplexing - OFDM
    - More advanced modulation - up to 64-QAM
    - Sophisticated transceivers - MIMO technology

2.5 LTE for Railway

GSM-R is an international wireless communications standard for railway communication and applications [25]. In railway transportation, GSM-R has widely used communication technology. GSM-R has lack of capacity, limited data transmission capabilities and inefficient in radio resource usage. These limitations are the driving forces to adopt other advanced communication technologies. Nowadays LTE is used to address the above problems.

4G is basically the extension of the 3G technology with more bandwidth and services offers in the 3G. 4G will offer many advancements to the wireless market, including downlink data rates well over 100 Mbps, low latency, very efficient spectrum use and low-cost implementations. With impressive network capabilities, 4G enhancements promise to bring the wireless experience to an entirely new level with impressive user applications, such as sophisticated graphical user interfaces, high-end gaming, high definition video and high-performance Ad-hoc and multi-hop networks (the strict delay requirements of voice make multi-hop network) [10].

Provides a Number of Capacity and Capability Advantages

LTE can address all of the major shortcomings of GSM-R. The benefits of LTE are described under Overview of LTE. LTE backbone [EPC] provides support for legacy 3GPP technologies such as GSM, which should ease the expected transition phase [4].

Improved End-to-End Performance and Reliability

Existing GSM-R services are expected to improve their performance while migrating to the flat, all-IP LTE infrastructure, especially services related to end-to-end delay. Another benefit from the LTE architecture is the reduction of NEs, which has, as a result, reduced the number of potential failures. Other features, like the MME pool, further improve network reliability [26].

Prevents Interference

LTE uses OFDM sub-carrier scheduling to detect frequency interference. This is a leading reference signal design that quickly and accurately detects interference by tracing channel changes on time and frequency domains. In addition, the simultaneous response of multiple LTE terminals helps speed the response to interference [26].

To avoid interference, LTE provides a complete mechanism for coding, re-transmission, and Interference Rejection Combining (IRC). This microsecond-level scheduling mechanism ensures that the LTE network schedules resources in a timely and dynamic manner. When detecting interference, or cross-talk, the sub-carrier with the highest Carrier/Interference (C/I) ratio will be allocated. LTE also provides AMC, which will dynamically adjust the modulation and coding method according to the RSRP and SINR, which further increase LTE's interference prevention capability [26]. To control interference inside the network, LTE provides a complete power control mechanism. Moreover, algorithms such as Inter-Cell Interference Coordination (ICIC) and Coordinated Multi-Point (CoMP) further improve LTE's capability to control interference. Depending on the measures employed, LTE can still provide some bandwidth to provide services with QoS guarantees when encountering interference [26].

Strong Security Defense

Security is an important feature of LTE networks. Measures are taken on User Identity Confidentiality, Entity Authentication, UE Authentication, Confidentiality and Integrity for Signaling and User Data, NAS Security, etc [26].

Chapter 3 Optimization of LTE Network

The interface between the UE and eNB is radio (air) interface and it has many parameters or radio parameters. That is there are many radio performance issues between them. Removing all issues facing the network by finding out the problem and finding out the solution is the process of optimization. Optimization can be at site, cluster or market levels. Generally, optimization is conducted to improve the network quality and to have good network performance.

The optimization of LTE network mainly refers to the pre-optimization and the continuous optimization before and after the network launched. Network optimization results and the level of network optimization work, directly related to the future performance of the network stability and capacity. A good network optimization can fully reduce interference level of the whole network, improve the network performance and call success rate, reduce service interruption, improve the data throughput, optimize the whole network handover success rate, and improve the network capacity. Optimization is necessary so the network performance satisfies certain thresholds or targets for KPI agreed beforehand with the operator. The required KPIs to be addressed during optimization are RSRP, RSRQ, Received Signal Strength Indicator (RSSI) and SINR [27].

3.1 QoS Measurement KPIs

Resource Blocks (RB)

RB is the physical amount of bandwidth which can be scheduled on the eNB and are allocated to the UE [28]. RB is the smallest unit that can be allocated to a user. It physically occupies $180\ KHz$ in frequency and $0.5\ ms$ in time. LTE supports flexible bandwidth that is 1.4, 3, 5, 10, 15 and $20\ MHz$. LTE has 12 sub-carriers in a resource block, and each sub-carrier has $15\ KHz$ bandwidth. Thus, a RB has $12 \times 15\ KHZ = 180\ KHz$ bandwidth. Mathematically number of RB is expressed as [28],

$$\#RB = \frac{Effective\ Bandwidth}{Bandwidth\ of\ One\ RB} \tag{3.1}$$

Except for $1.4\ MHz$ the effective/configuration bandwidth is $0.9 \times Bandwidth$ i.e. 10% less than the assigned bandwidth. The 10% bandwidth is used for guard band.

System Bandwidth (MHz)	1.4	3	5	10	15	20
Effective Bandwidth (MHz)	1.08	2.7	4.5	9	13.5	18
Sub-carrier Bandwidth (KHz)	15					
Physical Resource Block (PRB) (KHz))	180					
Number of Available PRBs	6	15	25	50	75	100

Table 3.1: Physical Resource Block (PRB)

Physical Throughput

Physical throughput can be defined as the actual throughput of data being transmitted in the physical layer.

Reference Signal Received Power (RSRP)

RSRP is the most basic of the physical layer measurements. Providing the UE with knowledge of absolute RSRP, is essential, since it provides information about the strength of the cells from which path loss can be calculated, and afterwards used in optimization algorithms [28].

Received Signal Strength Indicator (RSSI)

RSSI represents the entire received power, which is radiated on to UE, including wanted power from the serving cell, as well as all other co-channel power and noise [28].

Reference Signal Received Quality (RSRQ)

Given RSRP and RSSI, the RSRQ is an important measure, since it is defined as a ratio between RSRP and RSSI [28]. A mathematical expression of RSRQ can be seen in equation 3.2 [28].

$$RSRQ = \#RB_{dB} + \frac{RSRP}{RSSI} \tag{3.2}$$

$$RSRQ = 10 \times log10(\#RBs) + RSRP_{dB} - RSSI_{dB} \tag{3.3}$$

Signal-to-Interference plus Noise Ratio (SINR)

SINR is a measure which calculates the ratio between the wanted signal and levels of interference and noise. It can be expressed mathematically as [28],

$$SINR = \frac{P}{I + N} \tag{3.4}$$

where, P is the signal power, I is interference power and N is the noise power

Channel Quality Indicator (CQI)

The CQI report, uses measurements performed on the downlink conditions, in order to report to the scheduler on which combination of modulation and coding would have resulted in 10% Block Error Rate (BLER), if this combination had been used [28]. The method how the UE reports CQI to the eNB is shown in Figure 3.1.

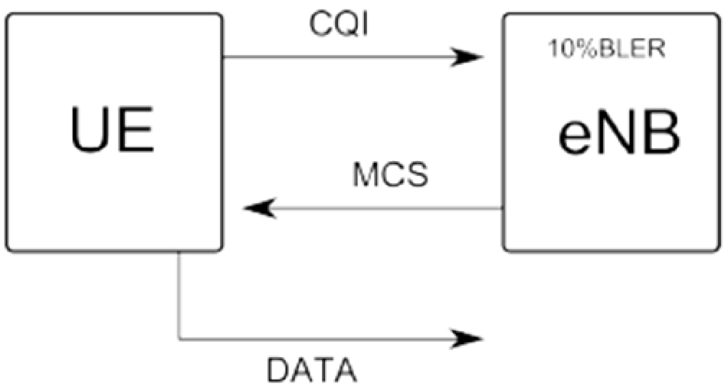

Figure 3.1: UE reporting CQI to the eNB [28]

Modulation and Coding Scheme (MCS)

After the CQI has been reported, the eNB responds with an MCS index. MCS is an index from 0 to 31 which indicates to the UE, what the modulation and coding it should transmit on next. In Figure 3.1 the UE receives the MCS index and on the basis of this information the data can be transmitted back with the chosen modulation and coding [28].

3.2 QoS Measurement Methods

3.2.1 Network Management System

Operation and Maintenance Client (OMC) NMS of LTE network provides device management and operation management at the same time. OMC manages eNB, Core Network (CN), terminal device and business software equipment as well as providing independent operation management.

The key counters used to generate the KPIs of the network, which are defined on the OMC, are predefined and initialized as soon as the eNB starts. There are a few KPIs that will adversely affect end-user experience if any of these KPIs under-perform and it is critical to monitor closely the performance of these main KPIs.

Some of the AALRTS LTE network key counters are connect setup success rate, measurement related to power (average UL interference and maximum UL interference), forwarding performance measurements (S1-U incoming and outgoing user traffic peak throughput), average establishment latency and so on.

The mobile network ecosystem is nowadays complicated and OMC statistics only provide an average and flat view of the cell that are not enough to have a clear picture of the actual status [27]. Hence, Drive/Walk Test is advisable measurement method.

3.2.2 Drive/Walk Test

In LTE, as with other cellular technologies, drive testing is a part of the network deployment and management life cycle from the early onset. Drive testing provides an accurate real-world capture of the RF environment under a particular set of network and environmental conditions. The main benefit of drive testing is that it measures the actual network coverage and performance that a user on the actual drive route would experience. It is argued that in today's networks with modern simulations, network engineers can mathematicaly model how a netwrok will perform. While this is true for certain extent, it is also essential to conduct drive testing as network parameter settings alter how the UE interacts and deals with the network environment. Such interactions can not be wholly predicted through mathematical modeling [29].

3.3 Quality and Coverage Thresholds

Telecom vendors and other research works LTE coverage defined by RSRP, RSRQ, RSSI and SINR values. From the LTE coverage analysis of ZTE Corporation; if the RSRP of an area is lower than $-105\ dBm$ after being tested by an antenna it is defined as weak coverage. If the RSRP value is less than $-95dBm$, the QoS become unacceptable and the throughput tends to decline down to zero at approximately -108 to $-100dBm$ [9]. The average values of the LTE RF measurements serving cell RSRP $-86\ dBm$, serving cell RSRQ $-6.7\ dB$ and SINR $13.9\ dB$ [30]. The acceptable range of those parameters are tabulated in Tables 3.2 and 3.3.

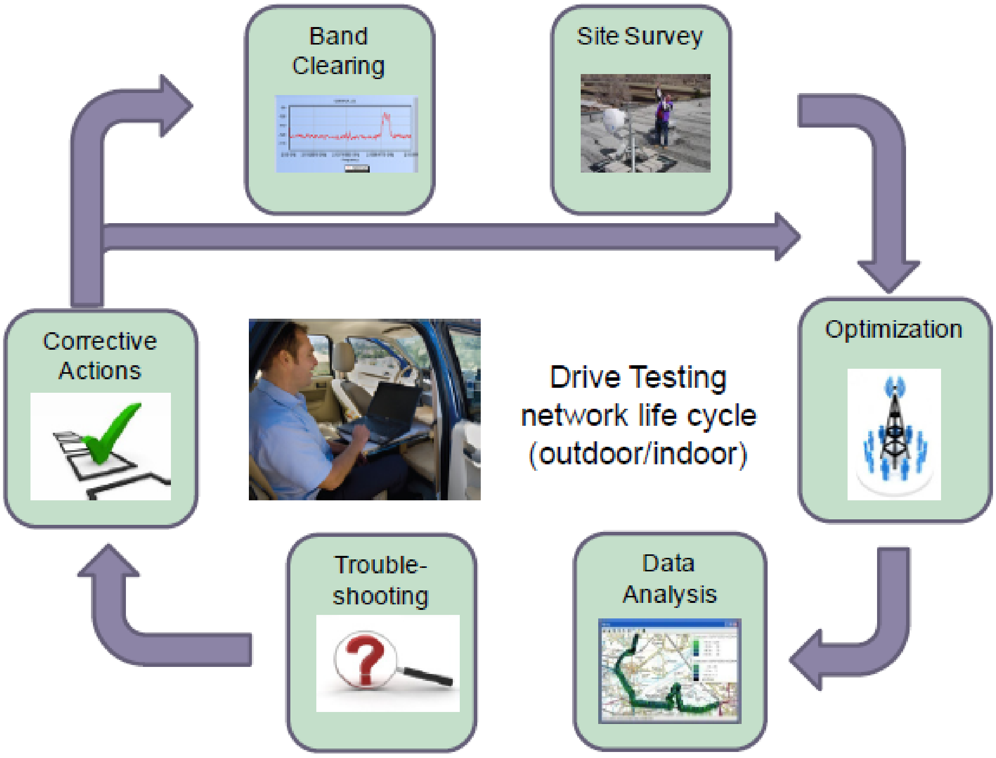

Figure 3.2: Network Planning Cycle [29]

RSRP in dBm	QoS Description
> -75	Excellent QoS
$-95 < RSRP \leq -75$	Slight degradation of QoS
≤ 95	QoS become unacceptable and throughput tend to decline

Table 3.2: RSRP Strength Thresholds [9]

RSRQ in dB	QoS Description
$> -9dB$	Guarantee the best subscriber experience
$-12 < RSRQ \leq -9$	Neutral with a slight degradation of QoS
≤ -12	Significant declines of throughput

Table 3.3: RSRQ Thresholds [9]

LTE Throughput (Data Rate)

The target of an LTE network is to improve the data rate of users. Hence, the throughput is the fundamental KPI of an LTE network. Some of the factors that contribute to LTE network throughput are SINR, multiplexing technique, number of Resource Blocks, and MIMO.

Throughput Calculation

$$\begin{aligned} Bits\ in\ a\ Subframe = RBs \times Sub - carriers\ in\ a\ RB \times Slots\ in\ a\ Sub - frame \times \\ Modulation\ Symbols\ in\ a\ Slot \times Data\ Bits\ in\ One\ OFDM\ Symbol \end{aligned} \quad (3.5)$$

RB for $3MHz$ bandwidth is 15 as shown in Table 3.1. The Sub-carriers in a RB are 12, the slots in a sub-frame are 2, the modulation symbols in a slot are 7 and a sub-frame time is $1ms$. The data bits in one OFDM symbol are depends on the modulation and coding scheme. LTE network selects MCS dynamically depending on SINR values. Let's see the three conditions of SINR values; poor, medium and excellent how it affects the throughput as shown in Table 2.2.

Weak SINR (SINR<7)

If the SINR is weak, the LTE network selects a QPSK modulation and coding scheme. Hence the data bits in one OFDM symbol will be 2.

$$Number\ of\ Bits\ in\ a\ Sub-frame = 15 \times 12 \times 2 \times 7 \times 2 = 5,040\ bits$$

$$Data\ Rate = \frac{Number\ of\ Bits\ in\ a\ Sub-frame}{Sub-frame\ time} = \frac{5{,}040\ bits}{1\ ms} = 5.04\ Mbps$$

The Data Rate for $2 \times 2\ MIMO$ is 2 times the above calculated data rate i.e. $10.08\ Mbps$. If $\frac{3}{4}$ coding is used for protecting the data, we will get $0.75 \times 10.08\ Mbps = 7.56\ Mbps$.

Medium SINR (7≤SINR<13)

If the SINR is medium, the LTE network selects a 16-QAM modulation and coding scheme. Hence the data bits in one OFDM symbol will be 4.

$$Number\ of\ Bits\ in\ a\ Sub-frame = 15 \times 12 \times 2 \times 7 \times 4 = 10,080\ bits$$

$$Data\ Rate = \frac{Number\ of\ Bits\ in\ a\ Sub-frame}{Sub-frame\ time} = \frac{10{,}080\ bits}{1\ ms} = 10.08\ Mbps$$

The data rate for $2 \times 2\ MIMO$ will be $20.16\ Mbps$. If $\frac{3}{4}$ coding is used for protecting the data, we will get $0.75 \times 20.16\ Mbps = 15.12\ Mbps$.

Excellent SINR (SINR≥13)

If the SINR is excellent, the LTE network selects a 64-QAM modulation and coding scheme. Hence, the data bits in one OFDM symbol will be 6.

$$Number\ of\ Bits\ in\ a\ Sub-frame = 15 \times 12 \times 2 \times 7 \times 6 = 15,120\ bits$$

$$Data\ Rate = \frac{Number\ of\ Bits\ in\ a\ Sub-frame}{Sub-frame\ time} = \frac{15{,}120\ bits}{1\ ms} = 15.12\ Mbps$$

The data rate for $2 \times 2\ MIMO$ will be $30.24\ Mbps$. If $\frac{3}{4}$ coding is used for protecting the data, we will get $0.75 \times 30.24\ Mbps = 22.68\ Mbps$.

Modulation and Coding Scheme	QPSK	16-QAM	64-QAM
Data Rate (in Mbps)	7.56	15.12	22.68

Table 3.4: Throughput of Different MCS Schemes

From the above data rate calculations, the throughput of 64-QAM is 1.5 times 16-QAM and 3 times QPSK throughput. The calculated throughput for 16-QAM is 2 times that of QPSK. The SINR value has a considerable effect on the throughput of the LTE network. Thus, SINR value improvement of an LTE network enhances throughput of that network.

3.4 Optimization Approaches

3.4.1 Antenna Parameter Optimization

The main method of the LTE network coverage optimization includes adjustment of the antenna azimuth, adjustment of the antenna down tilt, adjustment of the antenna height, adjustment of the location of the site, adding new sites or Remote Radio Unit (RRU) for the poor coverage area, adjustment of the Reference Signal (RS) power, and so on [27].

The target of this paper is to overcome the coverage problem of LTE network of AALRTS by tuning the antenna parameters, tilt, azimuth and height using simulation software. During optimization, the antenna parameters will be tuned separately or simultaneously. If this method could not address the coverage challenge; adding new site will be as a second option. This option may lead to additional cost.

Antenna Azimuth

The azimuth angle is the compass bearing, relative to true (geographic) north, of a point on the horizon directly beneath an observed object [31].

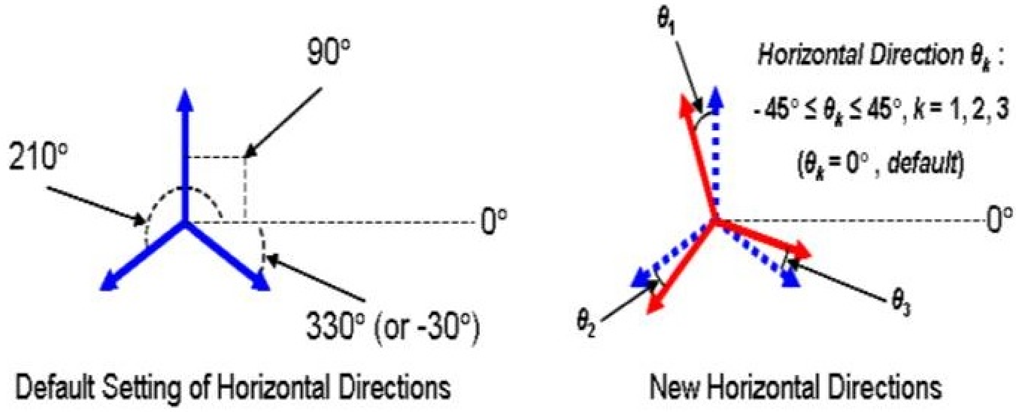

Figure 3.3: Azimuth [31]

Antenna Tilt

Antenna tilt 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 down tilt and up-tilt respectively. The antenna tilt is mainly affected by the coverage radius of the cell and the average SINR value in the coverage area, and the optimization of the tilt must take into account the balance between RF coverage and SINR [27].

Base station antenna tilting is a common technique for improving cell isolation and/or increasing coverage in cellular networks. Tilt is an important design parameter when considering coverage versus capacity during cell planning as well as when tuning live networks [32].

The Antenna Down tilt is the angle between the direction of antenna main lobe and horizon (the default setting is 8 degree). The Antenna Tilt Angle (ATA) can be adjusted mechanically or electrically.

When we change the ATA, the direction of the antenna's main lobe will be changed, and the coverage area of eNB will change accordingly [33].

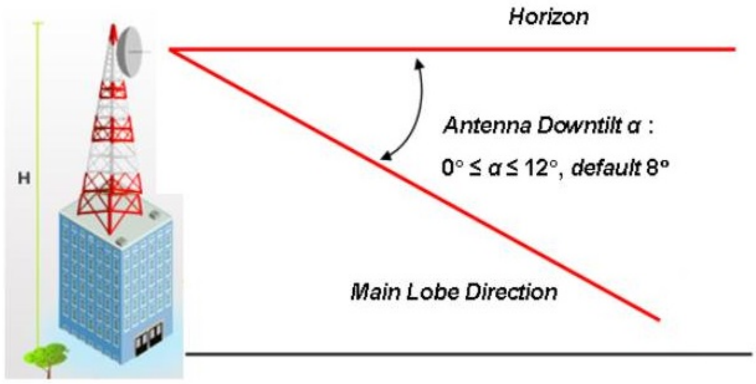

Figure 3.4: Down Tilt [31]

Antenna Height

The antenna height is the basis of base station coverage area. If the antenna height is increased path loss is lessened and on decreasing the antenna height path loss increases [34].The relationship between path loss and antenna height can be establish through the models proposed by Hata, Okumurah, Electronic and communication committee(ECC-33) and European cooperative for scientific and technical research(Cost-231) [35].

Beam Width

The antenna Beam Width along the main lobe axis in a specified plane is defined as the angle between points where the power density is one-half the power density at the peak [31].

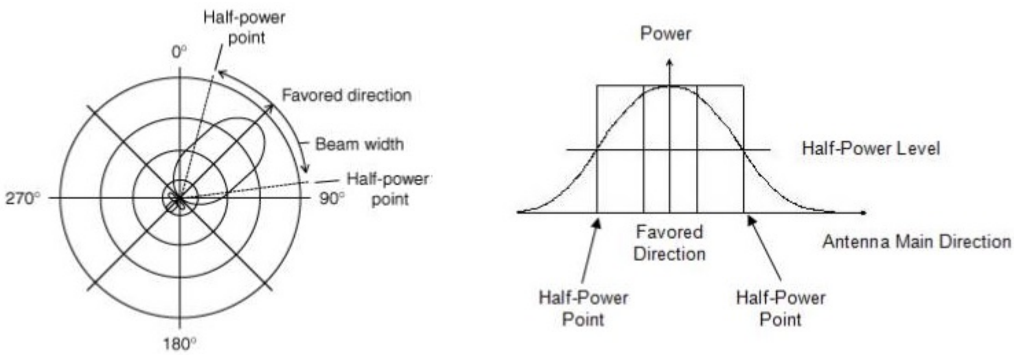

Figure 3.5: Beam Width [31]

Transmitter Power

Transmitter Power is base station (eNB) maximum transmission power having a typical value for macro cell from 43-46 dBm at the antenna connector and UE maximum transmission power of 23 dBm [36].

Antenna Directivity

Directivity is the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π (Area of sphere in steradians)

Antenna Gain

Gain is the ratio of the radiation intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically.

3.4.2 Adding New Site

In LTE coverage, optimization of antenna parameters is the fundamental solution. If this technique could not solve the coverage challenge; adding a new site is another proposed solution. To add new Site the initial question is where to locate it, that overcomes the coverage challenge at hand. A detailed study of site acquisition should be conducted.

In this work, a site survey was conducted to identify a suitable site for maximum radio coverage and construction ability. In addition to this, the nearby eNBs studied whether they can support additional site or not. The location of the site selected in the place where area coverage problem experienced. The antenna parameters height, power, azimuth, and tilt as well as the specific location coordinate selected by try and error during the simulation. In the simulation work, two scenarios considered; the first scenario was omni-directional antenna and the second one directional antenna.

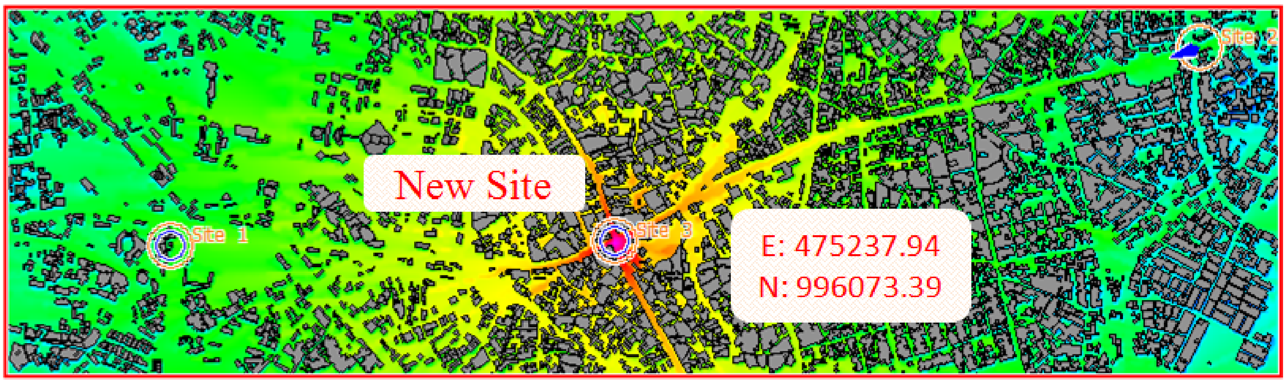

Figure 3.6: New Site Location

Chapter 4 Addis Ababa Light Railway LTE Network

4.1 Addis Ababa Light Railway

AALRTS is a semi-closed urban rail transit system. It consists of two lines East-West and North-South. The project was planned to construct two phases total of 75 km. The first phase covered 31 km and opened in September 2015. The East-West line extends 17.4 km, stretching from Ayat to Torhailoch, and passing through Megenagna, Meskel Square, Legehar and Mexico Square. The North-South line, which is 16.9 km, passes through Menelik II Square, Merkato, Lideta, Legehar, Meskel Square, Gotera and Kality. However, the two lines have a common track of about 2.7 km. These lines have 39 stations and five of them are common.

AALRTS carried on average 130,000 daily passengers and maximum of 145,000. The service frequency was 12 minutes during peak hours on both lines and 15 minutes during off-peak hours. On average there were 157 train trips on both lines 4305 train-kilometer on Line 1 and 3083 train-kilometer on Line 2.

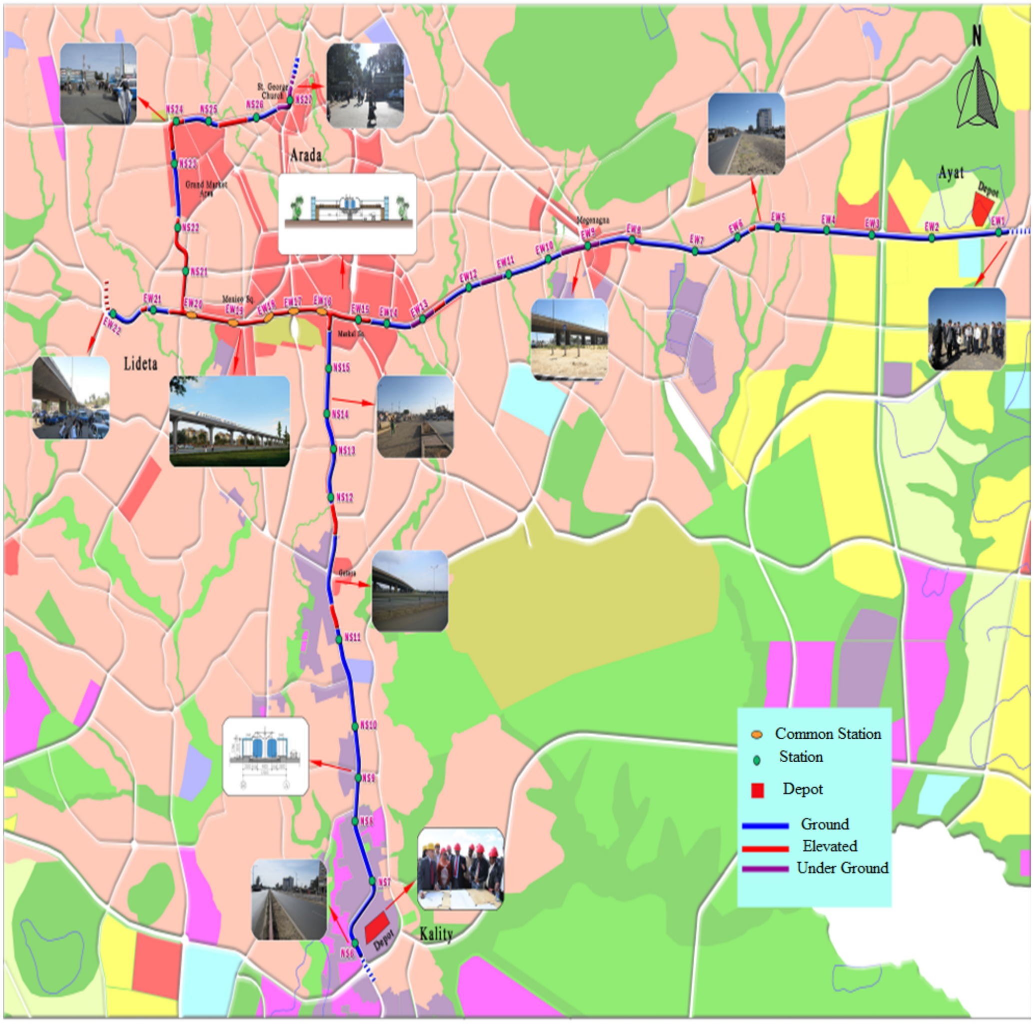

Figure 4.1: AALRTS Lines [37]

AALRTS Communication System

AALRTS communication system has deployed by Huawei Technologies. The Communication System consists of Wireless System, Transmission System, Telephone System and Intelligent Video

Surveillance (IVS) /Close Circuit Television (CCTV) System.

Wireless System: The Wireless System of AALRTS applies LTE network. It provides wireless communication services for wireless users; train drivers, operators, maintenance personnel, field workers, etc. It provides the channel for data transmission of signaling system, and transmits ticket information for ticketing system of a train.

Transmission System: The Wireless System of AALRTS applies the LTE network. It provides wireless communication services for wireless users; dispatchers, train drivers, operators, maintenance personnel, field workers, etc. It provides the channel for data transmission of the signaling system and transmits ticket information for the ticketing system of a train. The details of the Wireless System explained under next section (4.2).

Telephone System: AALRTS Telephone System used for internal office communication of Kality and Ayat depots, East-West, North-South power stations, level crossings, and lifts. It classified as a public and private telephone. It provides telephone services and some non-voice services (such as fax, etc.) as well as a variety of new features, such as alarm clock, call-waiting, call-forwarding, abbreviated dialing, etc.

IVS/CCTV: It is the modern auxiliary device for the operation and management of AALRTS and for Operation Control Center scheduling management personnel to monitor the real-time station passenger flow, incoming and outgoing trains, and the conditions at important level crossings of the line. It has the functions of remote control, historical video playback, and system management.

4.2 Addis Ababa Light Railway LTE Network

The LTE network features are low latency, a high-performance dispatching platform, and flattened network architecture. By integrating multiple networks such as the communication and ticketing networks, the system enables real-time wireless transmission of large amounts of data for the ticketing system and allows concurrent voice dispatching and data transmission. The radio communication system has the following functions: allow communication for dispatchers and radio subscribers, group and broadcast call, emergency call, system network management and data transmission functions.

The AALRTS wireless communication eNBs (sites) are located along the two lines; East-West and North-South. The sites are shown in Figure 4.2, which has taken from $GoogleMap$ and their location (latitude and longitude) is in $AppendixA$ Table A.1.

4.2.1 Network System Composition

Radio communication system consists of system equipment and wireless coverage equipment. System equipment includes central switching control equipment, on board radio set, portable radios, network management terminal, base stations, and so on. Wireless coverage equipment includes outdoor directional antennas, omni-directional antennas, outdoor antenna tower, Yagi antennas in tunnel, power divider, coupler, radio-frequency cables and so on. AALRTS LTE network consists of 1 core network and 4 eNBs of 9 cells along the two lines of Addis Ababa. The main components of the system are CN, Baseband Unit (BBU), RRU, directional, omnidirectional and Yagi antennas, and Network Management Terminals.

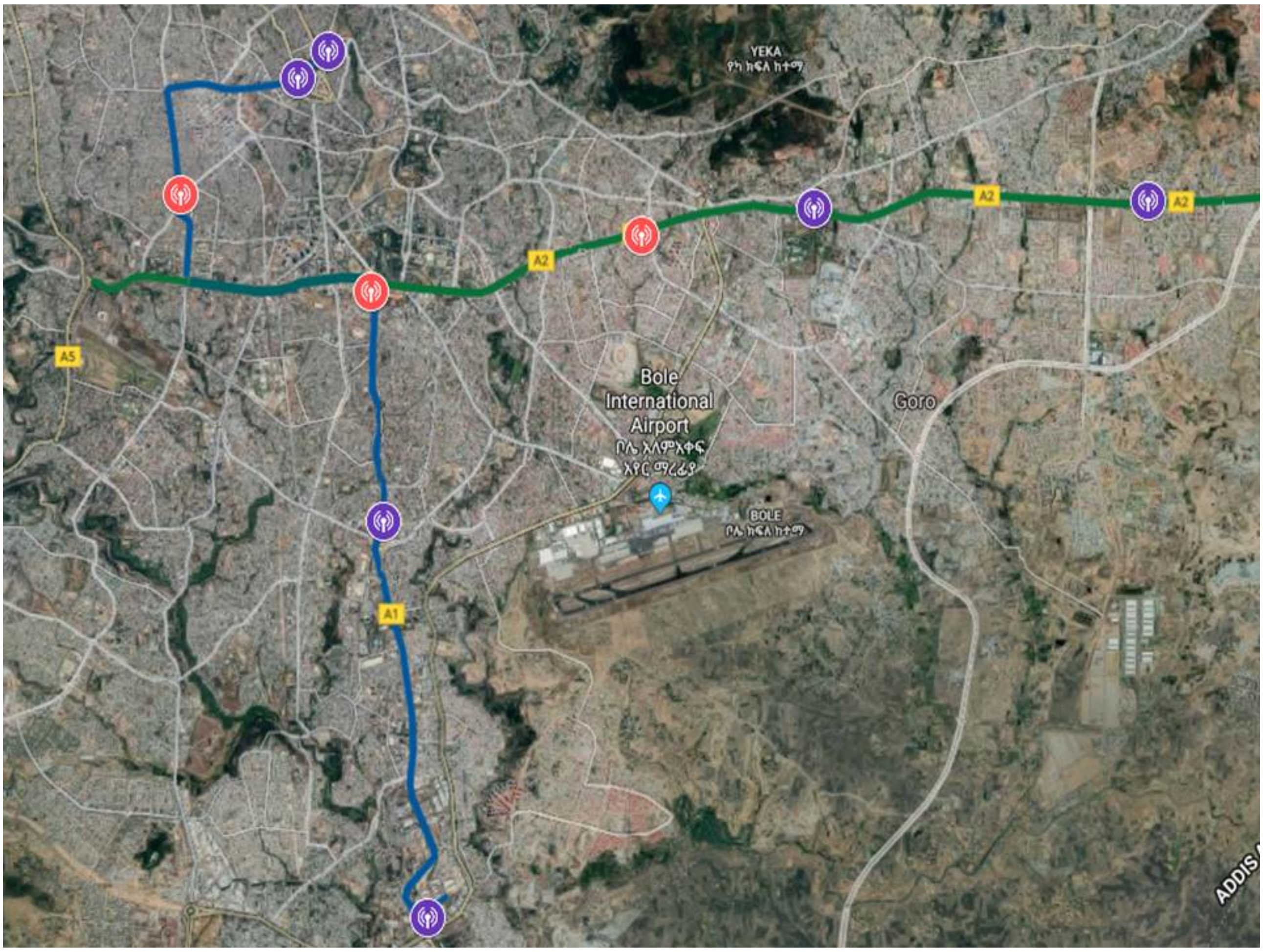

Figure 4.2: AALRTS Network Topology

4.2.2 Network Configuration

The AALRTS LTE network is a private network which operates at $400MHz$ frequency and the assigned system bandwidth is $3MHz$. The duplexing mode is Time Division Duplexing (TDD), the data channel type is Physical Uplink Shared Channel (PUSCH) and Physical Downlink Shared Channel (PDSCH) for the UL and DL respectively. The maximum UL and DL transmitter powers are $23dBm$ and $46dBm$ respectively; the MIMO scheme is 2×2 Space-Frequency Block Coding (SFBC). The existing network configuration is summarized in Table 4.1.

	Uplink	Downlink
Morphology	Urban	Urban
Frequency	$400MHz$	$400MHz$
System Bandwidth	$3MHz$	$3MHz$
Data Channel	PUSCH	PDSCH
Duplex Mode	TDD	TDD
MIMO Scheme	1×2	2×2 SFBC
Maximum Tx Power	$23dBm$	$43dBm$

Table 4.1: Network Configuration

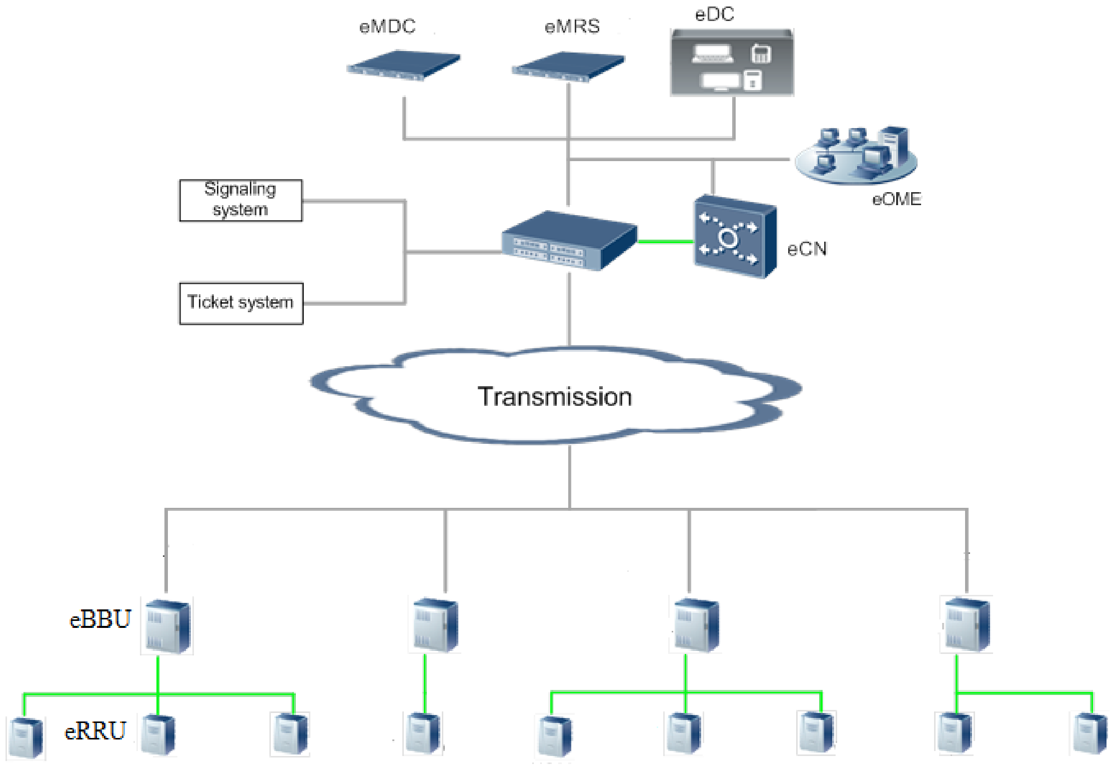

Figure 4.3: AALRTS LTE System Composition [38]

4.3 Existing Network Challenges

AALRTS LTE network faces coverage challenge in some areas along the lines shown in Figure 4.4. Existing LTE network performance evaluation has been collected from NMS for seven consecutive days. The connect setup success rate, incoming and outgoing user traffic, BLER (UL & DL QPSK), maximum traffic user, real-time attached users, and maximum and average interference counters are taken and analyzed for the cells with coverage challenge.

The average BLER of QPSK MCS for three cells is 22.5% and 15% for UL and DL respectively. Also the BLER QPSK of healthy serving cells and a cell that has coverage challenge are compared and shown in Figure 4.6. The cell with coverage challenge has greater BLER UL QPSK than the others. Healthy (normal) serving Cells' BLER UL QPSK is 2% and 7.5% which is very less than that of the cell faced coverage challenge, 22.5%. The acceptable BLER is 10% [28].

The connection setup success rate of the three cells is shown in Figure 4.7. The average connection setup success rate is around 85%. In railway communication QoS is a big issue. Hence, this connection rate is not sufficient. Incoming and outgoing user traffic peak throughput, maximum and average interference, maximum traffic user and real-time attached users graphs are enclosed in $Appendix\ A$; Figures from A.3 to A.8.

Generally, the above-collected data shows that the existing network faced coverage challenges in the identified areas. To make sure these results, drive/walk test conducted.

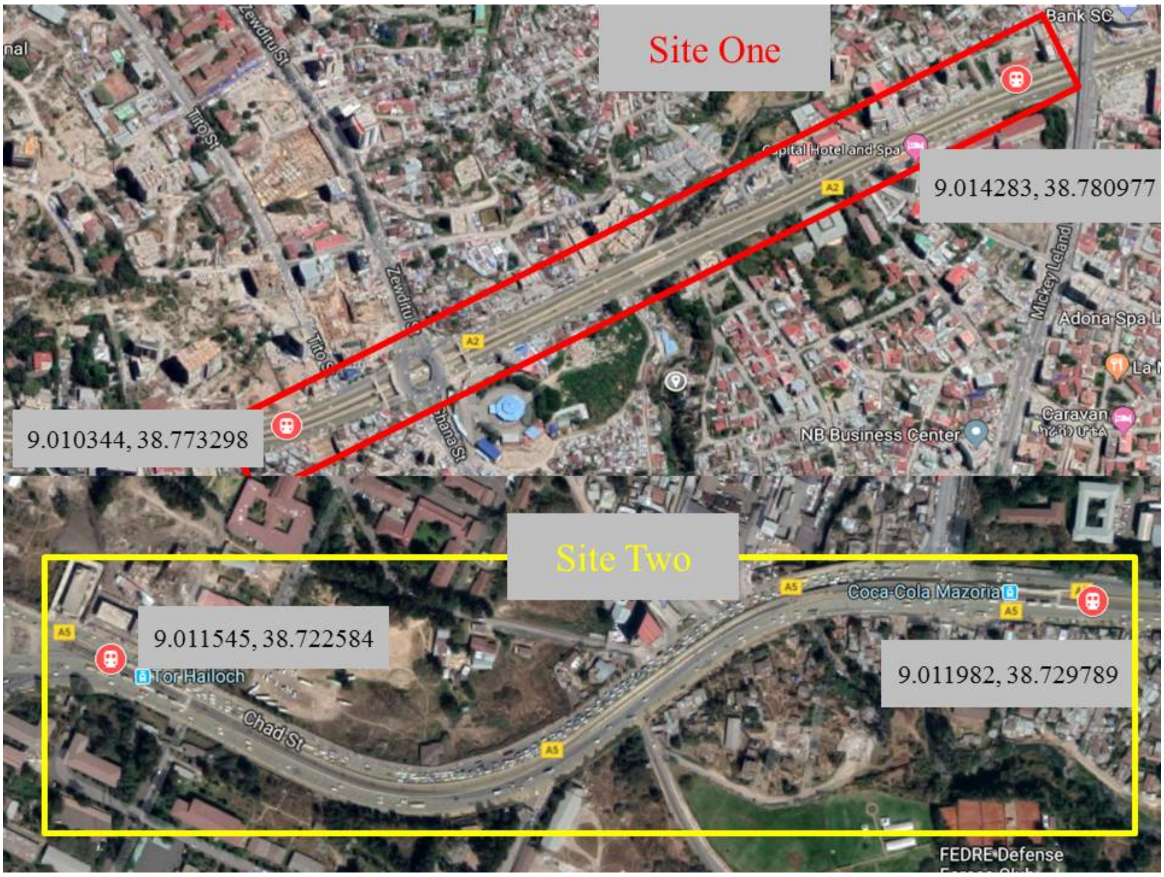

Figure 4.4: AALRTS Coverage Problem Site Locations

Modulation and Coding Scheme	QPSK		16-QAM		64-QAM	
	UL	DL	UL	DL	UL	DL
BLER (%)	22.5	15	1	0.5	0.15	0.15

Table 4.2: Existing Network Performance Evaluation

Required Services

Operators from the sites need to access NMS and Core Network (CN) to upload and download data, to make group calls, other crew members such as train masters, lift operators, ticket sellers access different services. The data rate for users in the sites is calculated as follows:

- Assume maximum number of trains in the site are eight: the data rate for single on board radio is 50 Kbps. $Data\ Rate = 8 \times 50\ Kbps = 400\ Kbps$
- To make group call: The allowed maximum groups are 20 and number of users in a group are 50 (each data rate 8 Kbps and 50 Kbps for handheld and on board radio respectively); if four groups of handheld and four trains each two radios are in active state ; $Data\ Rate = 4\times\ 50 \times 8\ Kbps + 4\times\ 2 \times 50\ Kbps = 2\ Mbps$
- Other movable radio user: Assume maximum of ten users around the site; $Data\ Rate = 10 \times 8\ Kbps = 80\ Kbps$
- Operator requires $2\ Mbps$ to access NMS

Total Data Rate = $4.48\ Mbps.$

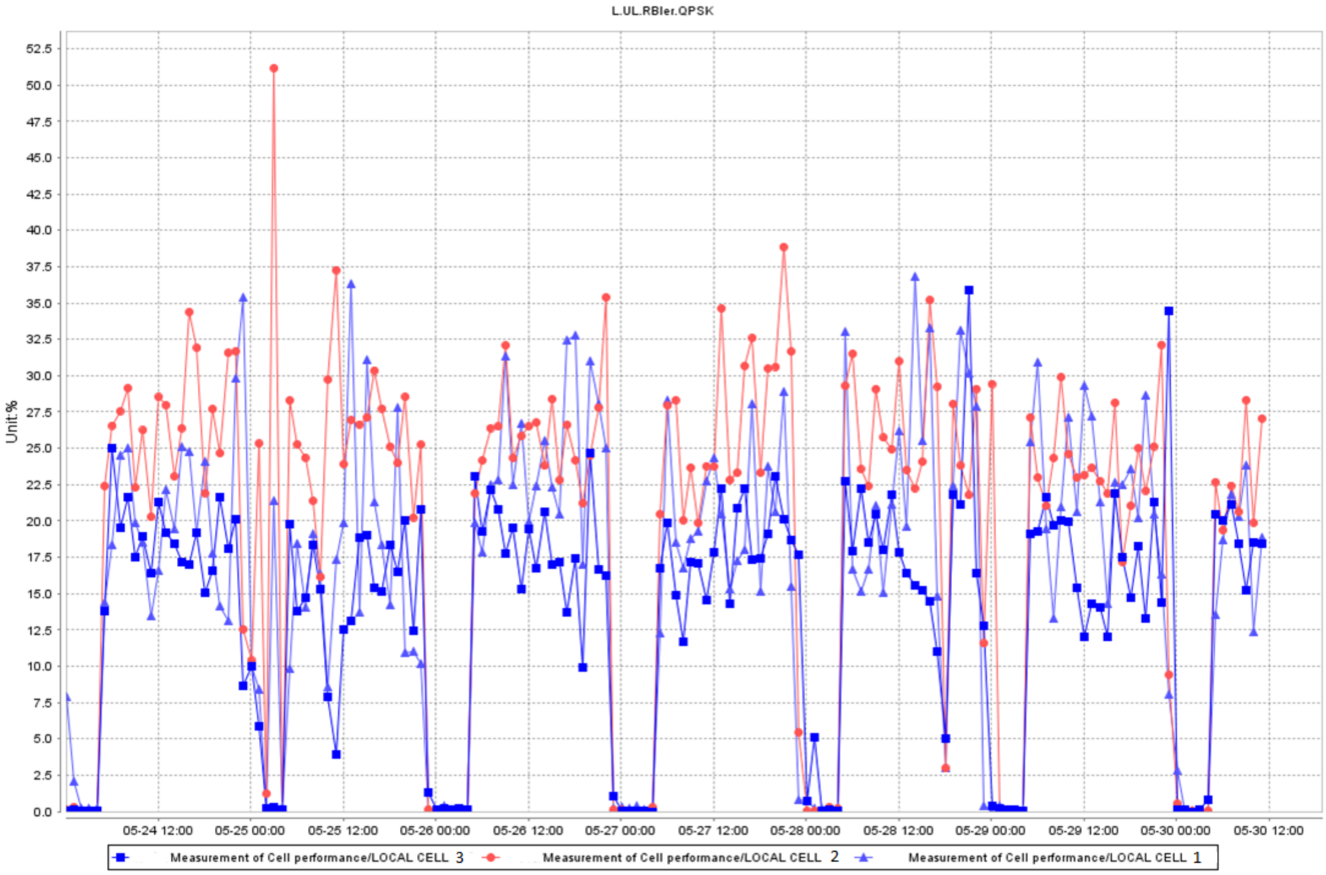

Figure 4.5: Existing Network Performance Evaluation of UL BLER QPSK

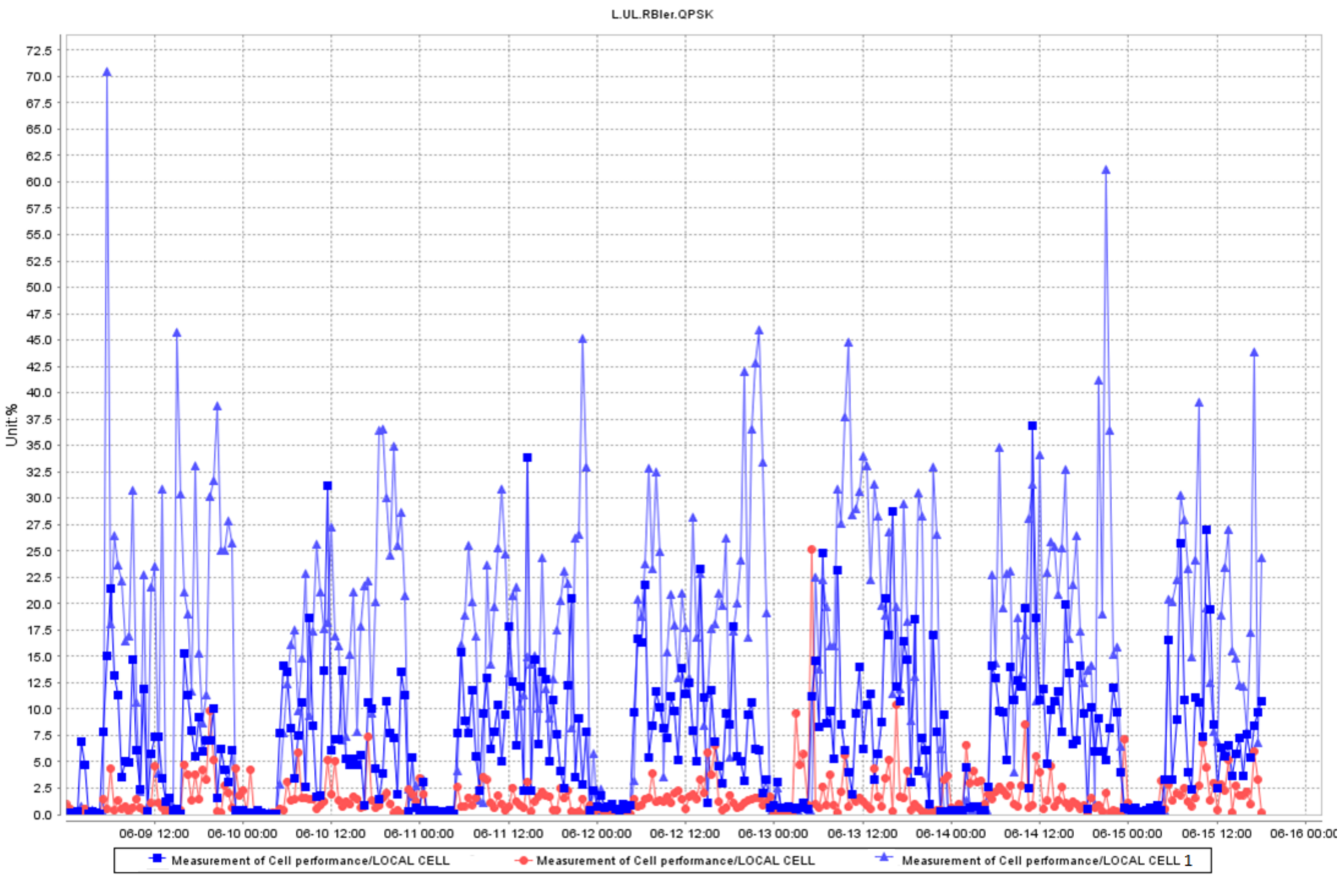

Figure 4.6: Comparison of BLER QPSK

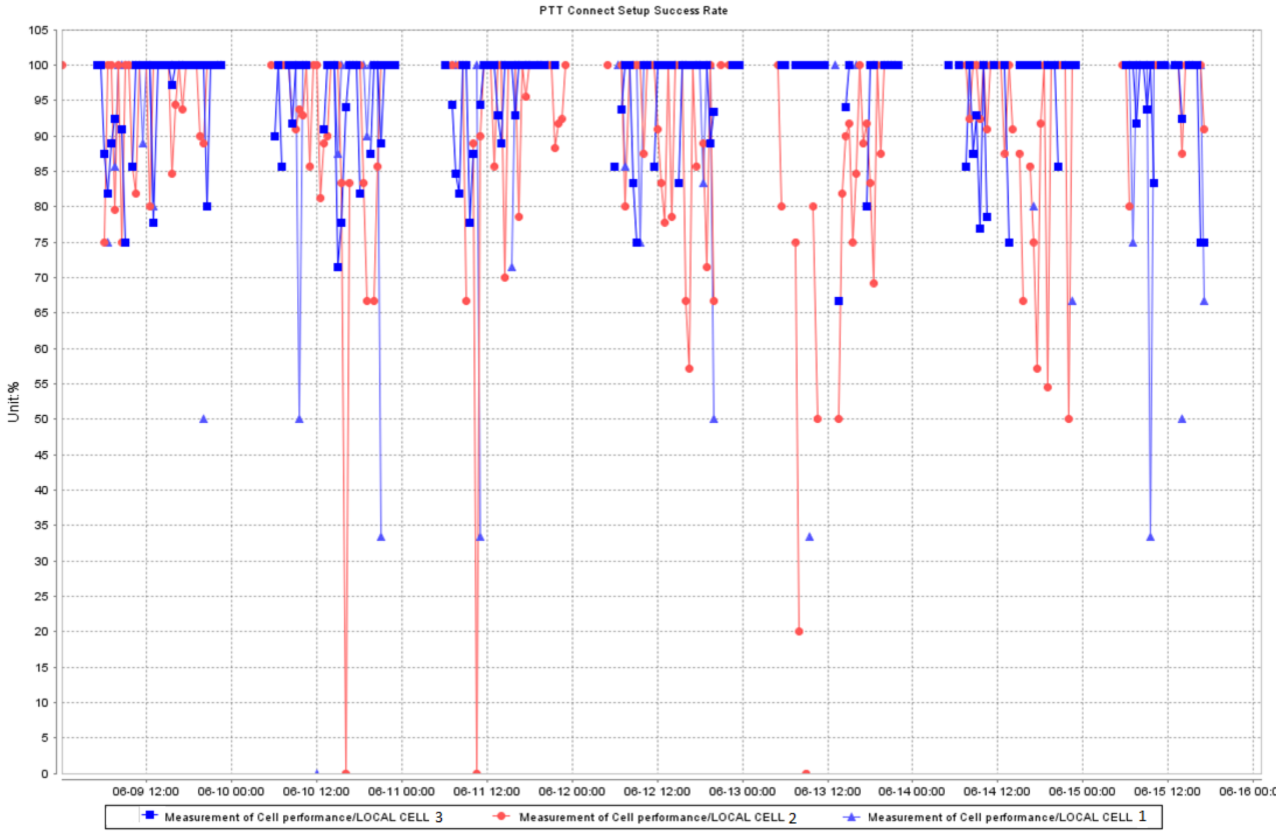

Figure 4.7: Connect Setup Success Rate

In addition to this service, ticketing system is under process for implementation (Assume four trains in a cell at the same time; single train and coupled train has 8 and 16 Point of Sale (POS) machines respectively, so 48 user can access and guaranteed bit rate is 256 Kbps: Data Rate = $48 \times 256 = 12.288 Mbps$) and considering other future expansion of services; the existing network data rate is insufficient, even it could not support the existing services in some areas. To improve the throughput of the existing network to get the desired services optimization of the network is an advisable solution.

Chapter 5 System Modeling and Optimization

In order to be able to optimize the coverage challenge of Light Railway LTE network a model had to be built which simulated the functionality of the network and the characteristics of the users. The Network Topology, Channel and Simulation Models are discussed below.

5.1 Network Topology

The AALRTS LTE network topology consists of 9 cells. The area intended to cover by the 3 red cells, in Figure 5.1 has coverage challenges. The yellow oval areas are the particular locations where wireless communication is interrupted due to the coverage challenge of the AALRTS LTE network.

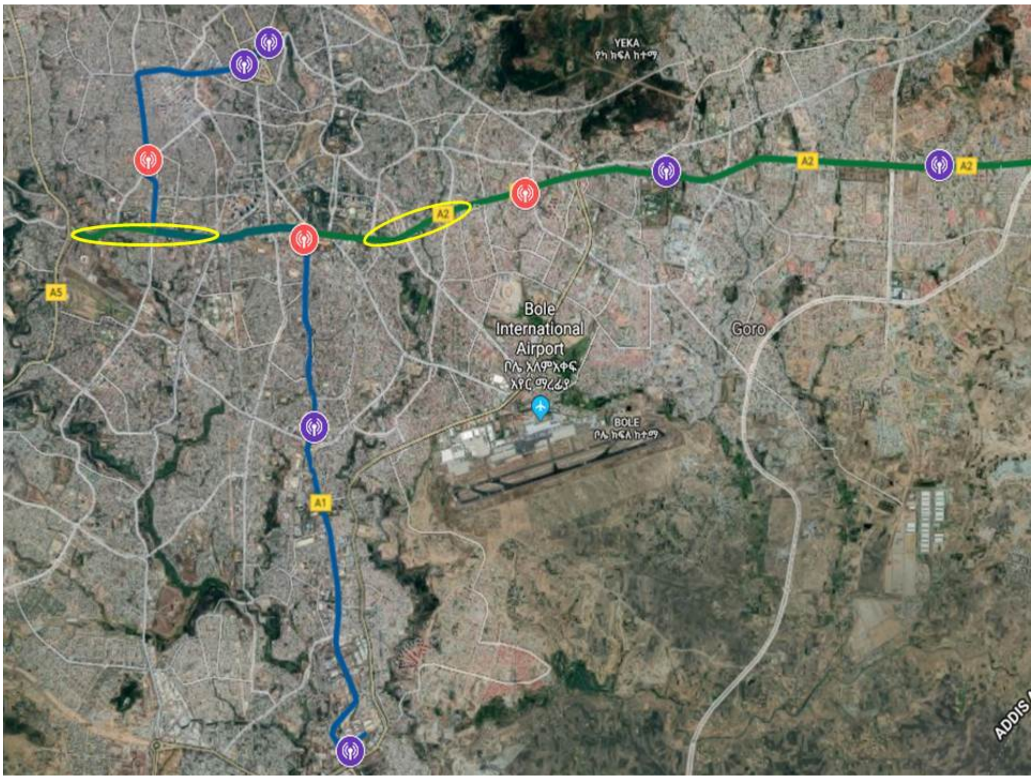

Figure 5.1: Network Topology

5.2 Antenna Pattern

The radiation pattern or antenna pattern is the graphical representation of the radiation properties of the antenna as a function of space [39]. That is, the antennas pattern describes how the antenna radiates energy out into space or how it receives energy. There are different types of antennas; among of them few antennas related to this work are discussed below.

***Omnidirectional Antenna*:** an antenna that has a non-directional pattern (circular pattern) in a given plane with a directional pattern in any orthogonal plane.

***Directional Antenna*:** is an antenna that radiates its energy more effectively in one (or some) direction than others. Typically, these antennas have one main lobe and several minor lobes.

***Sector Antenna*:** a sector antenna or sector panel is a specialized antenna frequently encountered in outdoor systems where wide coverage area required.Very often they are built from an array of dipoles placed in front of shaped reflector.

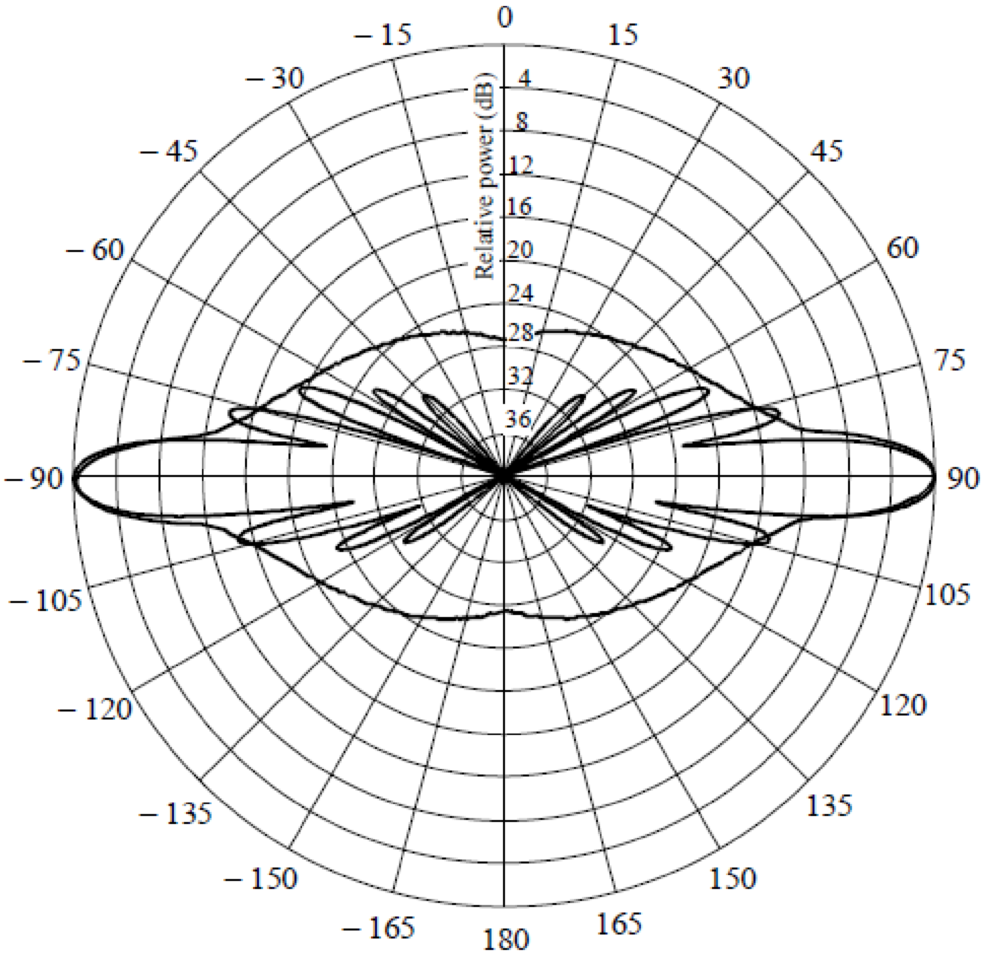

Figure 5.2: Omnidirectional 11dBi Radiation Pattern [40]

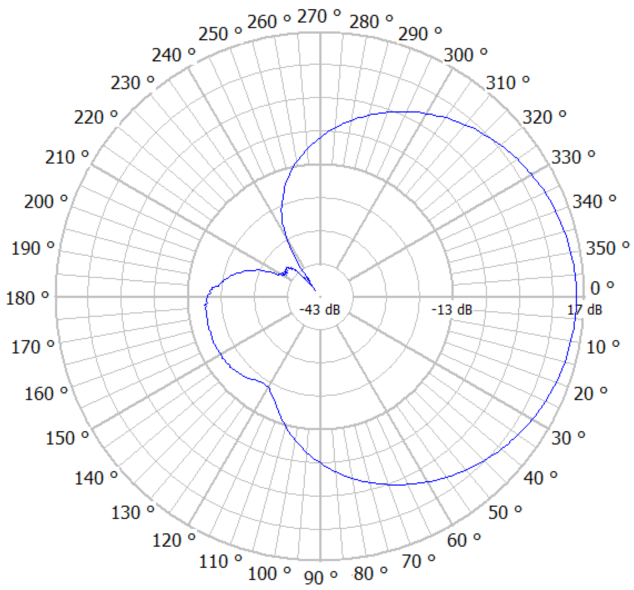

Figure 5.3: Sector Antenna 15dBi Horizontal Radiation Pattern

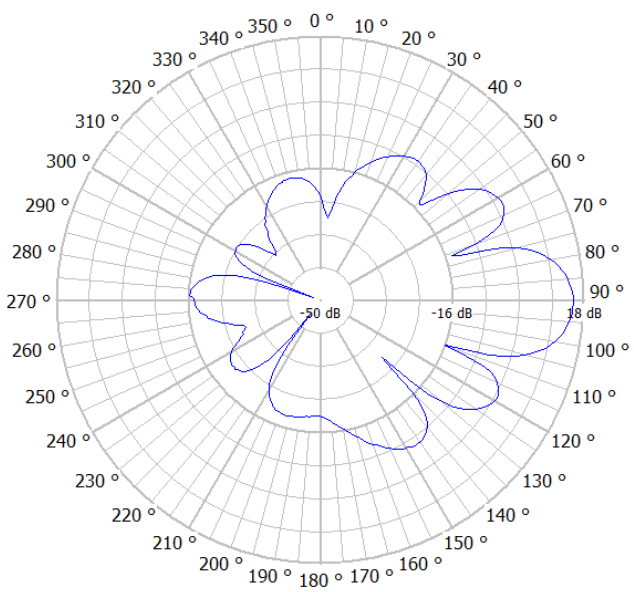

Figure 5.4: Sector Antenna 15dBi Vertical Radiation Pattern

5.3 Channel Model

Dominant Path Model

Dominant Path Model is not depend on each micro-detail in the vector database like ray-optics models. It focuses on the dominant paths and not computing hundreds of irrelevant paths. In this model simple calibration is possible with reference data [41]. Dominant path model can be subdivided into two steps: Determination of the dominant path and prediction of the path loss along the path.

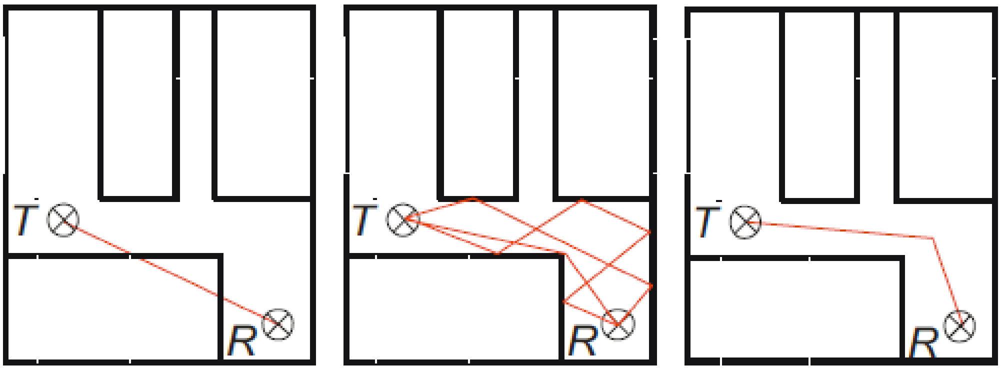

Figure 5.5: Empirical Models (left), Ray Tracing (center) and Dominant Path Model (right) [23]

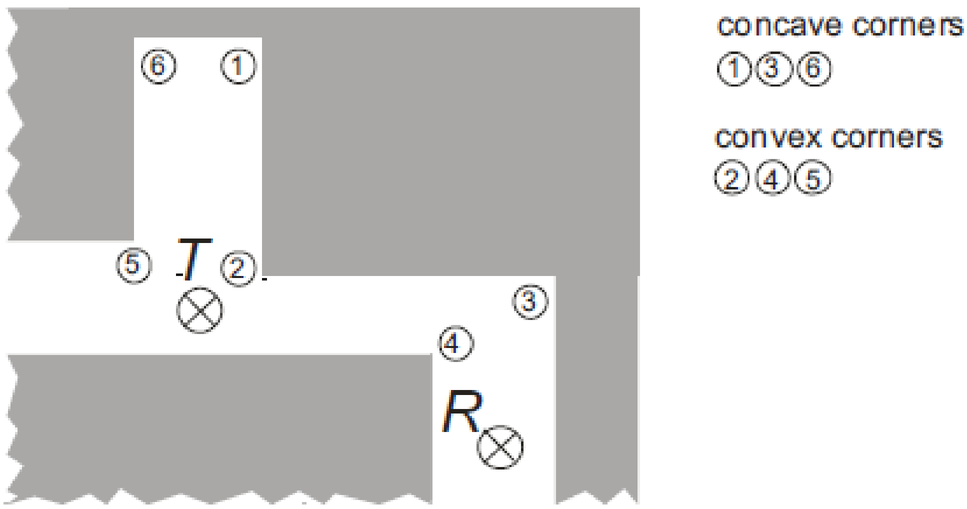

Figure 5.6: Buildings (gray), Transmitter (T), Receiver (R) and DDifferent Types of Corners [23]

Determination of the Dominant Path: the information about the arrangement of the buildings is used to determine the types of corners. The dominant path, in Figure 5.6, from T to R must lead via convex corners. For the determination of the path, a tree with all convex corners is computed. As shown in Figure 5.7, the corner-tree starts with the corners visible from the transmitter T.

Prediction of the Path Loss Along the Path: After computation of the tree, the algorithm has to decide which path is the best. The prediction of the path loss along the propagation path is used to decide which path is the best one.

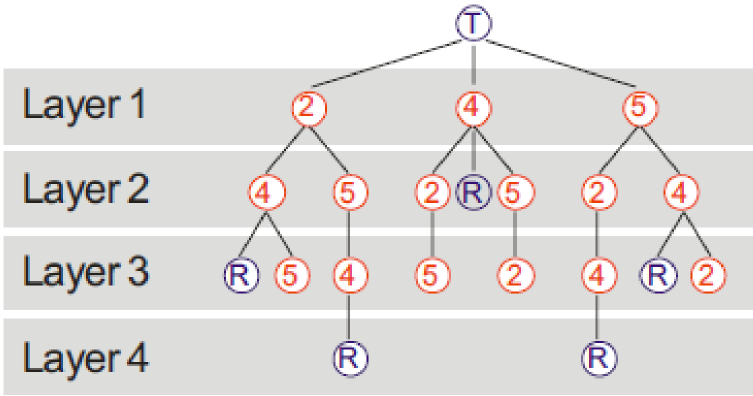

Figure 5.7: Determination of Dominant Path Tree Structure [23]

5.4 Optimization Method

The target is to solve LTE network area coverage challenge by optimizing existing network using antenna parameters or adding new site/s. To get better throughput; the KPIs such as SINR, RSRP, RSRQ and RSSI should be enhanced, SINR in this case. The flow diagram of the optimization is stated in Figure 5.8. The optimization steps followed in this work can be grouped in four categories; collect relevant information, optimize antenna parameters and add new site, simulation and performance checking.

Collect Relevant Information: Detail information of the existing network collected in three ways; NMS, drive/walk test and existing network simulation. Then analyze the existing network and identify the challenge. Here in this study SINR value is considered as the main performance indicator.

Optimize Antenna Parameters and Adding new Site: Tuning the antenna parameters; height, tilt, azimuth and power as well as adding new site. At the first time, the antenna parameters are selected based on previous research works and by engineering educated guess considering the geographical location of the sites, the existing site parameters and the problem at hand. The selected antenna parameters are listed in Table 5.1 below.

Parameter	Constraint
Height	$\pm$7m, at first 1m then every 2m
Power	$\pm$ 6dBm, every 1dBm
Tilt	0 to 8°, every 2°
Azimuth	$\pm$20°, every 5°

Table 5.1: Selected Antenna Parameters for Simulation

Simulation: Simulate the network with simulation tool using the antenna parameters as an input or adding new site then analyze the result.

Performance Requirement: As it is mentioned above, SINR is the main performance indicator in this work. Hence, compare the SINR value of the existing network and the new optimized one. Tune the antenna parameters again and again up to n iterations until acceptable improvement in SINR found. If it could not bring an improvement in the KPIs up to the maximum iteration; use alternative solution which is adding new site.

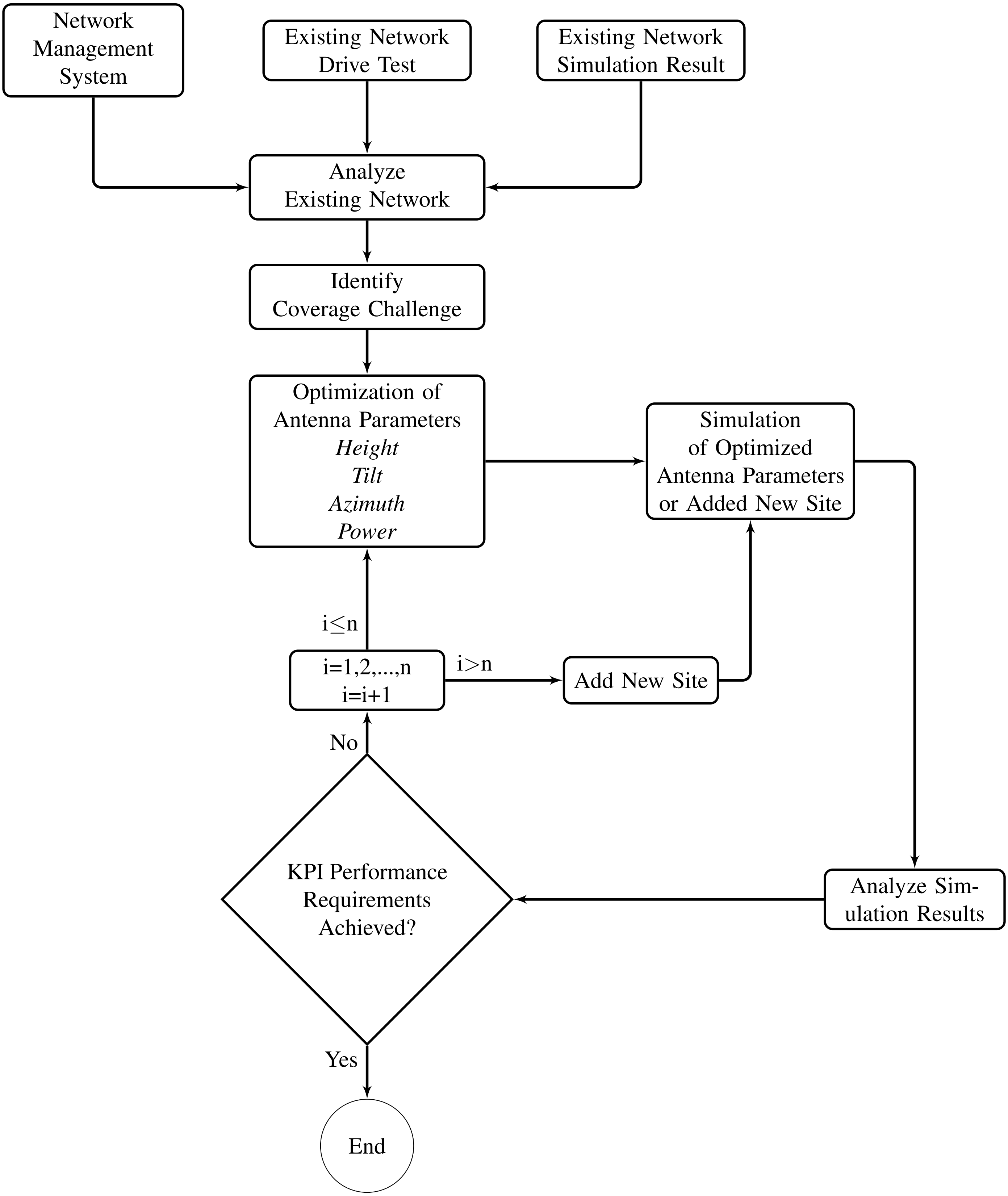

Figure 5.8: Applied Optimization Diagram

5.5 Simulation Model

WinProp and Matlab are the simulation and plotting tools that are applied in this work. WinProp is a 3D simulation software suite that enables users to simulate electromagnetic wave propagation and wireless network planning. The propagation model applied in this work is dominant path model. Matlab (matrix laboratory) is a multi-paradigm numerical computing environment and proprietary programming language developed by MathWorks.

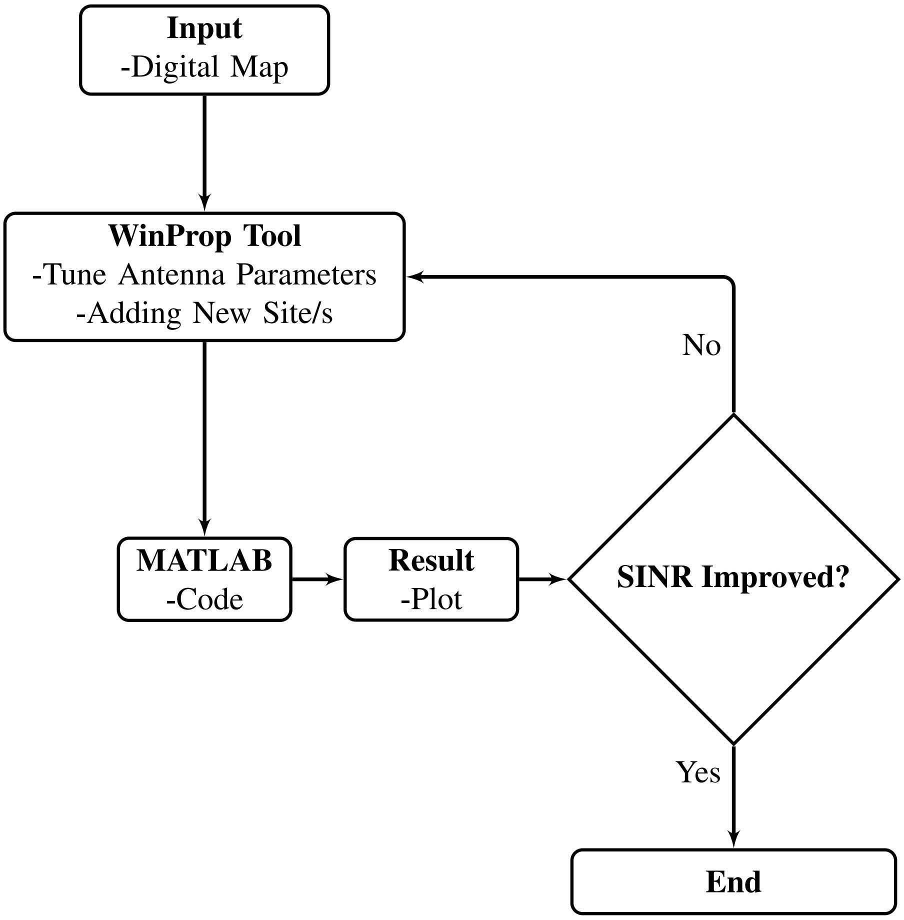

Figure 5.9: Simulation Model

Simulation Steps

1. Crop the required area from Digital Map of Addis Ababa City using WallMan tool and save it in .odb file format
   - Find Latitude and Longitude of the end points of the area from Google Map
   - Convert Latitude and Longitude into Universal Transverse Mercator (UTM) coordinate (Easting/Northing)
2. Open the .odb file using ProMan
3. Place the sites in the required position (using Latitude/Longitude or UTM coordinate)
4. Set all parameters of the ProMan tool and the antennas (cells): antenna height, azimuth, tilt, power, pattern, propagation model and location (Latitude/Longitude)
5. Run the ProMan
6. Using the ProMan tool extract the power (in dBm) in a matrix form and save it in .txt format
7. Access the data (the matrix in .txt) using Matlab code

8. Place a users in a random location within the range of the weak coverage area and find the maximum received power, interference and noise
9. Then calculate $SINR$ as shown below in Equation 5.1
10. Plot the CDF graph
11. Finally analyze the results

SINR Calculation

$$SINR = \frac{P_{max}}{I_t + N} \tag{5.1}$$

Where P_{max} is the maximum received power, I_t is the total interference and N is the noise

$$I_t = \sum_{i=1}^{n} I_i \tag{5.2}$$

where n is the total number of cells, which their signal can be detected in that particular area
In the AALRTS lines which encountered coverage challenges, the cells are 3. Hence the total interference, I_t, becomes:

$$I_t = \sum_{i=1}^{3} I_i \tag{5.3}$$

Drive/Walk Test

In this study, phone-based drive test is conducted. Phone-based drive test systems are useful for evaluating basic network performance and are essential to characterizing the end-user experience while using the network. Phone-based systems address the need to verify network settings such as cell selection and re-selection boundaries and to measure the voice and data application performance in the live network [29]. In this drive test the RF coverage and quality measurements SINR, RSRP, RSRQ and RSSI at various points in the Light Railway line, marked as Sites One and Two located in Figure 4.4, which intended to cover by three cells operating at 400 MHZ are measured using LTE terminal (Huawei EP680). The distance between two consecutive measured actual values of the parameters is 25 meter in both ends of Sites and 10 meters at the center of the Sites. Those values are recorded in Table A.2 and plotted graphically using Matlab plot. In *Appendix A* Table A.2 the 'x' symbol with a red color row is used to indicate that the cell not detected in that particular position.

Chapter 6 Results and Discussion

The existing network tested in three ways. Collecting performance evaluation of different counters from the NMS, drive test which conducted using an LTE terminal device (Huawei EP680); walk along the line and record the RSRP, RSRQ, RSSI, and SINR and simulating the existing network using WinProp simulation tool and Matlab plot. Results of the drive/walk test and existing network simulation discussed below. Whereas, the result of NMS explained in Chapter 4 under existing network challenges.

6.1 Existing Network Results

Drive/Walk Test Results

In the drive/walk test around 17% and 6% parts of Line 1 and Line 2 covered and the collected actual SINR values plotted in Figure 6.1. As shown in the Figure, the most measured SINR values are less than $7dB$. From the SINR signal strength level, in Table 3.3 as well as from vendors and research works those values are in the week signal strength range.

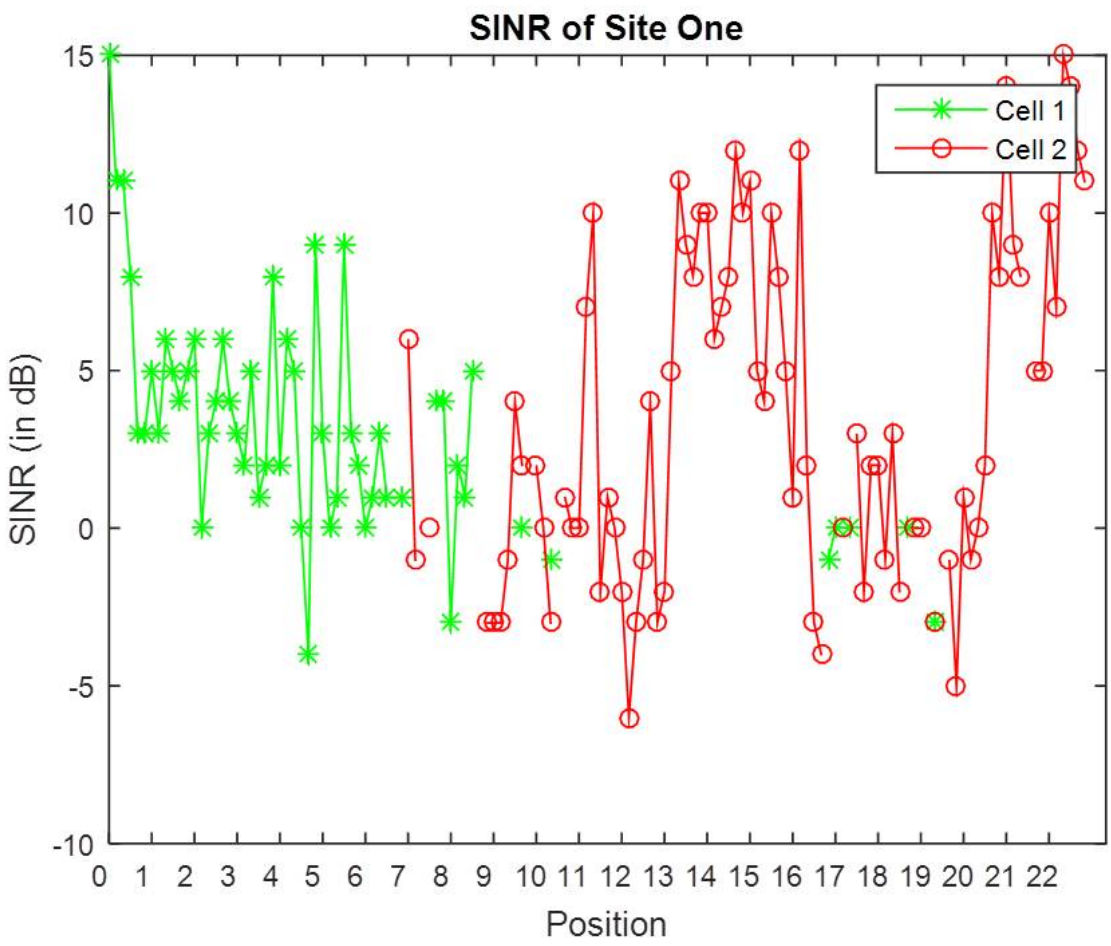

Figure 6.1: Measured SINR of Site One

Existing Network Parameter Simulation Result

The AALRTS existing LTE network of the selected areas are simulated using WinProp simulation tool and plotted graphically using Matlab. The power distribution of the selected areas, Sites One and

Two, are shown in the snapshot of the simulation result in Figure 6.2. The CDF versus SINR graph in Figure 6.3 shows that at $10\% - ile$ and $20\% - ile$, the SINR values are less than $6.6dB$ and $8dB$ respectively. When the SINR values of the existing network drive test and simulation results compared with the RF conditions versus LTE KPIs, it is in the weak signal strength range. The existing LTE network performance evaluation from NMS in Table 4.2, Figure 4.5, in $Appendix A$ Figures A.1 and A.2 show that; the network selects a QPSK MCS scheme. LTE network selects QPSK indicates the network experiences lower SINR. Hence, to improve the Cells' received power strength and SINR antenna parameters optimization is an advisable solution.

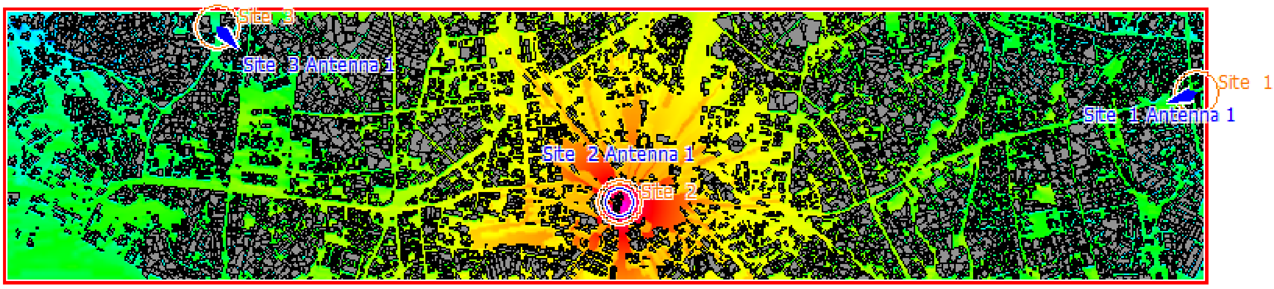

Figure 6.2: WinProp Tool Simulated Cells

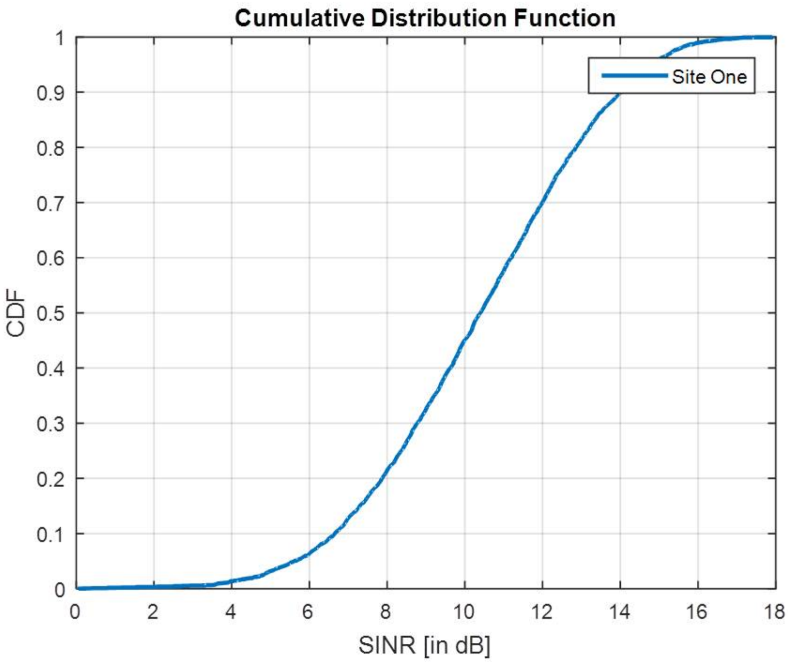

Figure 6.3: Existing Network CDF Graph of SINR

6.2 Antenna Parameter Optimization Results

The impact of antenna parameters and their effect on SINR in WinProp simulation tool and Matlab plot discussed below.

Impact of Antenna Height

The antenna height optimization results are plotted in Figure 6.4. As shown in the Figure, the SINR values of $1m$, $3m$, $5m$, $7m$ and $8m$ height change simulated. At $10\% - ile$ and $20\% - ile$ of the CDF graph, the SINR values improved by 36.36% and 30% from the existing network, respectively. These results can be described in another way as follows. In the existing network, the 90% and 80% users can get $\geq 6.6dB$ and $\geq 8dB$ SINR values respectively. In the optimized antenna height the 90% and 80% users can get $\geq 9dB$ and $\geq 10.4dB$ respectively.

The maximum received power in $8m$ height change is slightly better than $7m$; as shown in Figure 6.5. However, the SINR value is better at $7m$. The height change can result in higher maximum received power; but due to maximum inter-cell interference, SINR decreased.

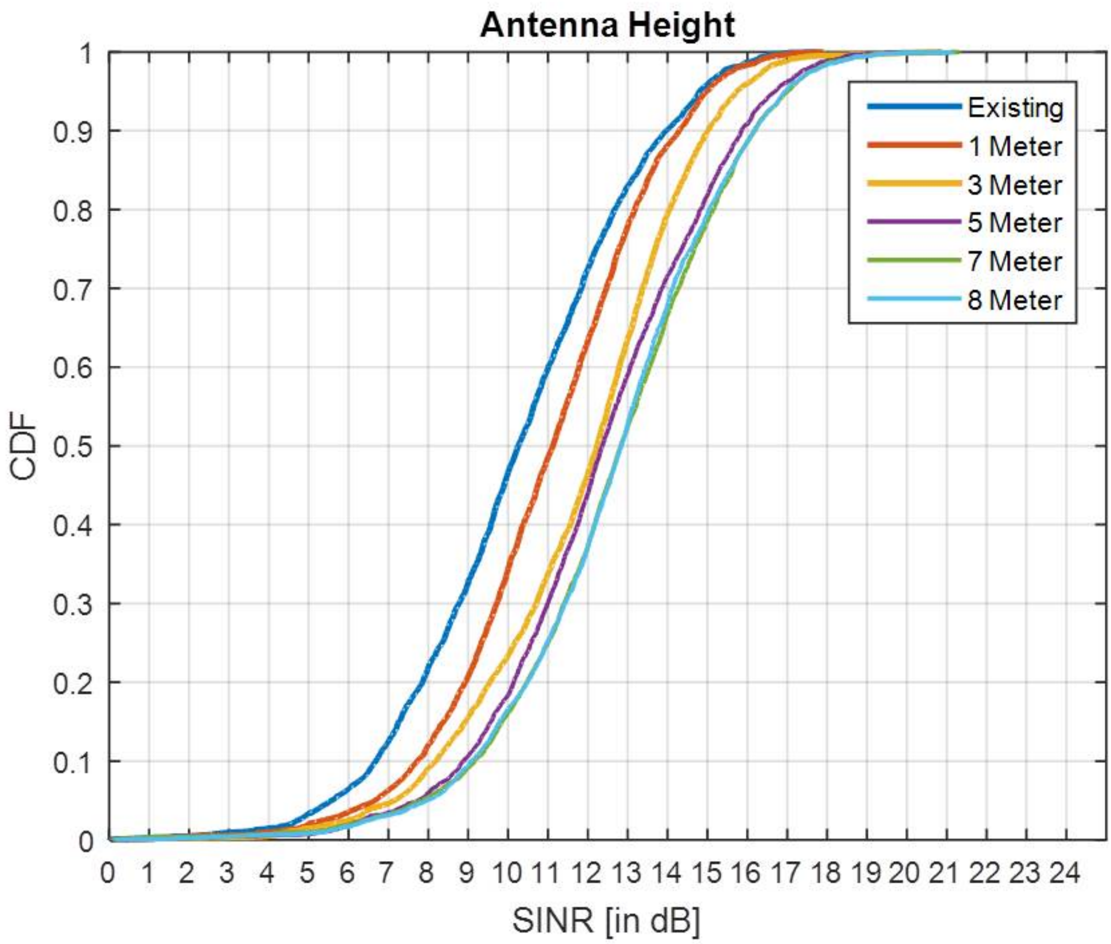

Figure 6.4: Impact of Height on SINR

Impact of Power

The antenna power optimization results shown in Figure 6.6, at $10\% - ile$ and $20\% - ile$ of the CDF graph, 37.87% and 28.75% improvement in SINR observed respectively. Hence, by increasing the transmitted power coverage area can be increased. However, in the AALRTS scenario, the cells are working in their maximum power capacity. The power optimization has been tested practically on the existing network. Since it is working in its maximum designed power; it could not be a solution.

Impact of Tilt

An antenna down tilt is the angle between the direction of antenna main lobe and horizon. The down-tilt angle is $0° \leq \alpha \leq 12°$ [31]. In this case study, the impact of the down tilt is negligible, as shown in the bar graph of Figures 6.7, at 10% of the CDF graph, 1.5% change in SINR observed.

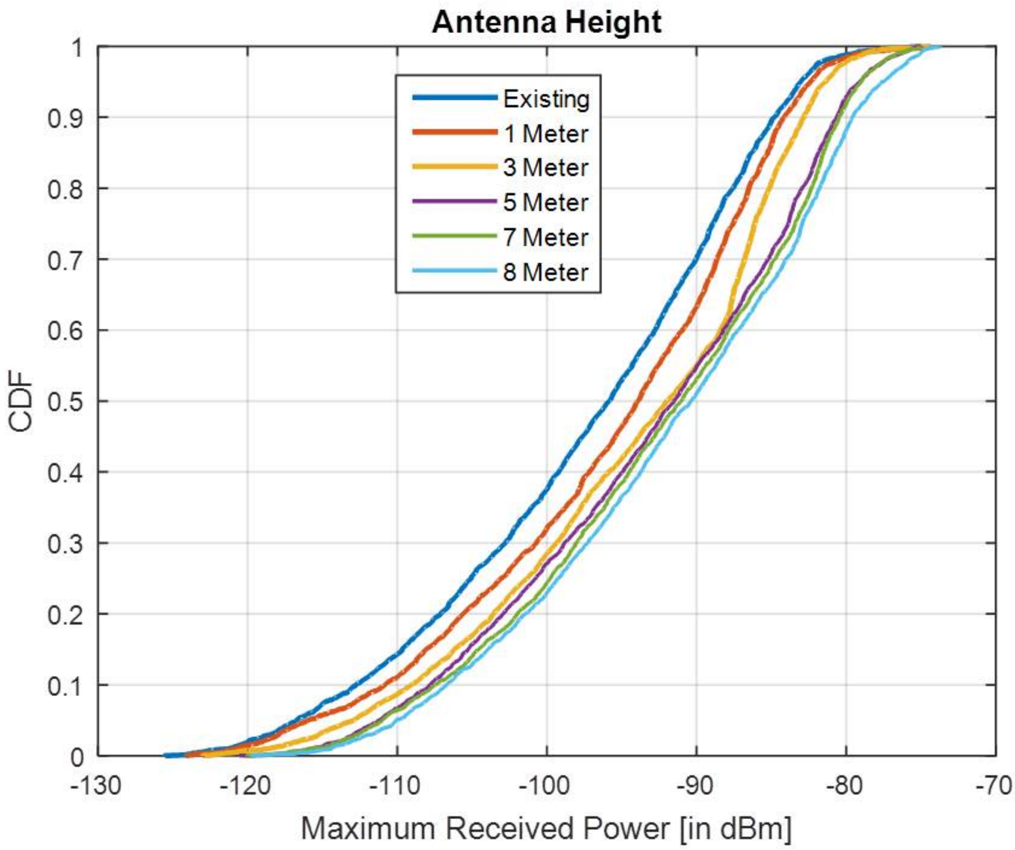

Figure 6.5: Impact of Height on Maximum Received Power

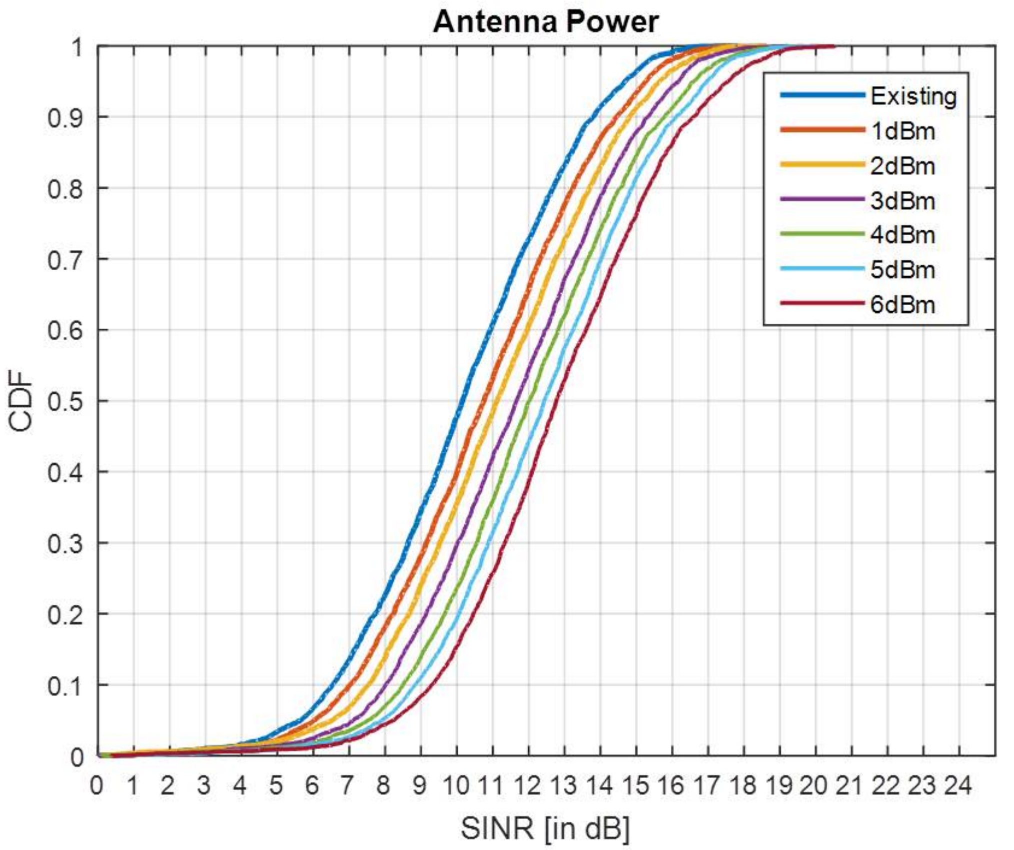

Figure 6.6: Impact of Power on SINR

Impact of Azimuth

The change in azimuth resulted in small performance improvement in SINR. As shown in Figure 6.8, the SINR bar graphs in different percentiles are almost the same as the existing network's bar graphs. For instance, at $10\% - ile$ of the bar graph, the change in SINR is almost 1.5%.

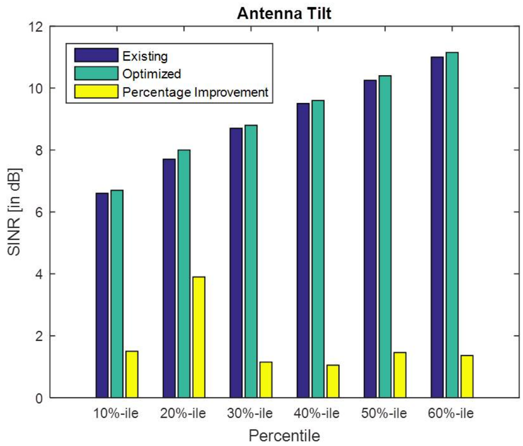

Figure 6.7: Tilt Impact on SINR

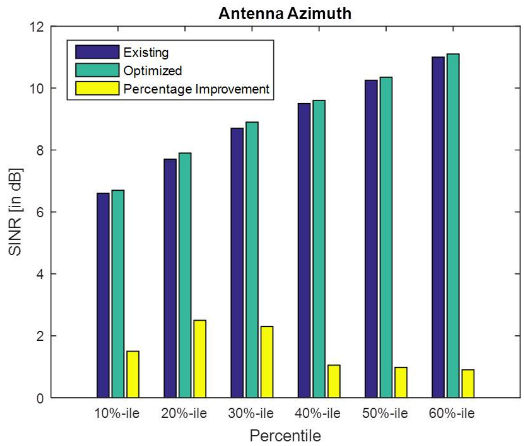

Figure 6.8: Azimuth Impact on SINR

Combined Impact of Power and Height

The combined impact of the power and height brought 68.18% and 56.25% SINR improvement at the $10\% - ile$ and $20\% - lie$ of the CDF graph, as shown in Figure 6.9.

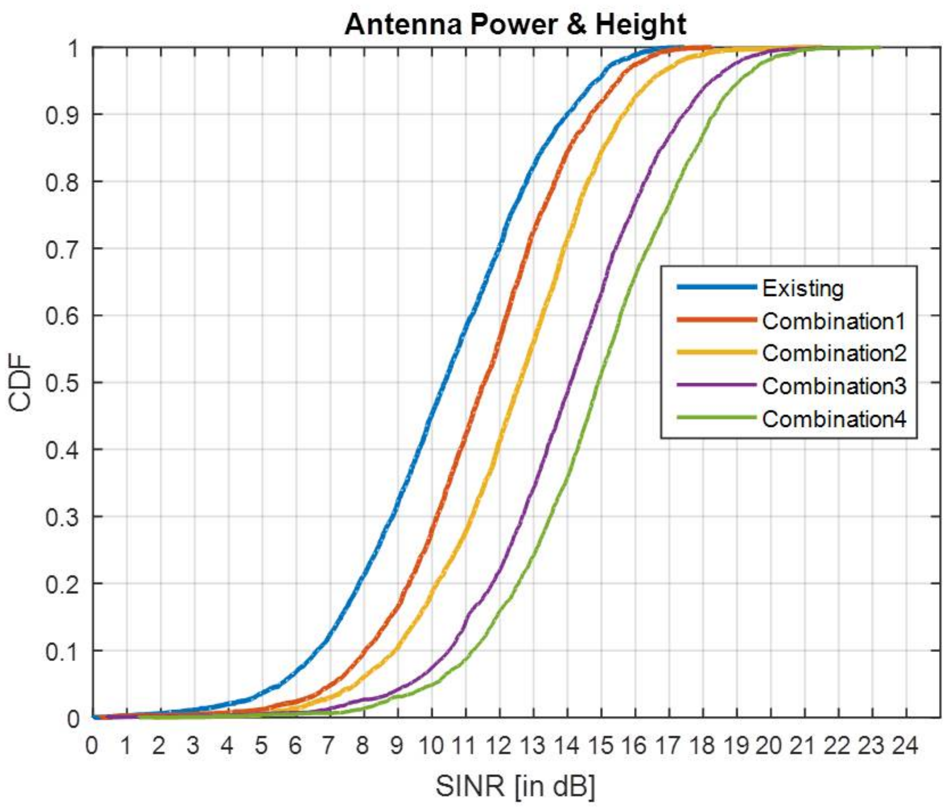

Figure 6.9: Power and Height Impact on SINR

Summary of Parameter Optimization Simulation Results

The optimization results summarized by the following two Tables, 6.1 and 6.2. The first Table contained the percentage improvement of SINR and the second Table, the percentage change (improvement) in users.

Antenna Parameters	Existing SINR (dB)	Optimized SINR (dB)	Percentage Improvement
Height	6.6	9	36.36%
Power	6.6	9.1	37.87%
Tilt	6.6	6.7	1.5%
Azimuth	6.6	6.7	1.5%
Height and Power (Combined)	6.6	11.1	68.18%

Table 6.1: Percentage Improvement on SINR (at $10\% - ile$)

SINR (in dB)	≤ 6	≤ 8	≤ 10	≤ 12	≤ 14
Existing Network	7%	21%	47%	70%	90%
Height	2%	6%	18%	39%	69%
User Percentage Improvement	5%	15%	29%	21%	21%
Power	2%	6%	17%	39%	64%
User Percentage Improvement	5%	15%	30%	21%	26%
Combined (Power and Height)	1%	2%	5%	15%	36%
User Percentage Improvement	6%	19%	42%	55%	54%

Table 6.2: Users Percentage Improvement of Antenna Parameters Optimization

6.3 New Site Optimization Results

Adding a new site is another proposed solution for area coverage challenges in addition to optimizing the antenna parameters. In this work, both omnidirectional and directional antennas simulated; as shown in Figures 6.10 and 6.11. The new site with omnidirectional antenna improves SINR value by 48.48%; whereas the one with a directional antenna the SINR decreases by 69.7% at $10\% - ile$. In the directional antenna new site optimization results, at $\geq 90\% - ile$ SINR improvement observed and the maximum received power values are higher than the existing network, as shown in Figure 6.12. From the author's observation and the CDF graphs, the directional antenna experiences high inter-cell interference than the omnidirectional antenna. The new site with directional antenna can improve SINR values of only 10% users that is near to the new site.

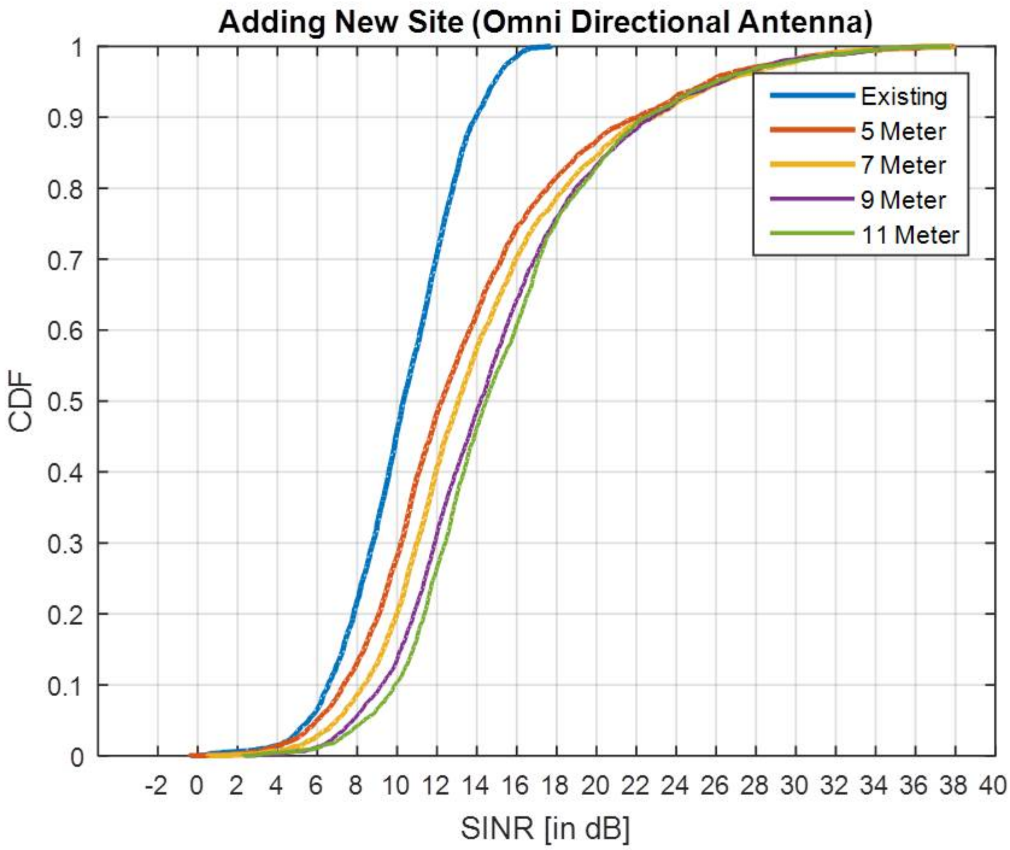

Figure 6.10: Impact of Adding New Site on SINR (Omnidirectional Antenna)

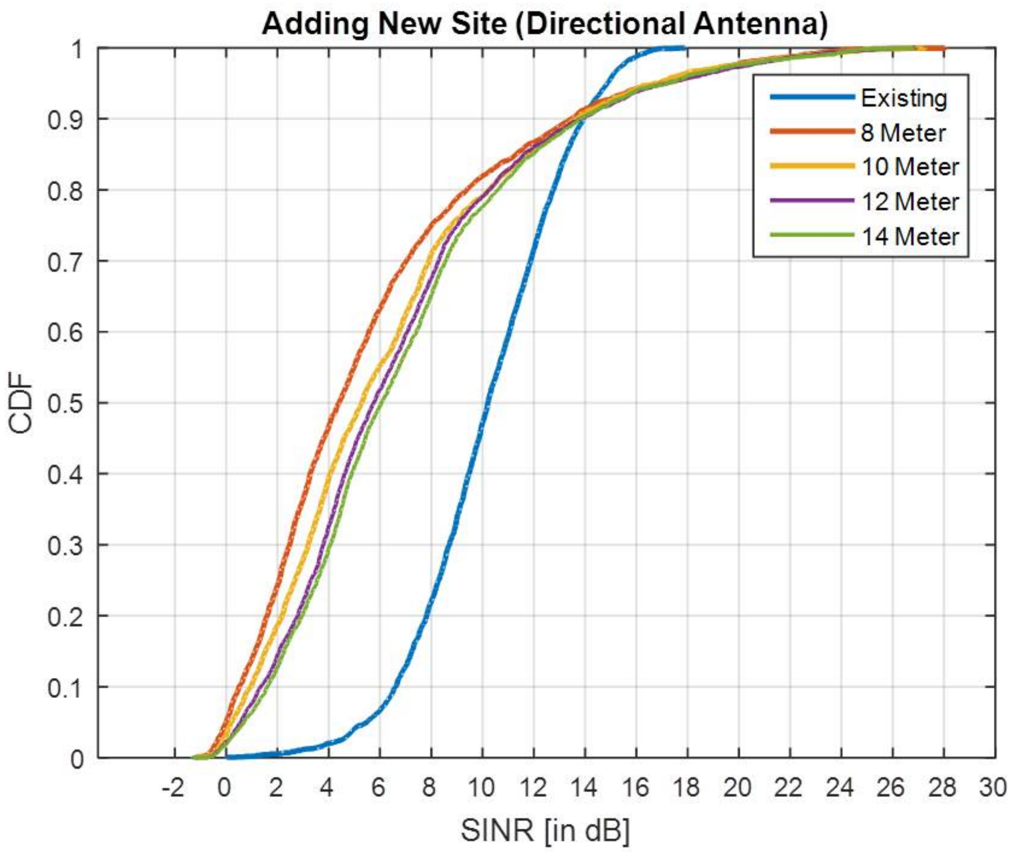

Figure 6.11: Impact of Adding New Site on SINR (Directional Antenna)

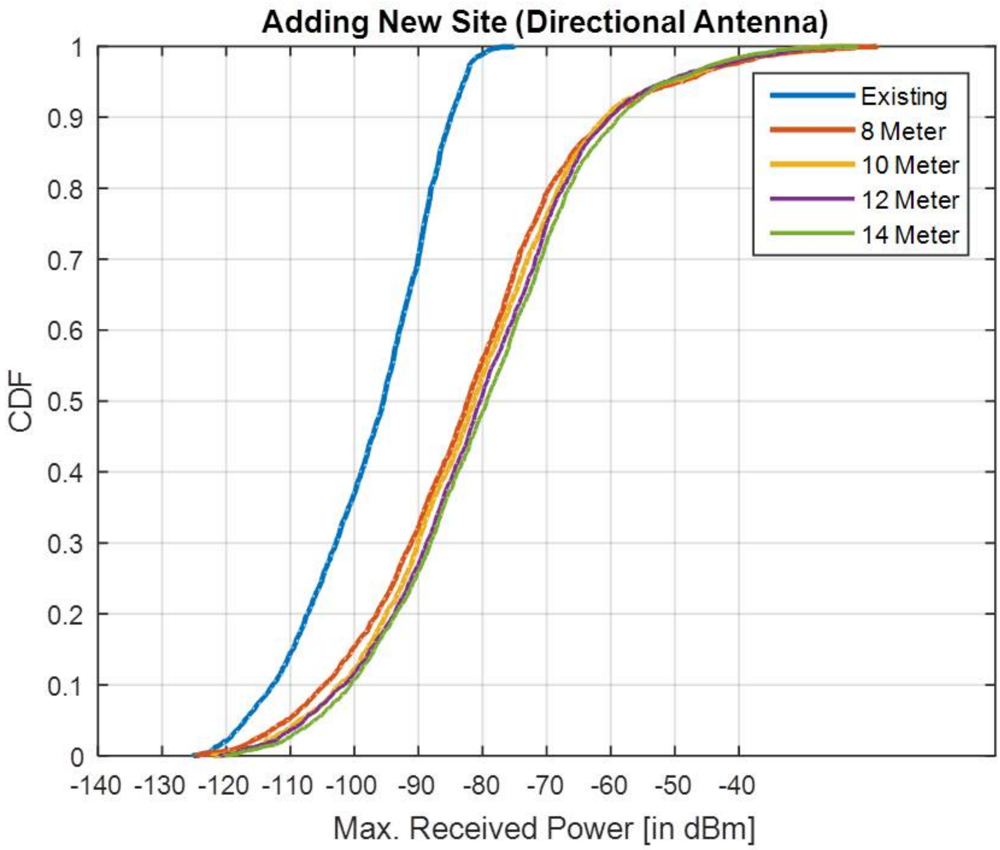

Figure 6.12: Impact of Adding New Site on Maximum Received Power (Directional Antenna)

Chapter 7 Conclusion

The QoS demand for communication in railway has driven to LTE with new features and new improvements over the existing conventional railway communications. i.e., GSM-R and TETRA. However, Light Railway LTE network has faced coverage challenges. This thesis has focused on LTE network optimization techniques that can mitigate area coverage challenge in AALRTS using WinProp simulation tool and Matlab plot by improving SINR value, which is one of the fundamental KPIs of area coverage.

The optimization AALRTS LTE network is the scenario which is near to test bed method. The existing parameters' values were collected in three ways. The first, the actual data was collected through a drive/walk test using Huawei EP680 LTE terminal along the Light Railway line and most of the SINR values were less than $7dB$. The second, the performance evaluation of the existing network was collected from NMS then the average BLER became 22.5%. The third one, the existing antenna parameters were simulated using WinProp simulation tool; from the simulation result, at $10\% - ile$ of the CDF graph, the SINR value was $6.6dB$. The collected and simulated SINR values together with BLER value of the network indicates that the existing network experienced coverage problem. To solve the aforementioned problem, antenna parameters (height, power, tilt and azimuth) optimization techniques and new site deployment were studied and simulated. AS a result, at $10\% - ile$, SINR has improved by 36.36%, 37.87% and 68.18% from optimizing height, power and their combination respectively. In this scenario, the impact of tilt and azimuth were negligible, which resulted in only 1.5% SINR improvement. Adding new site and optimizing its location and antenna parameters presented 48.48% SINR improvement.

The author recommends that AALRTS can apply one of the LTE network optimization techniques, simulated above, to address the coverage challenges in the selected areas. The antenna height and adding new site optimization techniques simulation results can mitigate the problem at hand. However, to avoid extra cost of adding new site, antenna height optimization is preferable.

As in a big city, LTE network in Light Railway requires continuous optimization in parallel with the environmental change of the city. In the future, autonomous self-optimization methods can be studied to avoid continuous manual optimization.

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Appendix A

Location Name	Latitude	Longitude	UTM Easting	UTM Northing
Cell 1	9.01685	38.79394	477352.13	996721.45
Cell 2	9.01027	38.75863	473470.73	995996.35
Cell 3	9.02157	38.73382	470744.73	997247.55

Table A.1: Location of Sites

Location	Cell One				Cell Two			
	RSRP (dBm)	RSRQ (dB)	RSSI(dB)	SINR(dB)	RSRP(dBm)	RSRQ(dB)	RSSI(dB)	SINR(dB)
1	-87	-9	-66	15	x	x	x	
2	-95	-10	-73	11	x	x	x	
3	-99	-10	-76	11	x	x	x	
4	-100	-10	-78	8	-107	-17	-78	
5	-103	-11	-79	3	-108	-16	-79	
6	-103	-13	-78	3	x	x	x	
7	-102	-12	-78	5	-104	-13	-78	
8	-100	-11	-77	3	-106	-16	-77	
9	-100	-11	-77	6	-106	-17	-77	
10	-100	-11	-76	5	-101	-13	-76	
11	-99	-11	-76	4	-103	-14	-76	
12	-101	-12	-77	5	-106	-17	-76	
13	-100	-11	-77	6	-107	-17	-77	
14	-101	-15	-74	0	-97	-10	-74	
15	-99	-11	-75	3	-99	-11	-75	
16	-100	-11	-77	4	-106	-19	-76	
17	-101	-12	-77	6	-103	-16	-75	
18	-98	-12	-73	-4	-105	-17	-74	
19	-100	-11	-76	3	-106	-17	-78	
20	-99	-12	-74	2	-106	-18	-75	
21	-95	-10	-73	5	-104	-16	-75	
22	-102	-14	-79	1	-107	-16	-79	
23	-103	-12	-78	2	-107	-17	-84	
24	-102	-10	-79	8	-112	-18	-82	
25	-101	-11	-78	2	-101	-12	-77	
26	-99	-10	-76	6	-105	-17	-76	
27	-99	-11	-79	5	-107	-16	74	
28	-99	-12	-75	0	-110	-19	-77	
29	-112	-14	-84	-4	-101	-15	-73	
30	-96	-9	-75	9	-108	-19	-75	
31	-102	-12	-78	3	-104	-14	-78	
32	-104	-14	-78	0	-105	-15	-78	
33	-102	-12	-77	1	-103	-14	-77	
34	-96	-9	-75	-9	x	x	x	
35	-102	-12	-78	3	-104	-14	-78	
36	-103	-12	-78	2	-105	-14	-79	

37	-104	-14	-78	0	-105	-15	-78	
38	-102	-12	-77	1	x	x	x	
39	-102	-10	-79	3	-109	-17	-79	
40	-106	-14	-80	1	-108	-15	-81	
41	-107	-14	-81		x	x	x	
42	-107	-13	-81	1	-107	-13	-81	
43	-103	-16	-74		-96	-10	-74	6
44	-107	-15	-79		-107	-16	-79	-1
45	-109	-17	-76		-108	-12	-76	
46	-109	-17	-80		-104	-12	-80	0
47	-106	-11	-83	4	x	x	x	
48	-105	-11	-82	4	x	x	x	
49	-110	-19	-79	-3	-102	-11	-79	
50	-104	-12	-79	2	-104	-12	-79	
51	-106	-12	-81	1	-111	-18	-82	
52	-105	-12	-81	5	-111	-18	-81	
53	-112	-15	-85		-112	-15	-85	-3
54	-110	-15	-83		-112	-15	-83	-3
55	-112	-16	-83		-107	-11	-83	-3
56	-113	-19	-81		-104	-10	-81	-1
57	-113	-19	-82		-105	-11	-82	4
58	-112	-17	-82		-106	-12	-82	2
59	-109	-14	-83	0	x	x	x	
60	-108	-14	-81		-106	-12	-81	2
61	-114	-18	-84		-111	-14	-84	0
62	-107	-12	-82		-110	-16	-82	-3
63	-109	-14	-82	-1	-108	-13	-82	
64	-112	-16	-84		-108	-12	-84	1
65	-111	-14	-85		-111	-13	-85	0
66	-117	-17	-88		-114	-14	-88	0
67	-117	-18	-86		-110	-12	-86	7
68	-116	-19	-83		-105	-10	-83	10
69	-114	-16	-85		-114	-16	-85	-2
70	-123	-19	-83		-108	-13	-83	1
71	-113	-16	-85		-111	-13	-85	0
72	-113	-16	-84		-110	-13	-84	-2
73	-113	-15	-86		-114	-16	-86	-6
74	-113	-17	-84		-111	-15	-84	-3
75	-115	-18	-85		-110	-13	-85	1
76	x	x	x		-108	-12	-84	4
77	-111	-13	-86		-114	-16	-86	-3
78	-112	-16	-84		-111	-15	-84	-2
79	x	x	x		-102	-10	-79	5
80	x	x	x		-98	-9	-77	11
81	-114	-20	-79		-102	-10	-79	9
82	x	x	x		-99	-10	-77	8
83	x	x	x		-98	-9	-77	10
84	x	x	x		-99	-10	-78	10

85	x	x	x		-98	-10	-76	6
86	-111	-19	-80		-103	-10	-80	7
87	-120	-19	-80		-102	-9	-80	8
88	x	x	x		-93	-9	-71	12
89	x	x	x		-96	-9	-75	10
90	x	x	x		-99	-9	-77	11
91	x	x	x		-105	-11	-82	5
92	x	x	x		-99	-10	-77	4
93	-127	-20	-75		-96	-9	-75	10
94	-109	-18	-77		-99	-10	-77	8
95	-115	-19	-81		-103	-11	-81	5
96	-121	-20	-78		-101	-11	-78	1
97	x	x	x		-99	-9	-77	12
98	-109	-13	-83		-109	-13	-83	2
99	-114	-16	-86		-114	-15	-86	-3
100	-117	-16	-88		-116	-16	-88	-4
101	-113	-15	-86	-1	-114	-15	-86	
102	-114	-16	-86	0	-110	-11	-86	
103	-114	-14	-88		-114	-14	-88	0
104	-114	-14	-88	0	-115	-15	-88	
105	-113	-16	-84		-108	-12	-84	3
106	-115	-15	-88		-115	-15	-88	-2
107	-115	-16	-87		-112	-13	-87	2
108	-115	-13	-89		-114	-13	-89	2
109	-119	-20	-87		-114	-14	-87	-1
110	x	x	x		-113	-11	-89	3
111	-113	-11	-89		-116	-15	-89	-2
112	-117	-15	-90	0	-117	-15	-90	
113	-124	-20	-89		-118	-12	-89	1
114	-116	-14	-90		-116	-14	-90	0
115	-120	-18	-90		-116	-13	-90	0
116	-120	-16	-91	-3	-118	-15	-91	
117	-123	-18	-92		-120	-15	-92	-3
118	-120	-17	-91		x	x	x	
119	-121	-17	-91		-118	-13	-93	-1
120	-119	-18	-88		-118	-15	-91	-5
121	x	x	x		-112	-11	-88	1
120	-122	-18	-92		-114	-12	-90	-1
123	-120	-17	-91		-118	-14	-92	0
124	x	x	x		-116	-13	-91	2
125	x	x	x		-106	-10	-84	10
126	x	x	x		-108	-11	-85	8
127	x	x	x		-100	-9	-79	14
128	x	x	x		-104	-0	-82	9
129	x	x	x		-103	-9	-81	8
130	-111	-19	-78		-100	-9	-78	
131	x	x	x		-106	-10	-80	5
132	x	x	x		-100	-10	-77	5

133	x	x	x		-104	-10	-82	10
134	x	x	x		-103	-10	-80	7
135	x	x	x		-99	-9	-78	15
136	x	x	x		-100	-10	-78	14
137	x	x	x		-102	-10	-80	12
138	x	x	x		-105	-11	-82	11

Table A.2: Measured RSRP, RSRQ, RSSI and SINR During Drive Test

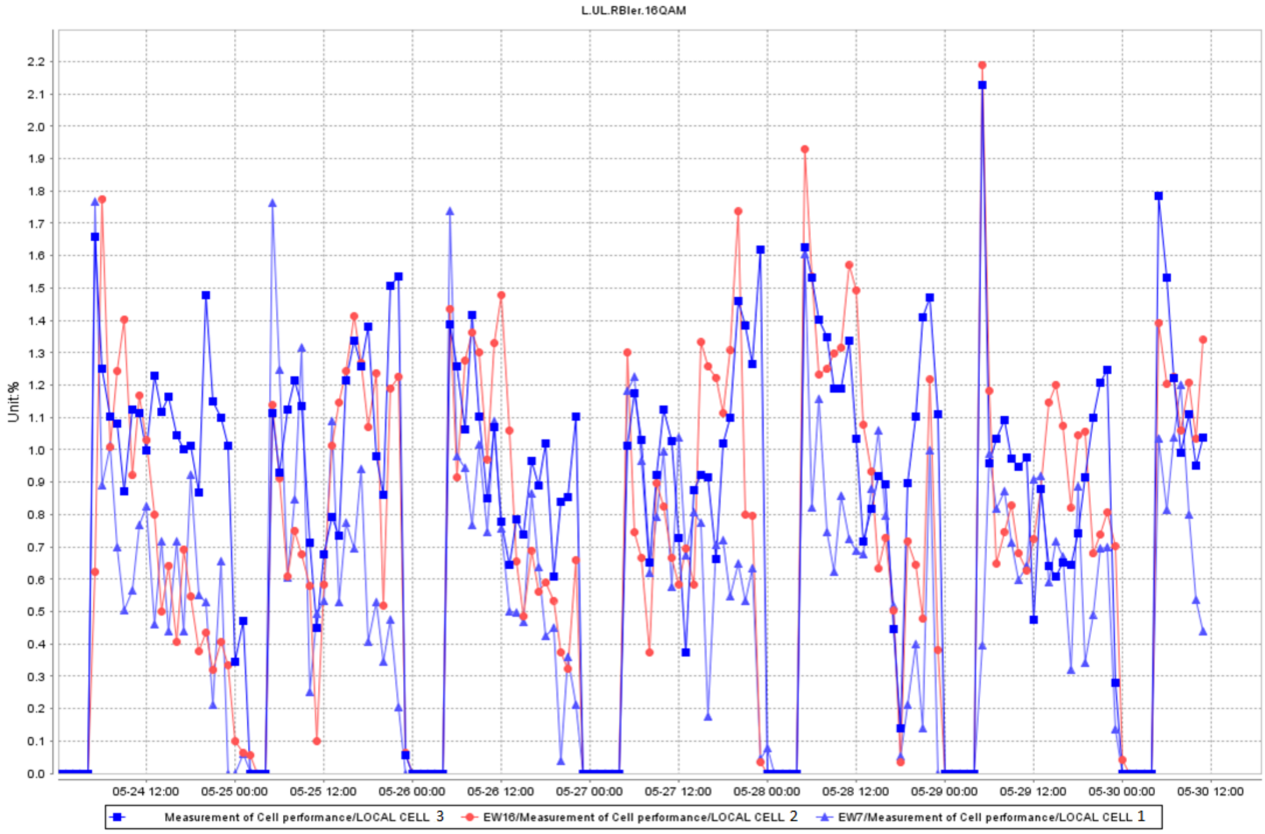

Figure A.1: Existing Network Performance Evaluation of UL 16-QAM

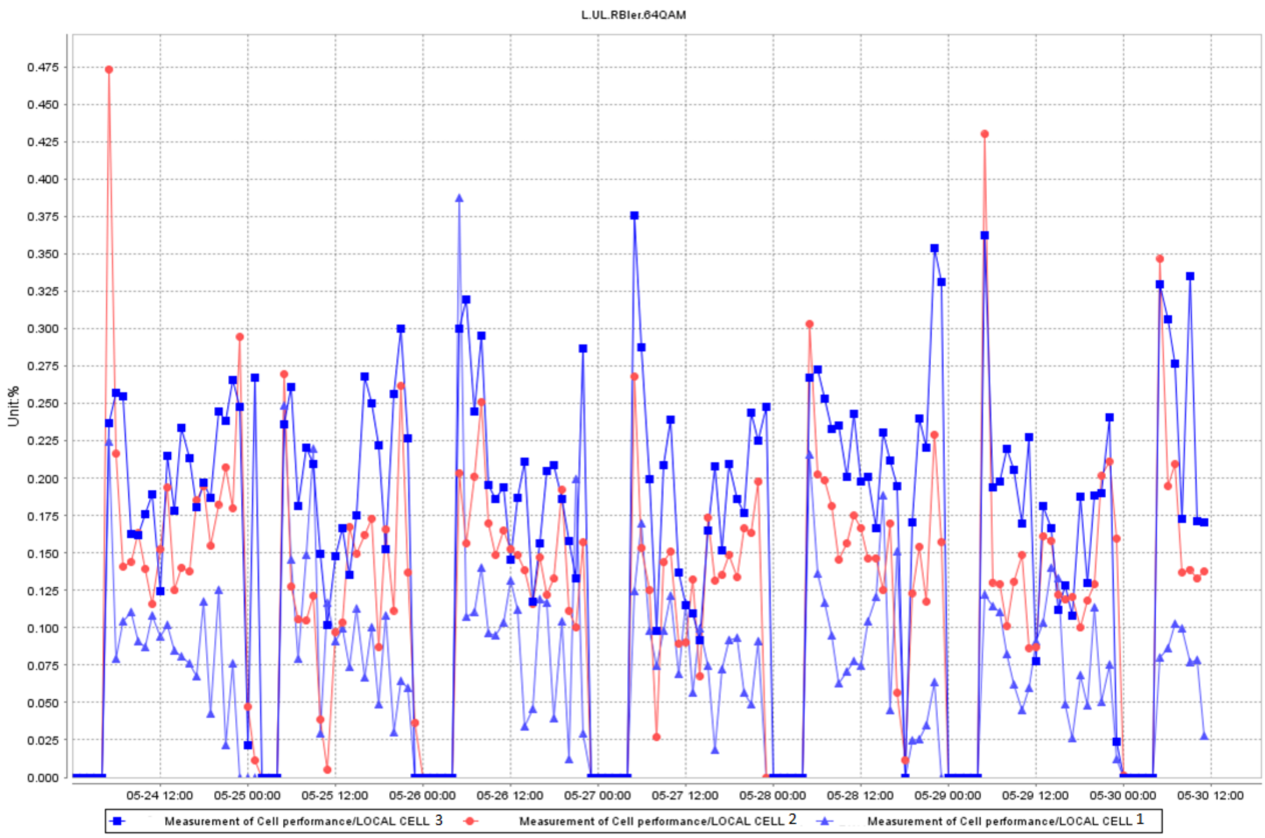

Figure A.2: Existing Network Performance Evaluation of UL 64-QAM

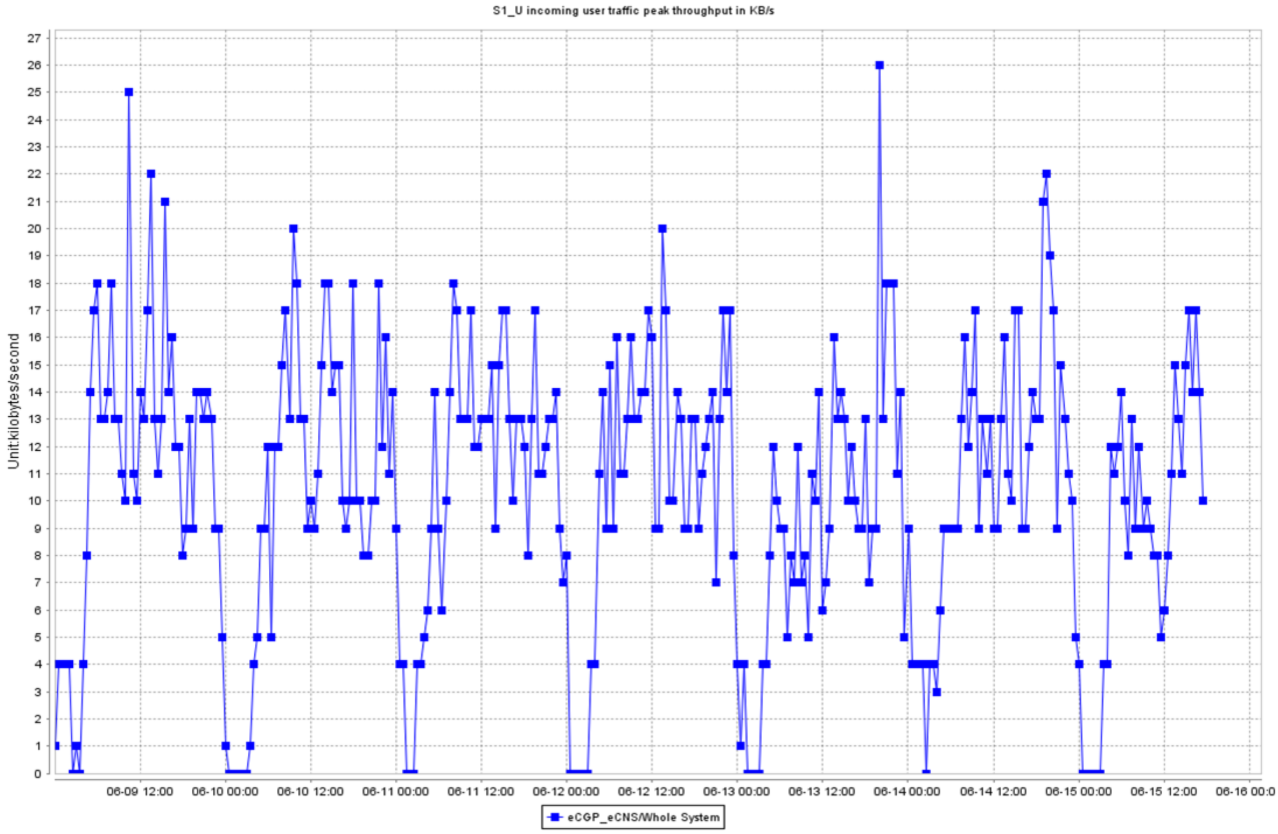

Figure A.3: Incoming User Traffic Peak Throughput

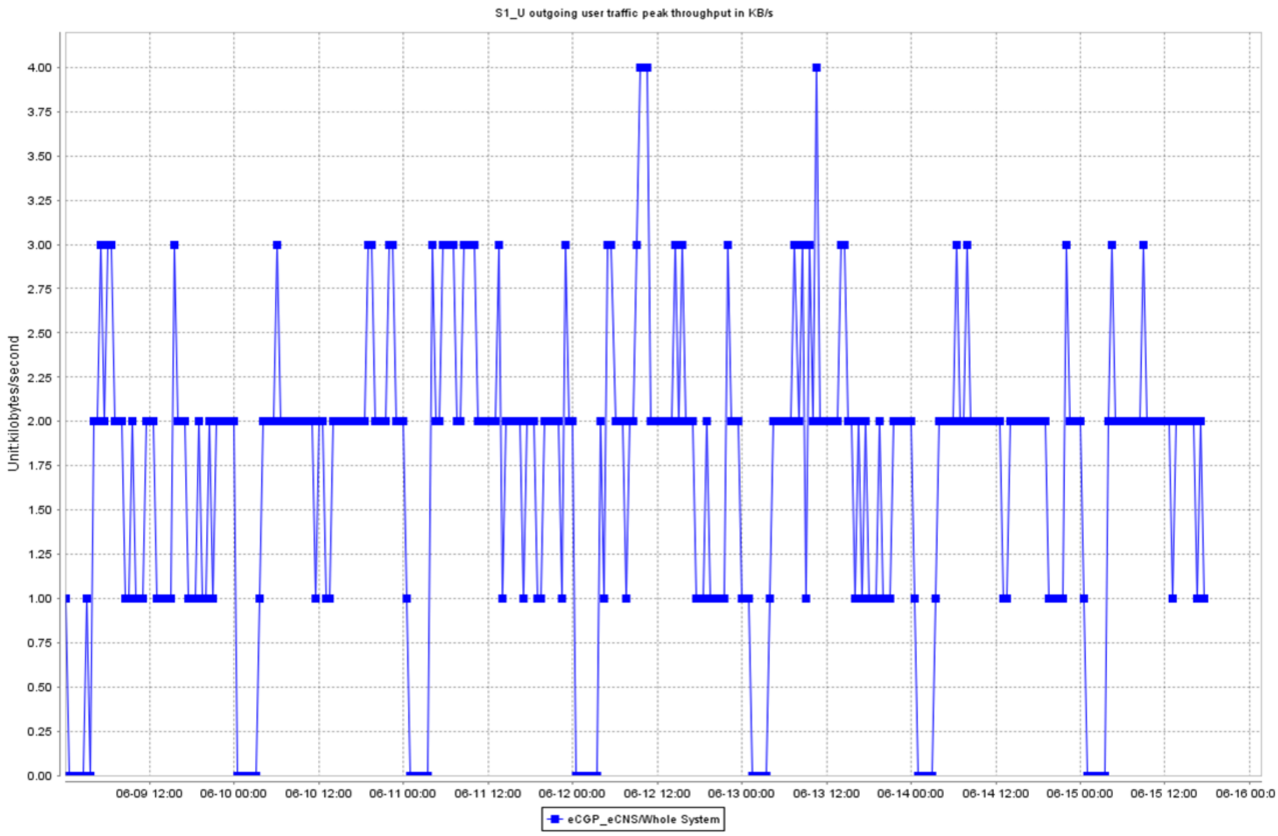

Figure A.4: Outgoing User Traffic Peak Throughput

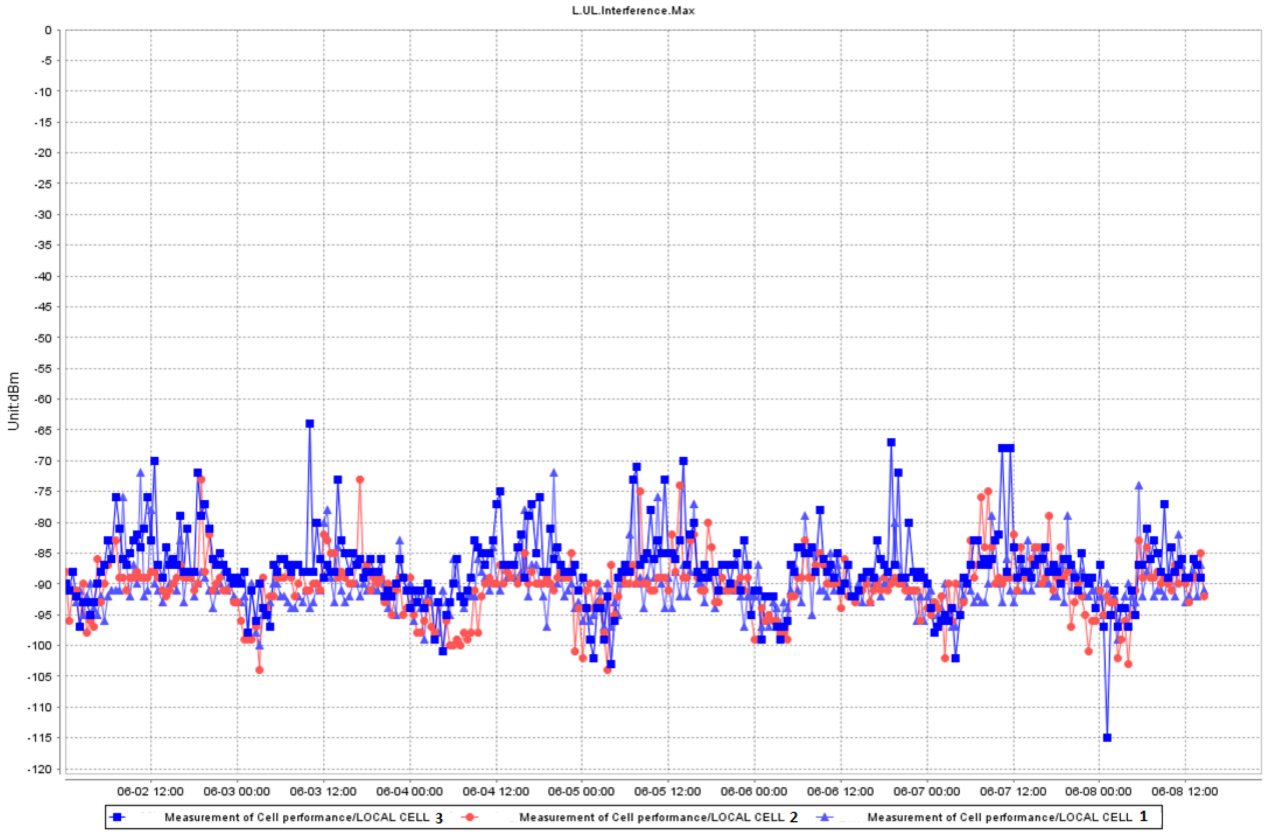

Figure A.5: Maximum Interference

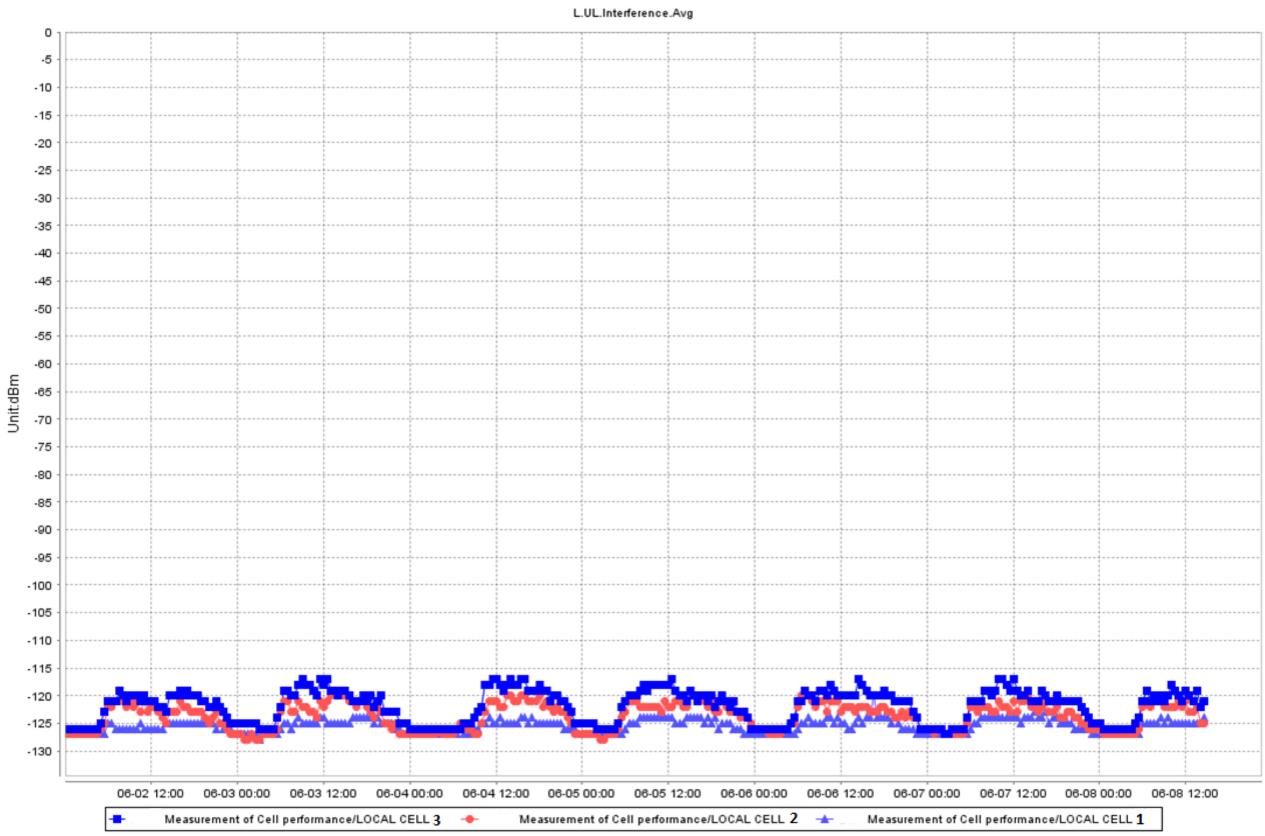

Figure A.6: Average Interference

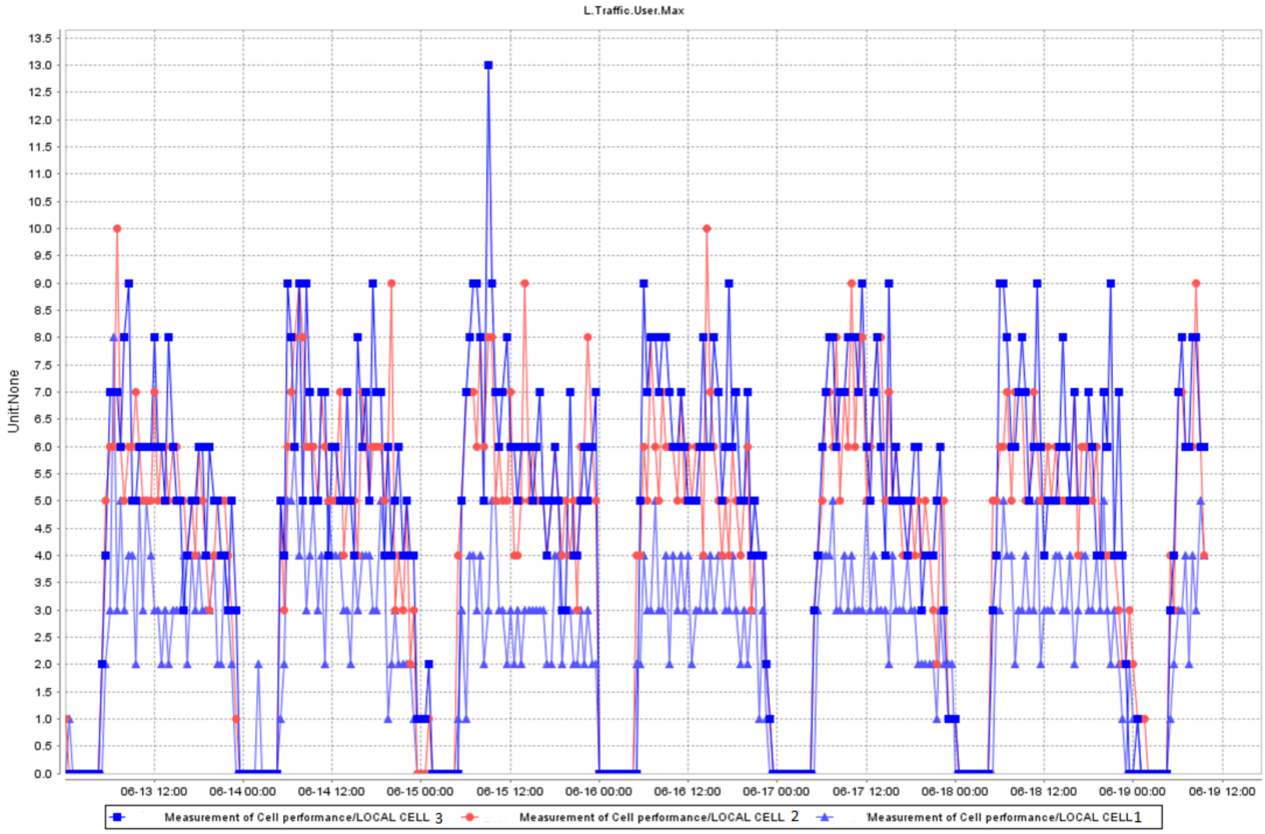

Figure A.7: Maximum Traffic User

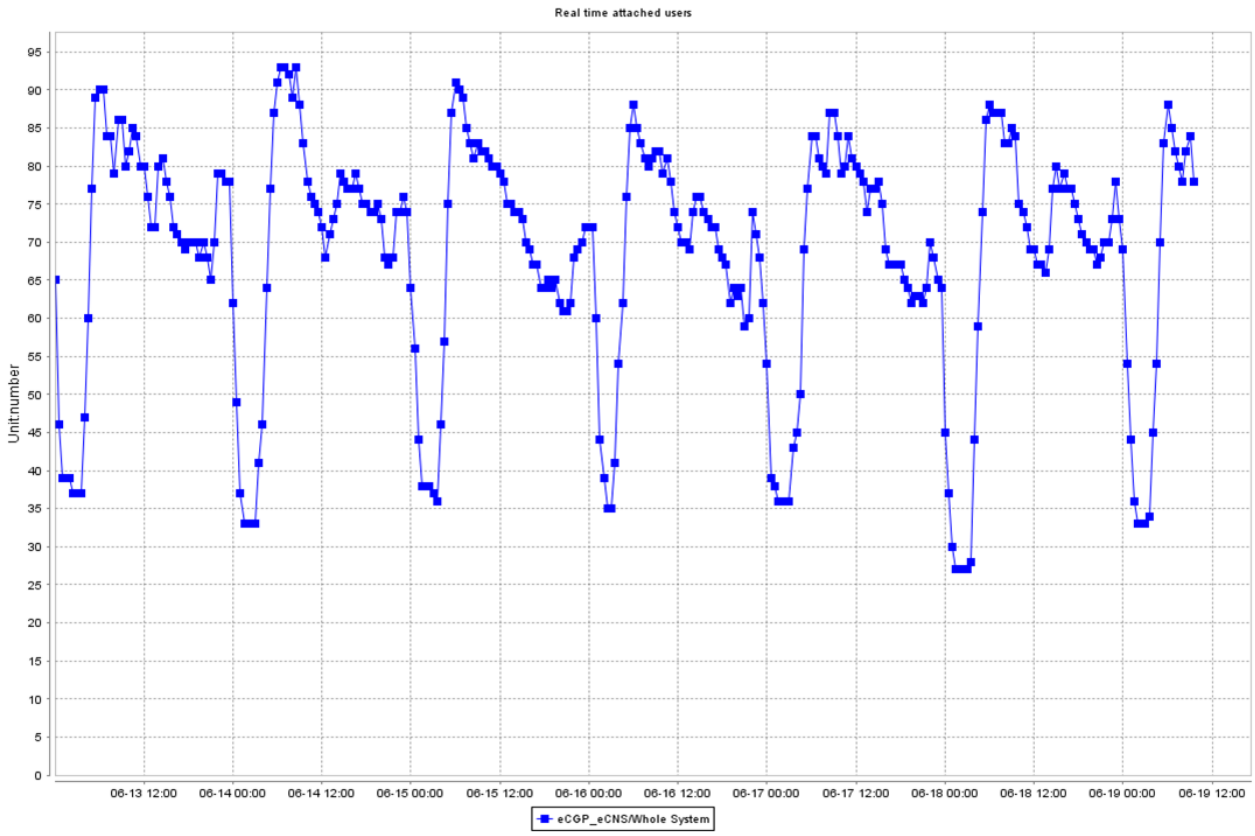

Figure A.8: Real-Time Attached Users

Appendix B

MATLAB Code

```
%*********************************************%
%*********** KEFYALEW BIRU FLATIE ************%
%*********************************************%
clear all;
% ****Simulation of Existing Parameters****
cell_Number=3;
for cell_Counter= 1:cell_Number
    filename = ['Site1_' num2str(cell_Counter) '.txt'];
    if cell_Counter ==1
        temp = importdata(filename, ' ',13);
    else
         temp = importdata(filename, ' ',14);
    end
    Power.ReceivedPower=temp.data;
    PowerData(cell_Counter)=Power;
end
for kk=1:400
z=10; %Assumed Number of Users in the Particular Area
Y=randi([442,611],1,z);
X=randi([92,179],1,z);
Com=complex(X,Y);
x=real(Com);
y=imag(Com);
for cell=1:cell_Number
   for t=1:z
    K(cell,t,kk)=PowerData(cell).ReceivedPower(x(t),y(t));
    end
end
for i=1:z
    Power_in_dB=K(:,:,:); %Received Power
    Power_in_Watt= exp( 0.1*(Power_in_dB));
    Max_Received_Power=max(Power_in_Watt); %Maximum Received Power
    Total_Received_Power=sum(Power_in_Watt);
    Interference_And_Noise=Total_Received_Power- Max_Received_Power;
    if  Interference_And_Noise ~=0
    SINR=Max_Received_Power ./ Interference_And_Noise; %SINR Calculation
    end
    SINR_in_dB=10*log10(SINR);
end
end
Distribution_Function=cdfplot(SINR_in_dB); %SINR Plot
set(Distribution_Function,'LineWidth',1.5);
hold on;
% ****Simulation of Optimized Parameters****
```

```
cell_Number1=3;
for cell_Counter1= 1:cell_Number1
    filename = ['Optimized1_' num2str(cell_Counter1) '.txt'];
   if cell_Counter1 ==1
        temp1 = importdata(filename, ' ',13);
    else
         temp1 = importdata(filename, ' ',14);
    end
    Power1.ReceivedPower1=temp1.data;
    PowerData1(cell_Counter1)=Power1;
end
for kk1=1:400
z1=10; %Assumed Number of Users in the Particular Area
Y1=randi([442,611],1,z1);
X1=randi([92,179],1,z1);
Com1=complex(X1,Y1);
x1=real(Com1);
y1=imag(Com1);
for cell1=1:cell_Number1
   for t1=1:z1
    K1(cell1,t1,kk1)=PowerData1(cell1).ReceivedPower1(x1(t1),y1(t1)
        );
    end
end
for i1=1:z1
    Power_in_dB1=K1(:,:,:); %Received Power
    Power_in_Watt1= exp( 0.1*(Power_in_dB1));
    Max_Received_Power1=max(Power_in_Watt1); %Maximum Received
        Power
    Total_Received_Power1=sum(Power_in_Watt1);
    Interference_And_Noise1=Total_Received_Power1-
        Max_Received_Power1;
    if (Interference_And_Noise1 ~=0)
    SINR1=Max_Received_Power1 ./ Interference_And_Noise1; %SINR
        Calculation
    end
    SINR_in_dB1=10*log10(SINR1);
end
end
Distribution_Function1=cdfplot(SINR_in_dB1); %SINR Plot
set(Distribution_Function1,'LineWidth',1.5);
title('Cumulative Distribution Function');
xlabel('SINR [in dB]');
ylabel('CDF');
legend('Existing','Change in Height');
hold on ;
```