



Addis Ababa University

Addis Ababa Institute of Technology (AAiT)

School of Electrical and Computer Engineering

***Distributive Train Track Communication System for Addis Ababa
Light Railway***

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Declaration

I, the undersigned declare that this thesis is my original work, and has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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Abstract

Rail transport is an important mode of transport that can play significant role for economic development of a country. Especially, Electric system train driving technology has many advantages for environment protection and fuel consumption reduction.

Train control system is a broad section in railway technology and has responsible for ensuring passenger's safety and security during their journey. It also improves travel comfort, providing real time multimedia information and access to social networks in stations or in motion. Accident in railway technology is very serious issue. So, maintaining safety is the first precondition for railway transport.

To have safe operation in railway technology, train operators need to put in place an effective and reliable train-to-ground and train to train communication technology. On the other hand, the commercial wireless technologies have been evolving from voice centric 2G systems (e.g. GSM) with limited data transmission capabilities to 4G broadband multiservice systems (LTE).

This Thesis addresses how the innovative commercial wireless technologies can enhance the safety and reliability of AA-LRT. It introduces the implementation of long term evolution (LTE) technology to Addis Ababa light railway. Each train communicates with their neighbor trains through modern communication system called LTE. The information like train speed, train distance and location of the train obtain from the speed capturing system and GPS technology. This information processed through Microcontroller and the system alert for the train pilot even it takes action on the braking system if necessary. The system decreases the need to construct additional track in the city and reduce the probability of train collision.

In this scenario, this paper investigates capacity and quality of service improvement; energy efficiency, mobility, passenger's safety and security and results obtained from simulations are presented.

Key words: LTE, Railway Communication, Budget calculation, coverage calculation

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Acronyms and Abbreviations

AAiT	Addis Ababa institute of Technology
AALRT	Addis Ababa Light Railway Train
AES	Advanced Encryption Standard
BBU	Building Base band Unit
CBTC	Communications-Based Train Control
CDMA	Coded Division Multiplexing Access
DSP	Digital Signal Processing
DSL	Digital Subscriber Line
DeNB	Donor eNB
EDGE	Enhance Data rates for GSM Evolution
EIRP	Effective Isotropic Radiated Power
EPC	Evolved Packet Core
ETCS	European Train Control System
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
eNBse	NodeBs
GCSE_LTE	Group Communication System Enabler for LTE
GPS	Global Positioning System
GSM	Global System for Mobile Communication
HDTV	High Definition Television
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LOS	Line of Site
LTE	Long Term Evolution

MIMO	Multiple Input Multiple Output technology
MME	Mobility Management Entity
MMOG	Multi Media Online Gaming
MPLS	Maximum path loss
MRS	Mobile Relay Station
NLOS	Non- Line of Site
OCC	Operating Control Center
OECD	Organization for Economic cooperation and development
OFDM	Orthogonal Frequency Division Multiplexing
PCRF	Policy charging and Rules Function
P-GW	Data Network Gateway
<i>PTT</i>	Push to Talk
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RLB	Radio Link Budget
RRU	Radio Remote Unit
<i>SINR</i>	Signal to Interference and Noise Ratio
S-GW	Serving Gateway
TDD	Time Division Duplex
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
VPL	Vehicle Penetration Loss
WiMAX	Worldwide Interoperability for Microwave Access
3GPP	3 rd generation partnership project (3GPP) evolution

Chapter One

Introduction

1.1 Background

The railway transport is the one which is essential mechanism for mass mobilization of goods and passengers. It is preferred for countries that are grown rapidly in economy and have large population growth. Especially the electric railway system has a merit for environment protection since it has almost zero pollution effect. Cities like Addis Ababa which have rapid population growth lead to use this technology to solve transport problem.

The Addis Ababa Light Rail Transit Project is a semi-closed urban rail transit system. For the project, modern trolley car (DC750V power supply type) is used as the passenger train; DC750V diversified power supply system is adopted for the power supply system; most of tracks are constructed on the ground and some sections are built on overhead bridges or in underground tunnels. Where the line has level crossing with the municipal roads, signal system is adopted for traffic control. The planned line has a total length of about 75 km which is to be constructed in two phases. Phase-I (only), covers the main line in length of about 31.025km, including a common rail section of about 2.662km long, in downtown area, to be run by both E-W line and N-S line. The main line of E-W line is about 16.998km in full length.

The construction of rail tracks needs millions of dollar per kilometers for initial cost. This is the bottle neck for countries that has motivation to use it. Now our country is the owner to 34 km light railway in Addis with in total cost of 475 million dollar.

One of the best solutions to minimize the expense of construction cost is efficient utilization of tracks. The study focuses on the efficient sharing of track by the train with in a safe manner by implementing train to train communication. We can use many trains at a time on a single track if there is a communication between them. It reduces the crowded effect roads and increase life usage of roads. People minimize the time that they lose on transport.

The communication of train through distributive train track communication may implement with the help of different communication technologies like GSM-R, Satellite, UMTS and other mechanism. However, from different point of view like safety, infrastructure cost, channel capacity, mobility, latency and other service requirements, LTE is the best choice for the

coupling communication of trains. LTE has special characters like network high availability and robustness demanded by signalization and control; A quality of service being able to carry and prioritize both vital and non-vital services; a bandwidth able to carry very “greedy” application such as video surveillance; Fast handover between cells compatible with High Speed and Communication robustness in urban environment.

The system implementation coordinates the GPS technology with network to track the position of the train and calculate the distance between two trains which is nearest. The microcontroller programmed to evaluate the distance and make decision for safety action.

1.2 Statement of problem

Railway technology is one of the latest land transports in the world [24]. It is massive transport for passenger and freight all over the world. But it has a great limitation which is highly initial cost to construct the railroad and take reliable safety. It takes billions of dollars to construct a single way. However it has attractive benefit after it construct. Specially, for our country it has unrestricted benefit to the community and makes dynamic change on our economy since we have a great expense on fuel consumption. If there is high population growth in the city, people need to construct additional track. But the major cause to this not only the population growth it is due to in efficient utilization of railroad. This is one of a big problem in railway industries. If we use the track in a proper manner by coupling trains, we can manage a lot of train on a single way and give solution for many people. The other problem is the safety and reliability of communication between trains. Accident in railway technology is a series issue and cause for mass killing behavior if there is a collision between trains. The other requirement for train communication is the need to have mobility support system and capacity of communication system. This thesis focuses on giving a response to this issue by design LTE network for the communication of train.

1.3 Methodology

The method to be employed to achieve the objectives of the research includes:

- **Literature Reviewing:** this includes reading books, articles, and simulation tools.
- **System modeling:** it involves formulating the mathematical relationship.
- **Simulation:** involves simulating the modeled tracking system using MATLAB

- **Performance comparison, and Analysis and Interpretation of the results:** This involves comparing the performance of the proposed schemes, and analyzing and interpreting the result.

1.4 Objective

1.4.1 General objective

- ✓ In general, the objective of this thesis is to propose how to share the track in a safe way using electrical coupling of trains that would drive one behind the other in a minimal distance as short as mechanically coupled train with LTE wireless network technology.

1.4.2 Specific objectives

Specifically; the aim of this thesis is to:

- ✓ To investigate the various train tracking technology
- ✓ Review the conventional wireless network technology and analyze their role in railway.
- ✓ Proposes how the existing wireless network technology can be used in railway signaling.
- ✓ Evaluate and compare the performance enhancement of the proposed LTE scheme.

1.5 Scope and Limitation

1.5.1 Scope

The performance analyses will be based on simulation of the proposed techniques as prototype implementation is not feasible. In as much as possible, an attempt has been made to drive analytical expression that will help to support the simulation.

1.5.2 Limitation

Here are challenges on the study:

- ✓ Shortage of time.
- ✓ No digital map information for the existing project.
- ✓ No data about the subscriber and no clear information on real subscriber information.
- ✓ No consistency on the existing Addis Ababa light rail signaling and communication plan.
- ✓ The project owner and contractors are looking as the third party not thinking as project owner. Hence they are not giving a chance to participate and we can't give direct solution to it.

- ✓ There is no transparency on the project information.

1.6 Literature Review

Reference [1] deals the LTE radio network planning for the case of Addis Ababa city. The study involves coverage estimation, capacity evaluation and frequency planning. The thesis commences LTE implementation in the area with initial radio planning to properly reduce the number of base stations from 40 to less than 10 eNodeBs. But the study focuses on public mobile telephone. There is parameter difference.

In reference [2], there is preliminary design of AALRT. It consists of surveillance camera system which monitors stations, depot, crossover and other special areas. System also has radio communication interfacing with fiber for communication purpose at departure, control centre and at offices. The real time video and voice data from station transmit to control centre through fiber optic communication. Here is the question arise on how much the radio communication support mobility and the complexity of three system implementation. The next chapter deals the communication and signaling system of AALRT.

At reference [3] there is Global system for mobile communication or GSM. The coordination of GSM system with GPS technology is the best work in order to track vehicles and other objects. The system implemented for the communication of trains. But this mechanism has the drawback of high infrastructure cost, limited capacity, handover effect, limited bandwidth and less mobility.

Reference [20] deals the mobile WiMAX (IEEE 802.16e) uses the 2048-point FFT OFDMA PHY specification. It provides service area coverage from 1.6 to 5 km, allowing transmission rates of 5 Mbps in a 5 MHz channel bandwidth, and with a user maximum speed below 100 km/h.

1.7 Contributions

In all the literatures seen so far, train control system has been investigated at various levels. However, some of the differences in the previous work and the current work are underlined in the following points.

- In this thesis, The LTE based train tracking system for AALRT which enable the transit system to provide on board and real time information, enhance operational efficiency,

and better passenger experience are proposed. The proposed system provide better train-to-train and train-to-ground communication to reduce train tracking distance.

- Compare the effect of barrier by taking different propagation model.
- Identify the limitation for the existing system and merits of LTE.
- Design the LTE coverage Area estimation plan and simulate the through atoll simulator.
- Obtain the number of enodeBs require for Addis Ababa light rail transit.

1.8 Outline of the Thesis

The detailed outlines are as follows

- In Chapter 2, we introduce the state of art train control system. We then describe the proposed system model of this thesis.
- In Chapter 3, discusses the Addis Ababa light rail communication and signaling system design today. It introduces the information ongoing process and the clear information on the location and position.
- While in chapter 4 a detail investigation on the precise train communication system at Addis Ababa light rail and train to train communication system scenario.
- In Chapter 5, simulation results of the system model considered for LTE network.
- Finally, in Chapter 6, we conclude based on the results obtained and recommendations to future works are given.

Chapter Two

State-of art of Train Control System

2.1 Railway Wireless Communication

This chapter introduces the wireless communication technologies and their requirements for railway communication. Here there are also standards for wireless communication to deploy on railway system.

Wireless technology has lately become the fastest evolving one of the communications industry. From the entry of GSM, customers have continuously increased the demand for mobility, services and capacity. Third generation mobile technology and UMTS appeared as a solution by supporting higher data rates than GSM and providing more advanced services as video conference.

The recent increase of mobile data usage and emergence of new applications such as MMOG, HDTV streaming, Web 2.0, music applications have motivated the 3GPP to work on the LTE. LTE is the latest standard in the mobile network technology tree that previously realized the GSM/EDGE and UMTS/HSPA network technologies that will ensure 3GPP's competitive edge over other cellular technologies.

Railway wireless communication has become an indispensable part to provide the reliability and safety of the railway operation as well as the improved railway services. In addition, advanced mobile communication technologies have triggered new railway customer services. Recently, railway wireless communication together with the train control has been crucial for the reliability and safety of the railway operation.

2.1.1 Requirement of Railway Wireless Communication

The integrated wireless network for railway has its own requirements for Mission Critical operations such as accident prevention of trains, immediate reaction to emergency and on-time operation. The recent wireless network for railway should achieve not only safe operation of trains but also advanced railway services provided in the future. Therefore, it should meet the general communication requirements as follows [5]:

1. *High-speed movement*: In general, the maximum speed of the high-speed train is 300 km/h or more. In addition, stable wireless connection should be guaranteed at the moving speed of 500 km/h or more in the future. Particularly, when considering the direct

communication between oncoming trains, train mobility of 1000 km/h or more should be taken into account.

2. *Broadband wireless transmission technology*: The recent technology railway communications include the video transmission function (for real-time monitoring of passenger and/or car states in case of unmanned operation) as well as various railway customer services. As a result, the broadband wireless transmission technology that can transfer a large amount of data in real time is essential.
3. *Low latency*: In European Train Control System (ETCS) Level 2, the maximum latency of end-to end communication for train control is specified as 500 msec. Shorter communication delay time is required if we consider the increasing speed of trains in the future. In addition, the voice call setup and connection should be quickly performed less than one second for an emergency event.
4. *Network reliability and availability*: The integrated wireless network for railway should provide the network reliability and availability where the network reliability refers to the stable transmission of data information for the safety of railway operation; and the network availability stands for continuous use in spite of various situations of failure.
5. *Quality of Service (QoS)*: The up-to-date wireless networks support various QoS depending on different types of traffic and services. In particular, the train control signal which can directly affect the safe operation of trains is mixed with general information signals in the integrated wireless network for railway. Therefore, for more efficient and safe management of resources in a wireless network, the exquisite QoS control is required in the next-generation integrated wireless network for railway.
6. *Independent frequency and network*: For the high reliability, availability, and safety of the network, it is necessary to independently configure both wired and wireless networks by separating from common commercial networks. This standalone configuration enables to protect the safety of train operation from the commercial network failure or external attack and provide the network operation and maintenance with high stability.
7. *Open standard*: If the next-generation railway wireless network based on open standards of wireless communication technologies is constructed, the existing system and/or equipment that have been already verified in other industries can be directly used and as a result, the high stability is expected. In addition, it leads to the reduction of the network

construction cost thanks to mass production. Furthermore, due to the long life cycle of the technology, these technologies can be used to construct and maintenance the network for a long period. Moreover, it enables to interoperate with the existing railway network and/or other communication networks.

2.1.2 Standards of Railway Wireless Communication

When the integrated wireless network for railway is deployed, one of the important parts is to ensure the interoperability of railway equipment between different manufacturers and/or different railway operators. For this purpose, it is necessary to make the standard design of the reference model specifications for the interoperability and its detailed technical information. In the case of our environment, the railway communication and signal systems introduce by foreign manufacturers and it results in the low compatibility with other devices depending on the characteristics by train and line. In order to deal with this problem, the international standard technologies for the next generation railway communication system should be discussed [7].

1. *Group call function*: Multi-party simultaneous call is a very critical function in the railway communication network and/or mission-critical communication system such as a public safety network. In addition, this function requires very high call connection rate and very short call set-up time. 3GPP is currently discussing the standardization of the LTE-based group call (GCSE_LTE Group Communication System Enabler for LTE) fulfilled these requirements.
2. *End-to-end direct communication function*: Direct call function between terminals is one of the important mission-critical functions required in the railway network and public safety network. 3GPP has established standards of direct communication between terminals.
3. *Push to Talk (PTT)*: The current standard of PTT over cellular has many lacks of functions to support the mission critical operation in LTE networks. Therefore, PTT standards are planned to revise so as to allow applying to railway network or public safety network.
4. *Mobile Relay function for High-speed Train*: 3GPP is preceding “Mobile Relay for Train” standard research for various passenger services and smooth handover of many passengers in the train at a high speed of 300km/h. Basic research is currently in progress including case study and requirements research.

2.1.3 Train Wireless Communication Technologies

Here are some of train wireless communication technologies that are implemented at the recent time and the most applicable mobile communication technology.

2.1.3.1 GSM-R

GSM-R is one of the most important communication networks for railways due to its growing popularity across Europe and other places around the world, where it substitutes legacy national railway communication technologies. Despite that, GSM-R has some major shortcomings in terms of capacity and capability, which are directly inherited from the commercial GSM.

The first major issue of GSM-R is that it offers only circuit-switched transmission. This mode of transmission is less efficient than packet-switched. The lack of packet-switched transmission leads to very low utilization of the GSM-R network and no flexibility. Another major problem with GSM-R is its insufficient capacity, i.e. 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. In areas with high train concentration such as central train stations there are problems with providing sufficient number of channels to serve all the trains that are to operate there simultaneously. The capacity of the GSM-R network becomes a bottleneck limiting the number of trains to be operated in a given area. Desirably, the only limitation should be related to the capacity of the railway infrastructure. Moreover, GSM-R is its very limited support for data communication. The maximum transmission rate per connection is limited to just 9.6 Kbit/s, what is sufficient only for applications with very low demands. Apart from that, message delay is in the range of 400 ms, what is too high to allow any interactive real-time application [3].

2.1.3.2 Satellite Communications

Satellite provides sufficient coverage to a large train operation area. Thus, there is no need to install a lot of ground communication equipment next to the tracks. The Doppler Effect almost has no impact on satellite communications. Less handover events occur due to the height of the satellite. However, blind spots exist when the satellite views are obstructed because of terrain or clutter. In addition, satellite communication links are bandwidth limited and have high costs. Therefore, satellite communications cannot provide massive high quality of service (QoS)

communications. Besides, satellite communications have considerably connection delay which makes them not suitable for real-time applications [4].

2.1.3.3 LTE System

The LTE system is most recent technology which has a power to overcome limitation on the above systems. It gives response for capacity, mobility and latency problem. This thesis wants to deploy LTE smart system for the Addis Ababa light railway control and communication system. The system supports the data communication between train and between control centers. Even we can use it for voice communication at the departure and real time event form stations. If we deploy the LTE system, no need of using GSM or telephoning communication system. This paper designs the LTE coverage area, signal strength and identify the number enodeBs for Addis Ababa light rail. The detail explanation and results show on the next chapters.

If we deploy the LTE system we obtain:

- ✓ Simple to deploy network;
- ✓ Less maintenance cost;
- ✓ High mobility support;
- ✓ Large bandwidth support;
- ✓ Reliable network;
- ✓ Less infrastructure cost;

Chapter Three

Addis Ababa Light Rail Control System

3.1 Introduction

This chapter mainly describes the Addis Ababa light railway communication system and signaling system. There is also background information here which describes the project.

The Addis Ababa light railway project was launched in 2011. It takes \$475m for the accomplishment of electrified rail. It has two lines E-W and S-N directions. The E-W (Phase I) Project starts from the south of the gate of Tor Hailoch Hospital in the west to Ayat which is the terminal end in the east, passing Mexico Plaza, Mesekel Plaza and Megenagna. The line passes through main roads such as Smuts St., Chad St., Ras Mekonen St., Jomo Kenyatta St., Haile Gebre Silase St. and Equatorial Guinea St. It has the sub grade section about 12.891km in length, the elevated section about 3.91km in length (including a common rail section 2.662km in length), and the underground section 0.197km in total length. The elevated sections consists a maximum height of 12m and minimum height 5.4m. A total of 22 stations are designed on the line, among which there are 6 elevated stations. The maximum and minimum intervals between stations are 1.26km and 0.435km respectively. The average station interval is 0.798km.

The N-S (Phase I) Project starts from the east of St. George Church in the north and turns towards the south after a section lay along the north of Mercoto Market, then passes through the west of the market to Chad St. and integrates with the E-W line. Then the line is laid towards the east and turns towards the south after arriving at the west of Mesekel Plaza, and finally arrives at Kallti, which is the terminal end in the south, after crossing beneath Meshalokia Bridge and Sino-Ethiopian Friendship Bridge. The line passes through main roads such as Fitawrari Gebeyebu St., Gyorgis St., Central African Republic St., Dej. Mekonin Demisaw, St., Dej. Bekele Weya St., Chad St., RasMekonen St., RasBiru St., Sierra Leone St., Beyene Aba Sebsib St. and DebreZeit Rd. It has the sub grade section about 10.057km in length, the elevated section about 5.977km in length (including a common rail section 2.662km in length), and the underground section about 0.655km in length. A total of 22 stations are designed on the line, among which there are 8 elevated stations (including 5 common rail stations) and 1 underground station. The rest are built on the ground. The maximum and minimum intervals between stations are 1.972km and 0.435km respectively. The average station interval is 0.773km.

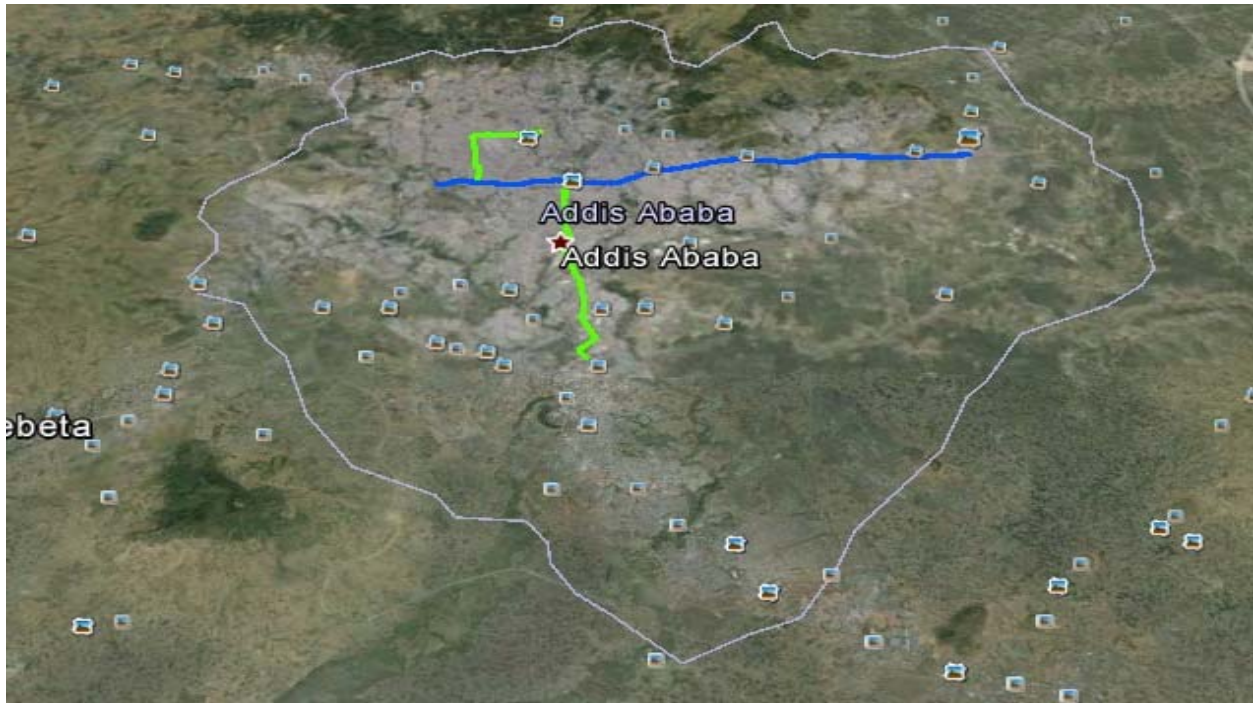


Figure 3.1: The Addis Ababa Light Rail transit from Google Earth

Some of the details especially on communication and signaling system of the project are given below.

3.2 Communication system

The project Addis Ababa light railway planned to deploy several communication techniques for the communication of information at the stations and from wayside equipments. The AALRT project includes Vehicle public addressing and passenger information display. Vehicle public addressing shall have the functions Automatic broadcasting of station names and precautions; Artificial broadcasting of station names and precautions; Intercom between cabs at both ends; intercom between individual cabs of vehicles for double-heading and Alarm and intercom within passenger saloon. The Passenger information display system consists of LCD display, LED display and corresponding equipment, and supplies passengers with quality video information and necessary operation specific messages. The Passenger compartments and driver's cabs shall be equipped with video surveillance systems. To implement these functions the project design and use several communication system like telephone system and radio communication.

3.2.1 Telephone System

Telephone system consists of telephone business and non-telephone business. It provides business contact between management department, operating department and maintenance department. It is interconnected with local public telephone network (the interconnection is excluded in the scope of the Project). There are many telephone users in the depot of lines such as management and maintenance personnel of E-W line, which are relatively centralized.

To sum it up, the functions are as follows:

- ✓ It provides the users with telephone call between internal users of the light rail.
- ✓ It provides the users with local telephone calls and national and international long-distance calls after the interconnection with local public telephone network.
- ✓ It provides the users with voice mail service.

3.2.2 Radio Communication System

Radio communication system is an important supporting measure to ensure traffic safety, to increase transportation efficiency and management level and to improve service quality. This system provides radio communication services for all the related users in the control centre and the depot, including dispatcher, driver and staff, operating personnel, site personnel, etc. The radio communication system has the following functions:

- ✓ Dispatchers and radio subscribers and radio subscribers between radio subscribers can communicate directly. There are selective calling, group calling, and general calling and broadcast in response to business contact of different subscribers.
- ✓ Record and search the call conversations of dispatchers.
- ✓ Emergency call (insert) function.
- ✓ System network management (saving and monitoring) function.
- ✓ Data transmission function and can transport data for signal system

Radio communications system consists of system equipment and wireless coverage equipment, and system equipment include central switching control equipment, onboard radio set, portable radios, network management terminal, base station, etc. Wireless coverage equipment include outdoor directional antenna, Omni-directional antenna, outdoor antenna iron tower (derrick), directional antenna in tunnels, power divider, coupler, radio-frequency cable, etc.

1. Central switching control equipment: Central switchboard is installed in the communications room of N-S line depot which can complete various organization and management operations.
2. Network Management Terminal: A complete set of network management terminal with printer is installed in the communications equipment room of depots in the system.
3. Base station equipment: Base station is installed in the inter-section substations and depots, which mainly include trans-receiver, control equipment, power supply unit, interface, etc. Distributed base stations are adopted which consists of BBU and RRU. The BBU installed with frame-type is set up in equipment room while RRU installed with wall-hanging type is set up in equipment room or proper locations outdoors in accordance with the actual conditions. BBU and RRU are connected by optical fiber and power supply of RRU is provided by nearest equipment room.
4. Vehicle radio set: Vehicle radio set (including host machine of station, antenna, control box, power supply unit, installation frame, etc.) is set up in the driver's cab at both ends of the train, and the low-profile disk antenna is installed on top of the train. Both shape and dimension of the onboard radio set meet the installation requirements of depot.
5. Outdoor antenna: Outdoor antenna consists of Omni-directional and directional antennas. Outdoor Omni-directional antenna is installed in depot which mainly covers the area of the depot. Directional antenna can be divided into two types, one of which is installed in the iron tower (derrick) on top of the inter-section substation to be used in on-ground and overhead lines; the other type is installed in the underground tunnels to cover the underground lines.

The system is operated under the frequency bands of 400MHz or 450MHz, and the specific frequency band is to be determined after negotiation with wireless management department of Ethiopian in the next stage. In order to meet the wireless coverage requirements, this design is calculated based on two frequency bands such as 400MHz and 450MHz during the coverage plan.

3.2.3 Fiber Communication

Two-core optical fiber in the optical cable laid at both sides of the lines is used to form E-W transmission loop and N-S transmission loop, which is tangent to each other at the control center to form the transmission system. The transmission system is protected by the protection ring at the two-fiber bidirectional multiplexing section. Schematic diagram of system composition is as follows:

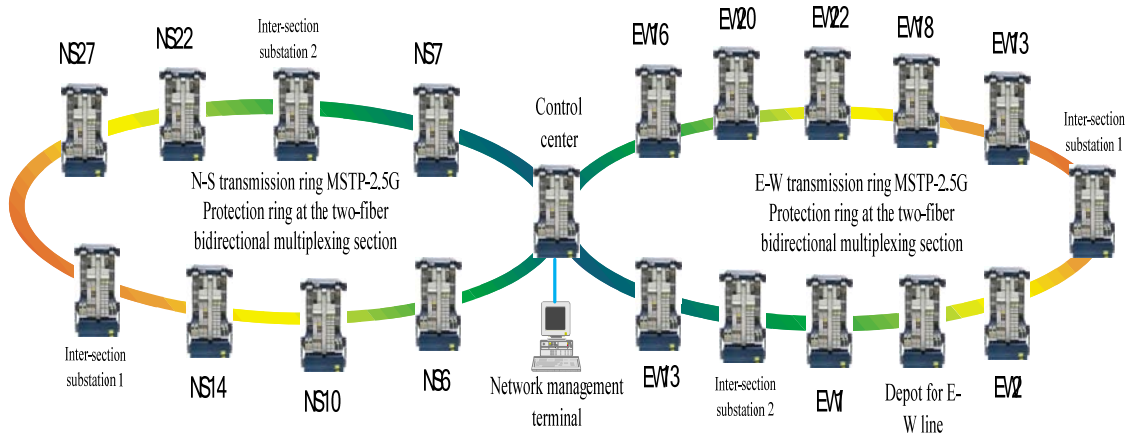


Figure 3.2: Schematic Diagram of Transmission System

3.2.4 Video Monitoring System

- Video monitoring system is the supporting equipment for modernization of light rail operation and management. It is used by dispatching management personnel of control & command centre for real time monitoring of passenger flow of station and situations of entering & departing station and important level crossing of lines to improve organization and management efficiency of operation and to ensure safe transportation of passengers on schedule by train. System functions are as follows:
- Image monitoring function: Relevant dispatcher and controller can monitor important areas like station platforms of the whole line, important level crossing of line, substation, and switch section of depot.
- Image selection and control function: Relevant dispatcher and controller can monitor all the images from cameras in the whole line via video control terminal equipment and can selectively display the images on the monitor wall in the OCC Hall.
- There are two modes for selection of the image displayed by monitor of the system: Automatic cycle monitoring mode (Automatic cycle monitoring can be conducted to fixed

combination of monitor areas that are already determined. Interval of cycle scanning can be set manually.); manual monitoring mode (Monitoring of determined monitor areas can be selected manually).

- Single selection of monitoring mode can be conducted manually to video recording object of system video equipment (single selection of monitoring can be conducted manually to any video camera image), and recorded image can be replayed on monitoring terminal.

From the preliminary design [2] the Addis Ababa light railway project will have the following band width allocation.

S/N	Name of Service	Species	Interface Type	Bandwidth Allocation	Remarks
I Internal Subsystems of Communications Systems					
1	Tel.	Voice	FE	100Mb/s	Bus shared
2	Radio Communication	Voice	FE	10Mb/s	Bus shared
3	Video monitoring information	Data	FE	2*100Mb/s	Bus shared
4	Communications power network management	Data	FE	10Mb/s	Bus shared
II Other Systems					
5	Monitoring information of the substation	Data	FE	10Mb/s	Bus shared
III Reservation					
6	Reserved	Data	FE	4×10Mb/s	Bus shared

Table 3.1: bandwidth allocation

3.3 Signaling System

The Addis Ababa light rail is running within the public transport spaces through the streets rather than a completely independent mass transit system. The line of the Project is greatly different from the common metro or fully-enclosed overhead railway line. In view of the maximum running speed of not more than 70 km/h, the main design principles of the signaling system for the Project are as follows[18]:

1. For the line section constructed on the ground, manual driving by viewing shall be adopted. The driver shall drive the train manually through control of the running speed and the safety headway with the front train .The driver shall ensure the operation safety of the train through this driving mode.
2. For the line section built underground and overhead, the headway between the trains shall be controlled by technical measure. In the Project, fixed block system is used for control of the space headway between the trains. The driver shall manually drive the train in accordance with the indication of the signal and the speed limit signs of the line.
3. Although the operation safety of the train is on the driver's responsibility, to ensure the safety of the train running through the route of the sections with switch area on the main line and prevent any accident arising from false operation of switch, head-on collision or side collision of trains, etc., the control system for the switch area of the main line shall be provided to allow correct interlocking and route control among the track sections, signals, and switch.
4. The Auxiliary operation dispatching system shall be provided in the control center to achieve the functions of manual setting of route in the switch area of the main line, train ID tracing, scheduling of timetable, and centralized maintenance and management of main line equipment, etc.
5. The route request equipment shall be provided in the switch area of the main line to realize, together with car borne signal equipment and switch area control system equipment, the automatic route setting and manual route setting by driver in the switch area.
6. The level crossing signaling system shall be provided at the level crossing between the railway line of the Project and the roads, to give the priority to the trains.
7. The computer interlocking system shall be provided for ensuring safe and complete interlocking relationships and route control in the depot.

8. The equipments related to operation safety of the Project shall have the corresponding level of safety integrity:
 - a) The safety integrity of the CBI system of the depot shall reach SIL4.
 - b) The safety integrity of the track occupancy/vacancy detection equipment in the track section of the main line shall reach SIL4.
 - c) The safety integrity of the control system in the switch area of the main line shall not be lower than SIL3.
9. The trackside signal equipment of the main line shall fully consider environmental factors such as temperature and humidity of different climates so as to fit the climate of Addis Ababa
10. Equipment of the signaling system may be able to prevent lightning and electromagnetic interference, and adopt systematic and complete lightning protection, grounding and electromagnetic interference prevention measures.
11. The signaling system should be able to interface with systems, like rolling stock and power supply in a safe and reliable fashion, and meet relevant interconnection functions and performance requirements.
12. The safety evaluation report shall be provided for the signaling system before the no-load trial run and the safety certificate to prove that the train is allowed to carry passengers shall be provided before the railway line is put into operation.

The signaling system is composed of operation assistant dispatching system in control center, control system in the switch area of the main line, route request system, signaling system at crossings, computer based interlocking system in the depot, and car borne signaling system. The composition of the system overall composition is shown on figure below.

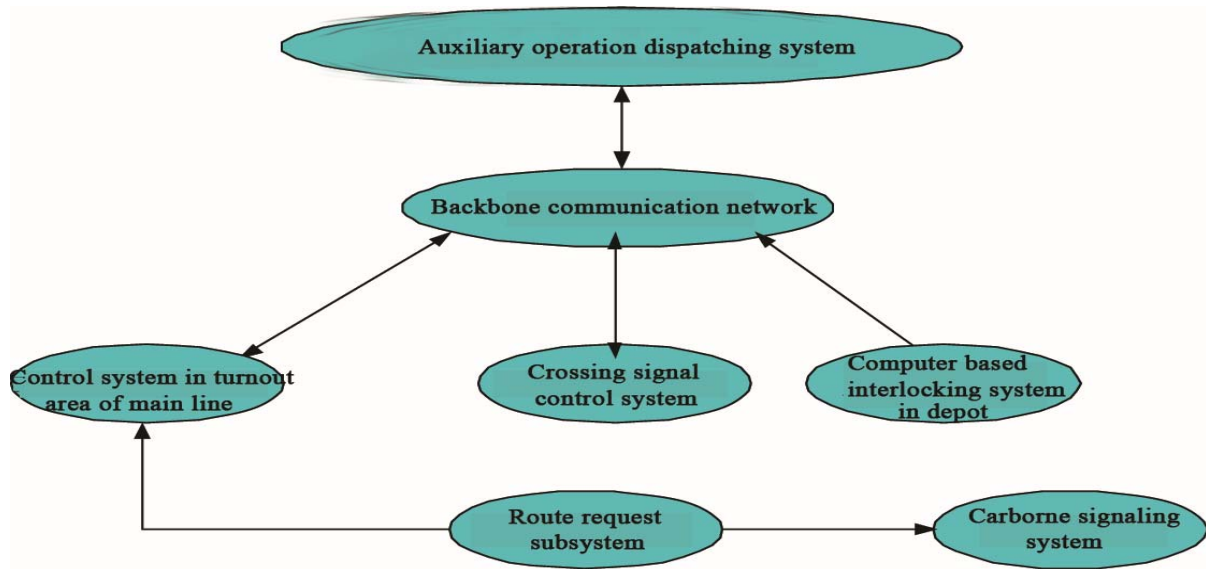


Figure 3.3: Modular Construction of Signaling System

Chapter Four

Train to Train Communication System

In this chapter there are discussions about train to train communication system through LTE network, System architectures and circuit diagram of the overall train to train communication model. The components for train to train communication also observe here. There are also flow charts introduce the instruction require to drive trains.

4.1 System Architecture Overview

The distribution train track communication implement by the coordinate of LTE, Microcontroller AT89C52 and GPS technologies. The system composed of other sub system like speed capturing circuit; relay for automatic brake; alerting devices and display equipments like LED and LCD. The GPS system tracks the position of trains which announce the longitudinal and latitude position of trains. The embedded microcontroller AT 89C52 calculates the distance between trains by the help of “Haversine formula”. The speed capturing circuit determines the speed of train based on pulse width analysis. Each train receives the message through LTE network which contains Identification Number, Direction, position and Speed of the neighbor trains. Even we can communicate real time scenarios of the train. Microcontroller identifies the nearest train and the speed condition from the data received. If the train speeds above the limit with relative to breaking distance of the system, the embedded microcontroller makes decision based on the instruction. The instruction consists of options like alarm, automatic brake and caution signals in the cab. The light Emitting diode, LCD alarm devices alert the train master for different situation before accident occur. The system architecture on Figure shows 4.1 the overall communication and control system.

Here are hardware system components:

- ✓ **GPS:** Track the longitudinal and latitudinal position of trains.
- ✓ **Microcontroller:** process the data and instruction received from different components.
- ✓ **LTE modem:** the modem which receives and transmits train messages.
- ✓ **Max232:** interfacing the modems like LTE and GPS.
- ✓ **LED:** different color light emitting diodes for status information
- ✓ **LCD:** to display information like train ID, position, speed and direction of the nearest train and its profile.

- ✓ **Speed capture circuit:** for measuring speed of train.
- ✓ **Alarm:** alert the train master.
- ✓ **Relay driver:** for the control of train speed.
- ✓ **Power supply:** power source for components which has no internal battery.

The block diagram on Figure 4.1 shows the coordination of these components on a single train. Each train consists of these components to have reliable communication between trains.

Feasibility of the system:

- No need of central control.
- Flexible system to drive train everywhere.
- Train driver adjusts the speed and position.
- No need of some way side equipments like block signaling equipment, axle counter and ballise.
- Reduce train running gap less than 2 Km.
- Reliable system for safety driving.
- Less maintenance cost required.

The next section presents some of these components like GPS, speed capture circuit, microcontroller, LTE system etc.

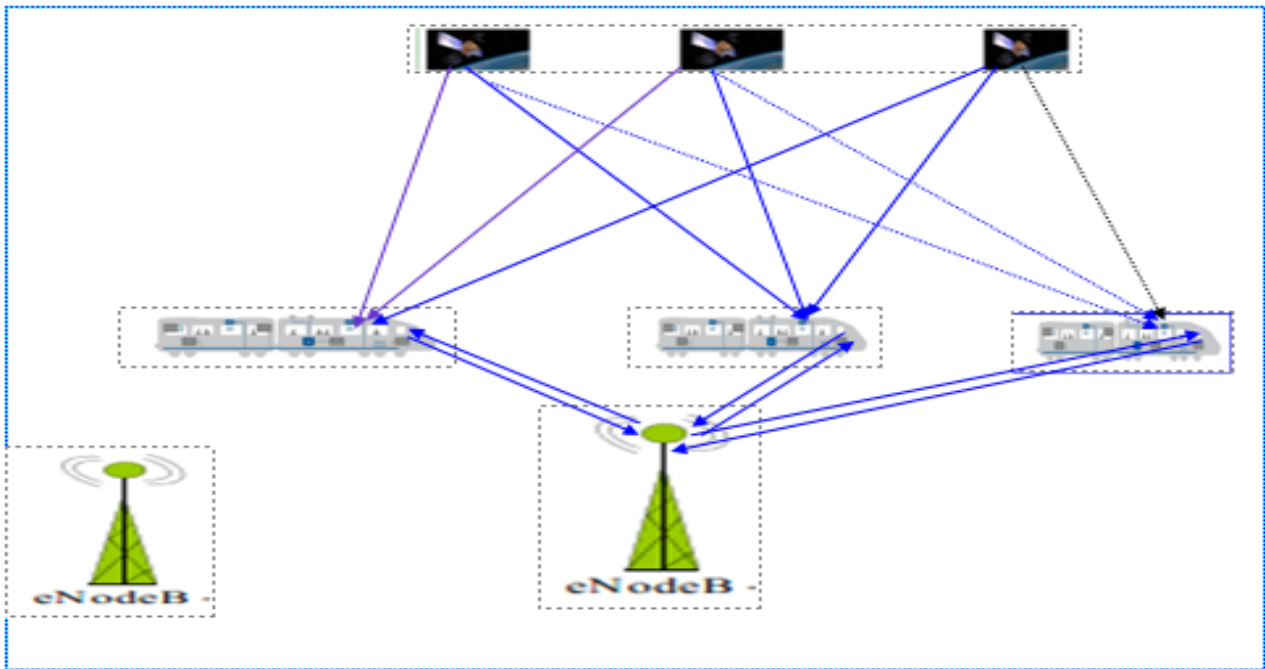


Figure 4.1: System Architecture

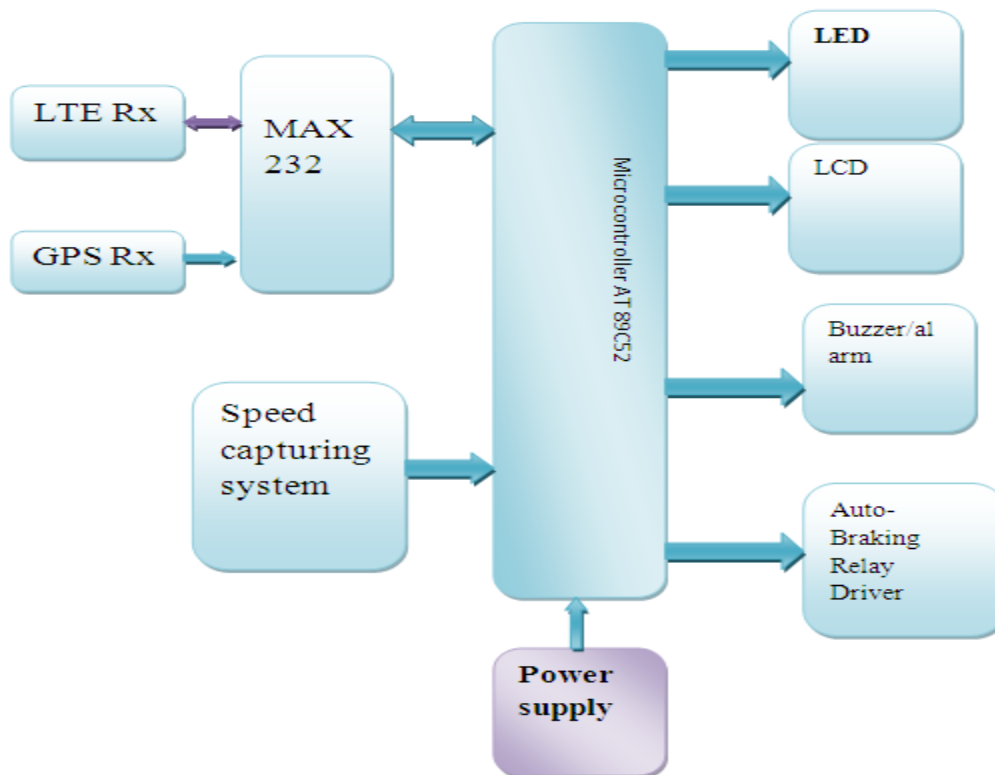


Figure 4.2: System block diagram for a single train

4.1.1 Global Positioning System

Global position system (GPS) is one of the main components in this system. It is a relatively new technology that uses signals sent from satellites orbiting the Earth to very accurately determine the location of receivers on the surface. GPS is based on technologies developed for military and aerospace research, notably radio astronomy and satellite tracking. These satellites continuously transmit radio signals back to Earth. To determine its precise position on Earth (longitude, latitude, elevation), each GPS receiver must simultaneously obtain signals from at least four satellites.

GPS relies on two dozen navigational satellites that orbit our planet at 20,000 km (12,500mi) above the surface every 12 hours, as part of the Navistar system of the U.S. Department of Defense. Spacing was determined so that from any point on Earth, at least 4 satellites will be above the horizon and detectable [11]. Each satellite has:

- 1) A computer,
- 2) An atomic clock (Universal Time Coordinated, UTC)
- 3) A radio.

With a computerized understanding of its own orbit, it continually broadcasts its changing position and time via radio signals. Once a day, each satellite checks its own time and position with a ground station to make any needed corrections.

The GPS receiver on the ground detects the radio signals from the satellites and the computer “triangulates” its own position by getting bearings from a minimum of 3 satellites. If 4 or more satellites can be received, the receiver/ computer can figure out the altitude as well as the geographic position.

Triangulation is a geometric calculation of the distance from, and the angle to, each satellite. The more satellites the GPS receiver “sees” the more accurate the location determination will be. The result is provided in longitude and latitude and can be accurate to within a range of 10–20 meters for hand held GPS, and to within millimeters for anchored (differential) GPS stations. The most advanced GPS receivers used for the Plate Boundary Observatory can determine their location to a precision equal to the size of a grain of rice.

There are two commonly used GPS type. Most of the time we know handheld GPS units, which people use for navigation (for example, some cars now come equipped with GPS units), recreation (for example, hiking and geo-caching), mapmaking, and land planning. But there is another GPS

unit which is called high-precision (“differential”) .There are several important differences between handheld GPS units and the high-precision (“differential”) GPS units that Earth scientists use in their research [13].

Handheld GPS receivers calculate positions that are known as autonomous solutions. In other words, each handheld GPS receiver is independent from all other receivers and uses only satellites to calculate positions. As a result, handheld GPS receivers are unable to correct for many error sources like clock, atmospheric, multipath, Ephemeris (orbital):

Differential GPS uses two GPS receivers to calculate a position: a stationary receiver (“base station”) whose location is accurately known from surveying and a roving (moving) receiver. Both receivers continuously calculate their positions from the satellites. The base station compares the calculated position with its known location and “**differences**” the two measurements to determine the error in the GPS signal. Then, the base station sends the error corrections to the roving receiver. Using differential GPS allows scientists to minimize the errors associated with measuring positions. Here is the major difference between two units.

- GPS satellites send out two different signals: L1 and L2. Differential GPS receivers measure both L1 and L2, whereas handheld GPS receivers measure only L1.
- Differential GPS uses antennas specially constructed to reduce multipath error.
- Differential GPS receivers store position data. Handheld GPS receivers do not.
- Differential GPS data are processed at data storage facilities and corrected for errors. Handheld GPS data are not processed.

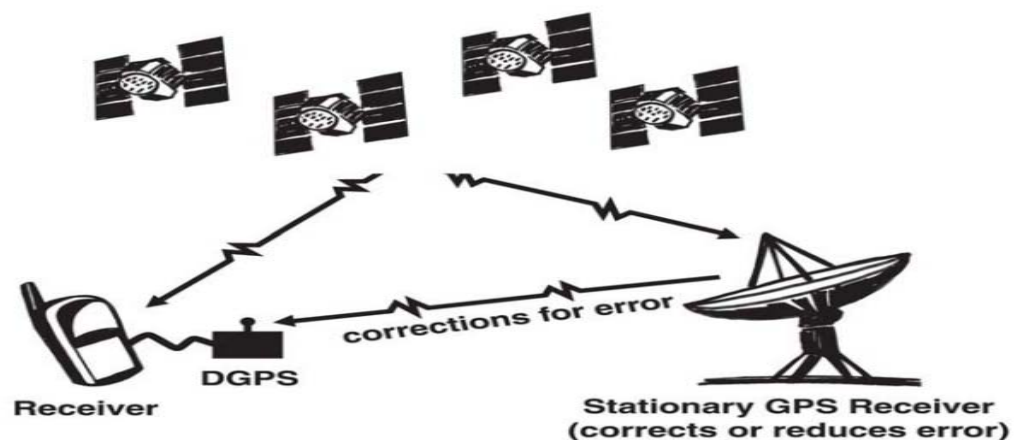


Figure 4.3: Real time Differential GPS

There are several different models and types of GPS receivers. When working on an incident with a GPS receiver it is important to [15]:

- Always have a compass and a map.
- Have a GPS download cable.
- Have extra batteries.
- Know memory capacity of the GPS receiver to prevent loss of data, decrease in accuracy of data, or other problems.
- Use an external antennae whenever possible, especially under tree canopy, in canyons, or while flying or driving.
- Set up GPS receiver according to incident or agency standard regulation; coordinate system.
- Take notes that describe what you are saving in the receiver.

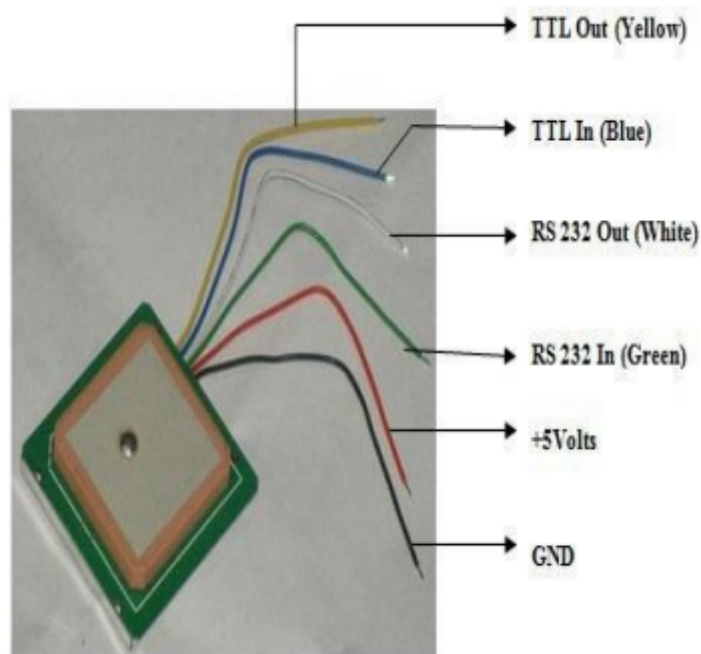


Figure 4.4: GPS Receiver

There are data collection and computing distance between points by using Haversine formula [12]. let $d(x_i, x_j)$ is the measured difference between points i and j . $d(x_i, x_j)$ is a nonnegative number that is close to 0 when two points i and j are near each other.

The distance between two points is calculated by using *Haversine formula*:

$$a = \sin^2(\Delta\phi/2) + \cos(\phi_1) \cdot \cos(\phi_2) \cdot \sin^2(\Delta\lambda/2) \dots \dots \dots (4, 1)$$

$$c = 2 \cdot \text{atan2}(\sqrt{a}, \sqrt{1-a}) \dots \dots \dots (4, 2)$$

$$d = R \cdot c \dots \dots \dots (4, 3)$$

Where ϕ is altitude, λ is longitude, R is earth's radius (mean radius=6371km); angle in radians.

4.1.2 Train speed capture (speedometer)

Before any control takes place, the train speed has to be captured. This is done by using a light source (LED), which emits narrow rays towards a reflector mounted on one of the train wheels. The reflected light is picked up by a phototransistor. The output of the phototransistor is in the range of 1.62-2.07 V on no light, and 2.31- 2.89V on reflected light presence. This voltage is fed to a buffer (LM358N) for matching purpose. The buffer output is compared with a 2.25V voltage through another LM358N operational amplifier, to produce a pulse train, with zero volt for low voltage (<2.25V) and 5 V for high voltage (>2.25V). The duration of pulse is proportional to the train speed.

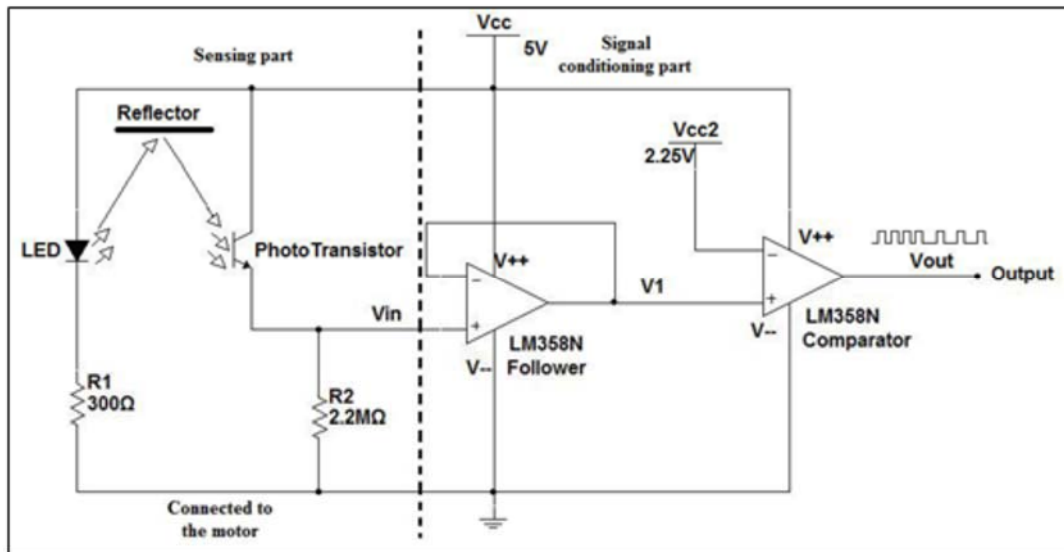


Figure 4.5: speed capture circuit

The pulses are captured through the data capture port of the microchip AT89C52 microcontroller, where each two successive leading edges are detected. The AT89C52 has four 16 bit timers. In this project only Timer0 is used and programmed as a free running timer. On each leading edge, the timer value is read in a buffer. Then its value is read on the following leading edge into a second buffer. The difference between the two values gives the duration of

the pulse. The shorter is the pulse, the faster is the train. So the speed is inversely proportional to the pulse duration. $V = K/T$ where V is the speed, T is the pulse period and K is the proportionality constant. K is expressed in terms of radius of wheel.

4.1.3 Signaling Principles

Cab signaling uses speed capturing circuits which generate pulse code from the emission of light and reflection from wheel. The code specifies the speed of train. This speed is displayed in the driver's cab. Moreover, the distance between trains is calculated from the message received through LTE network. For the system we have reference speed and distance for the determination of signaling status. Compared to color-light signals, the driver can more easily adjust train speed close to the optimum and has less concern about overrunning a trip stop. Problems with signal visibility on curves and in inclement weather are reduced or eliminated.

Cab signaling avoids much of the high capital and maintenance costs of multiple-aspect color-light signals, although it is prudent and usual to leave signals at interlocking and occasionally on the final approach to and exit from each station. In some situations, dwarf color-light signals can be used.

Moving-block signaling systems are also transmission based or communication-based signaling systems potentially misleading because cab signaling is also transmission based. A moving-block signaling system can be likened to a fixed block system with very small blocks and a large number of aspects. Several analytic approaches to moving-block systems use this analogy. However a moving-block signaling system has neither blocks nor aspects. The system is based on a continuous or frequent calculation of the clear (safe) distance ahead of each train and then relaying the appropriate speed, braking or acceleration rate to each train.

This requires a continuous or frequent two-way communication with each train, and a precise knowledge of a train's location, speed and length; and fixed details of the line curves, grades, interlocking and stations. These may be contained in a table that allows changes to be made without the normal full rigor required for changes to safety-critical software. Temporary changes can be easily made to add speed restrictions or close off a section of track for maintenance work. Based on this information, a computer can calculate the next stopping point of each train often referred to as the target point and command the train to brake, accelerate or coast accordingly. The target point will be based on the normal braking distance for that train plus a safety distance.

Safety Distance: Braking distance is a readily determined or calculated figure for any system. The safety distance is less tangible because it includes a calculated component adjusted by agency policy. In certain systems this distance is fixed; however, the maximum throughput is obtained by varying the safety distance with speed and location and, where different types of equipment are operated, by equipment type.

In theory, the safety distance is the maximum distances a train can travel after it has failed to act on a brake command before automatic override (or over speed) systems implement emergency braking. Factors in this calculation include

- System reaction time;
- Brake actuation time;
- Speed;
- Train load (mass) including any ice and snow load;
- Grade;
- Maximum tail winds (if applicable);
- Emergency braking rate;
- Normal braking rate;
- Train to track adhesion; and
- An allowance for partial failure of the braking system.

The safety distance is frequently referred to as the “worst-case” braking distance, but this terminology is misleading. The truly worst case would be a total braking failure. Worst case implies reasonable failure situations, and total brake failure is not regarded as a realistic scenario on modern rail transit equipment that has multiple braking systems. A typical interpretation of the safety distance assumes that the braking system is three-quarters effective.

Train Position and Communication: Without track circuits to determine block occupancy, a moving-block signaling system must have an independent method to accurately locate the position of the front of a train. The location of the front train calculated from the message received from it which consists of position and speed.

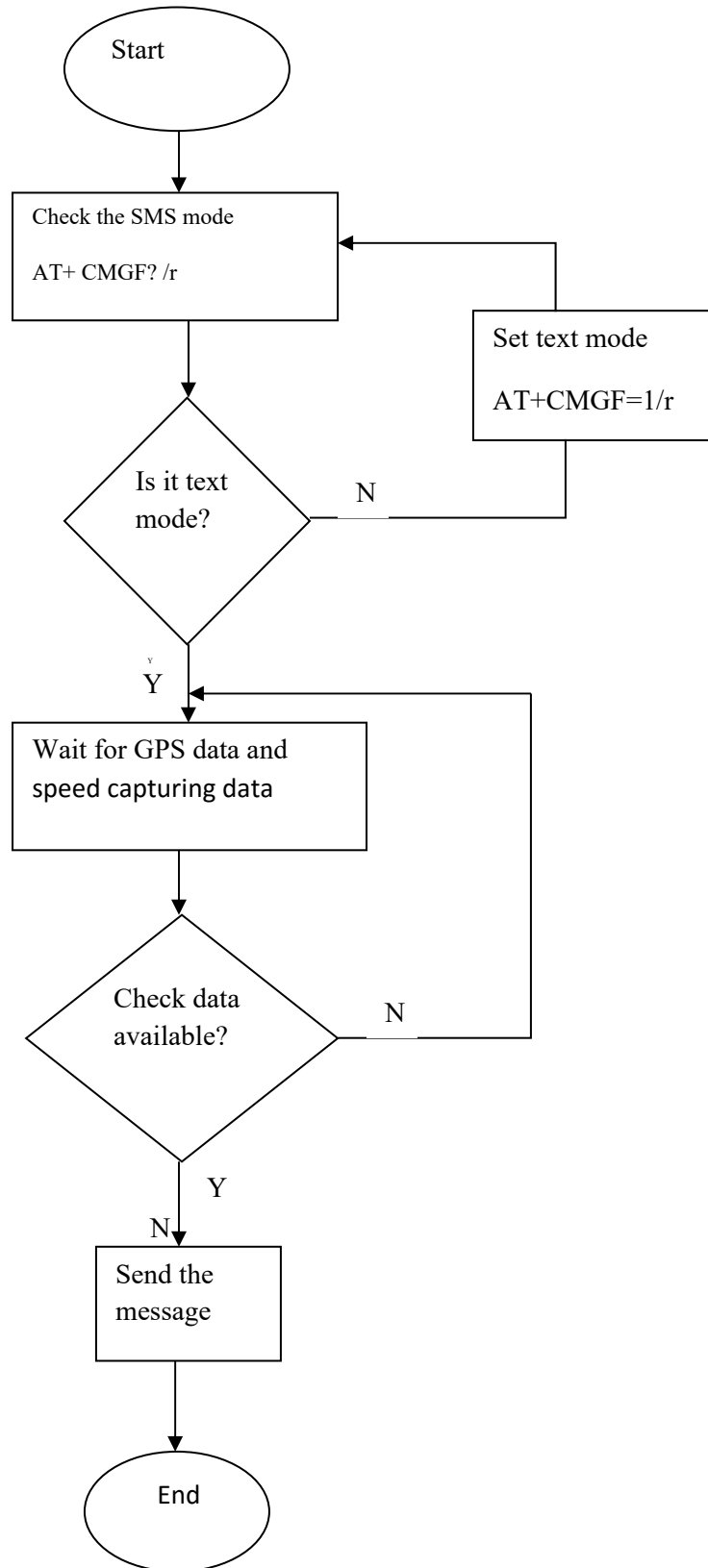
Data Processing: The first moving-block signaling systems used mainframe computers with a complex interconnection system that provided high levels of reliability. There is now a move toward the use of much less expensive and space-consuming personal computers and microcontroller.

The Atmel AT89C52 Microcontroller that calculate distance between, speeds and control a cab-block signaling system can be located on each train, at a central control office. The most common arrangement is a combination of on-board and central control office locations. Communication equipment, microcontroller and GPS tracking equipment are found on central control office. AT89C52 is a low power; high performance CMOS 8-bit microcomputer with 8 KB of Flash programmable and erasable read only memory (PEROM). It has 256 bytes of RAM, 32 input/output (I/O) lines, three 16-bit timers/ counters, a six-vector two-level interrupt architecture a full-duplex serial port, an on-chip oscillator and clock circuit [14]. The system clock also plays a significant role in operation of the microcontroller. An 11.0592MHz quartz crystal connected to pins 18 and 19 provides basic clock to the microcontroller. Power-on reset is provided by the combination of electrolytic capacitor and resistor.

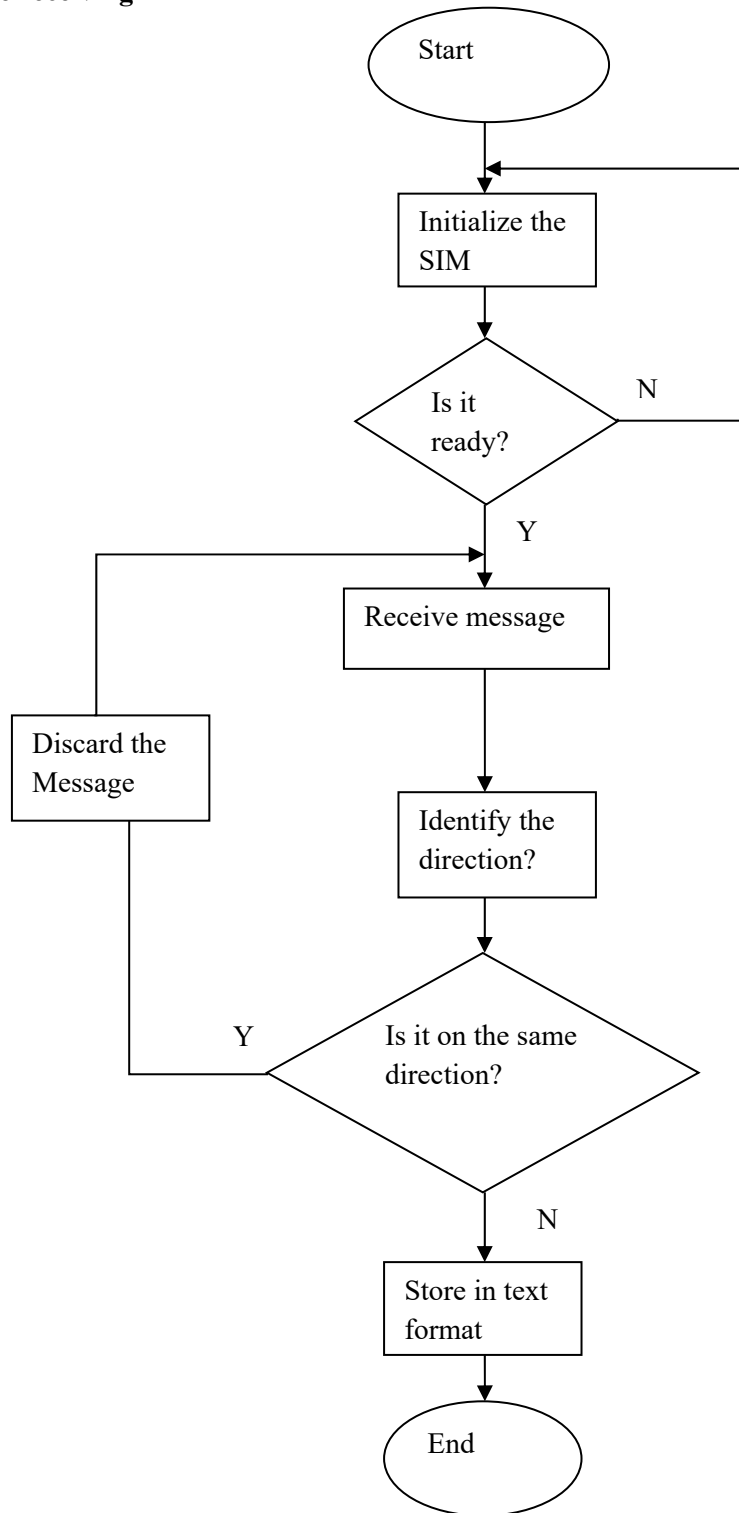
The main functions for microcontroller here are:

- Receive message from MAX232 and process it.
- Read speed from speed capture circuit.
- Calculate the distance between trains.
- Determine the status of the train.
- Display the LED signal in the cab.
- Take action on braking if there is gap less than the allowed speed.

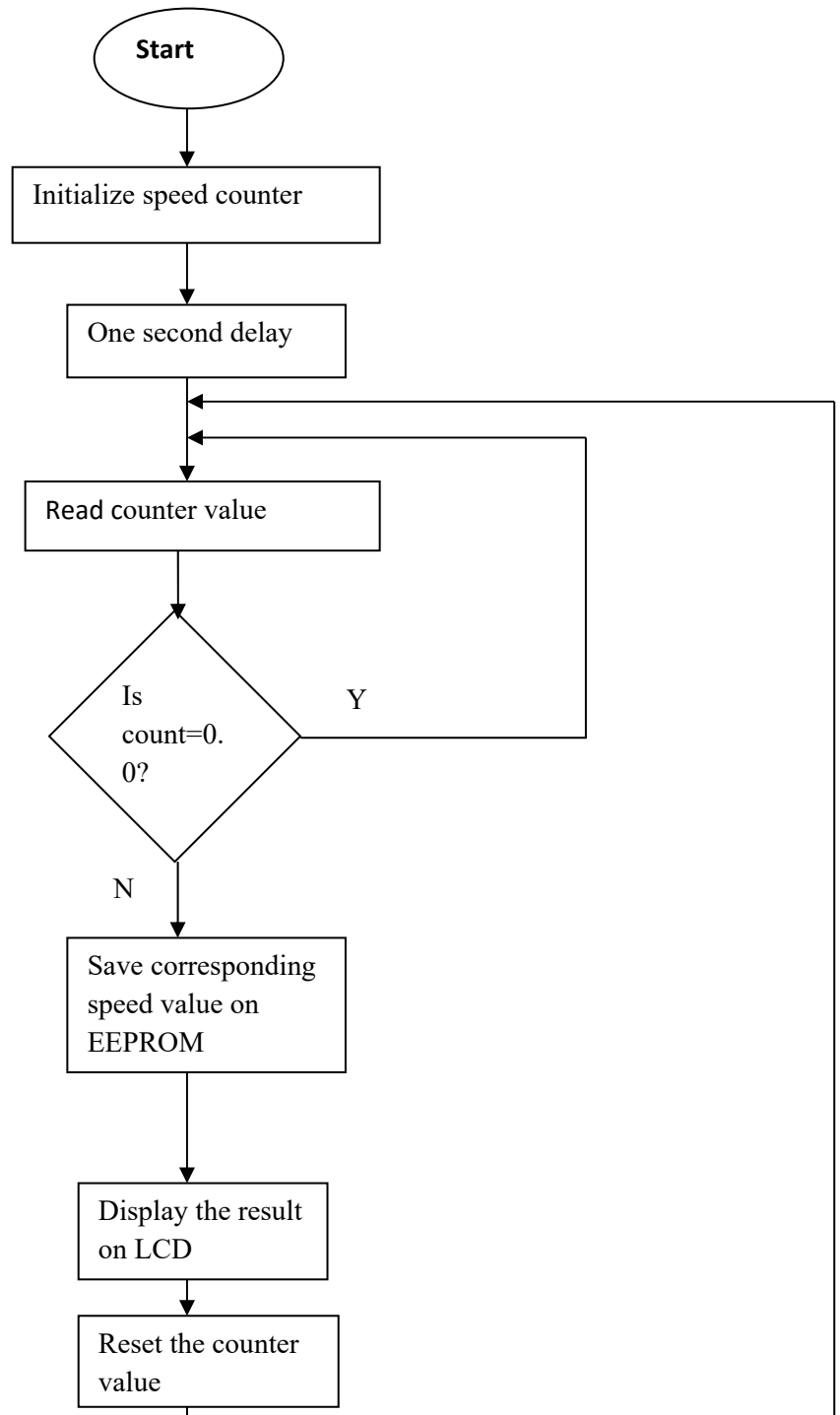
a) Message sending



b) Message receiving



c) Speed Capture



d) Alarm procedure

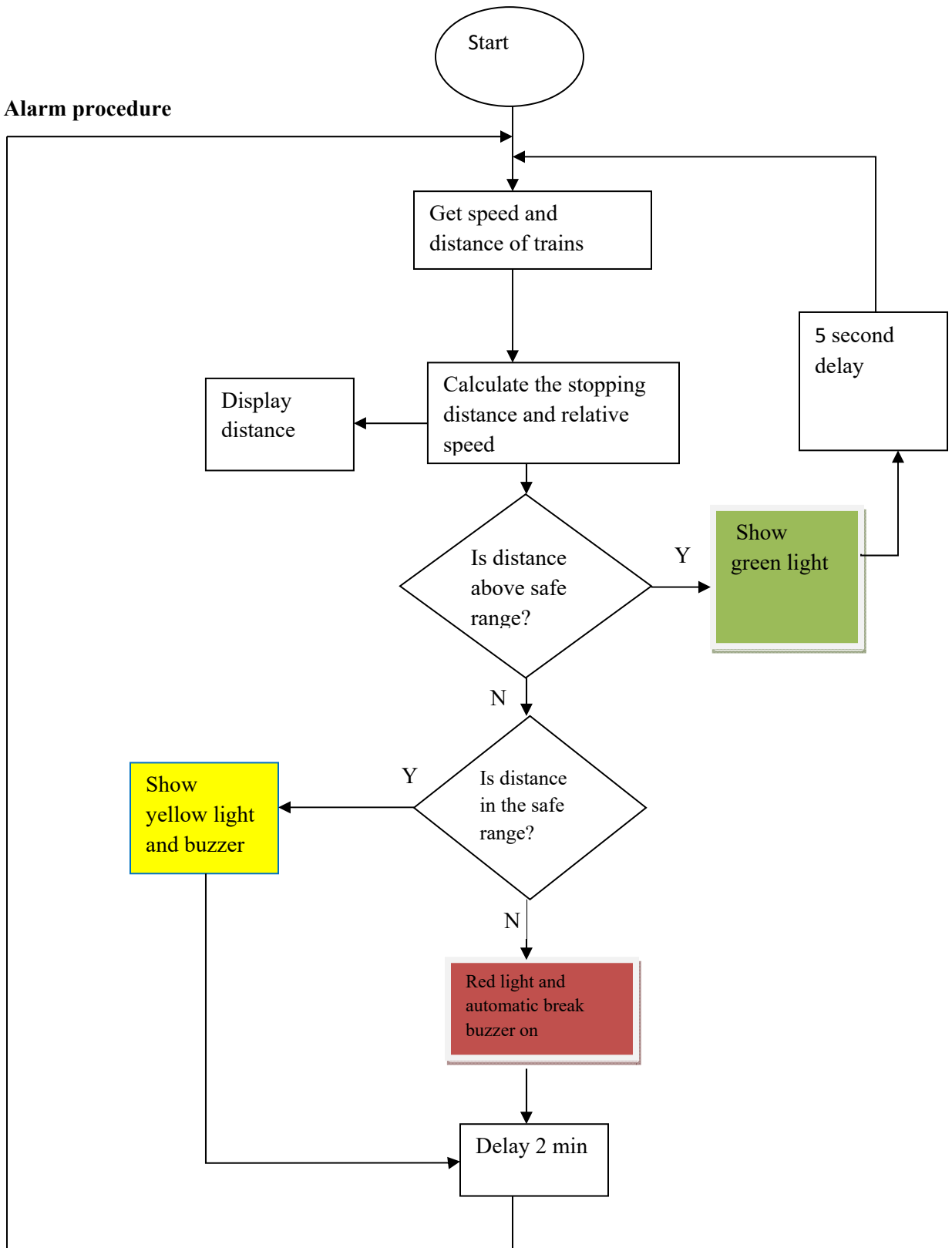


Figure 4.6: a, b, c, d Procedures for train to train communication

4.2 LTE for Train Communication

The proposed communication system for train control and communication purpose is LTE technology. In this section the merit of LTE over the other network for Addis Ababa light rail project is discussed. Here there is also planning procedures and propagation models for the design of the LTE system.

The LTE or Long Term Evolution is a fourth generation network (4G) which is a standard for wireless data communications technology and a development of the GSM/UMTS standards. The goal of LTE was to increase the capacity and speed of wireless data networks using new DSP (digital signal processing) techniques and modulations that were developed around the turn of the millennium. A further goal was the redesign and simplification of the network architecture to an IP-based system with significantly reduced transfer latency compared to the 3G architecture.

The LTE specification provides downlink peak rates of 150 Mbps, uplink peak rates of 50 Mbps and QoS provisions permitting a transfer latency of less than 5 ms in the radio access network. LTE has the ability to manage fast-moving mobiles and supports multi-cast and broadcast streams. LTE supports scalable carrier bandwidths, from 1.4 MHz to 20 MHz and supports both frequency division duplexing (FDD) and time-division duplexing (TDD). The IP-based network architecture, called the Evolved Packet Core (EPC) and designed to replace the GPRS Core Network, supports seamless handovers for both voice and data to cell towers with older network technology such as GSM, UMTS and CDMA2000. The simpler architecture results in lower operating costs (for example, each E-UTRA cell will support up to four times the data and voice capacity supported by HSP [16]).

LTE introduces a new design for the radio access network and system architecture compared to 2nd and 3rd Generation networks (2G and 3G). The system architecture is based on the Internet Protocol (IP) and is therefore designed to support packet based information.

4.2.1 LTE Architecture

The two main components of LTE are the Evolved Universal Terrestrial Radio Access Network (E-UTRAN), which consists of eNodeBs, and the Evolved Packet Core (EPC), which consists of the Mobility Management Entity (MME), the Serving Gateway (S-GW) and the Packet Data Network Gateway (P-GW) [6].

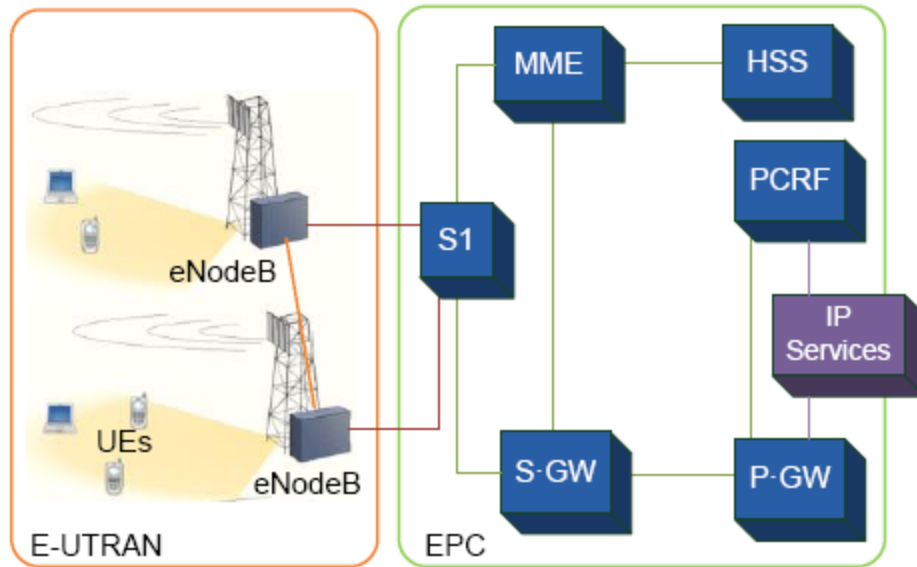


Figure 4.7: LTE Architecture

E-UTRAN: The E-UTRAN is composed of a number of radio stations called *eNodeBs* that handle the physical and link layers of the protocol stack, managing radio resources and controlling transmitting devices. All *eNodeBs* are directly connected to the Evolved Packet Core .there is no equivalent to GSM-R Base Station Controllers.

EPC: This consists of a number of functional blocks that handle mobility management, authentication and policy charging, as well as connectivity with legacy networks and external networks. These functional blocks do not necessarily correspond with physical hardware; they are exclusively software based, and this feature allows for a greater degree of scalability and virtualization than it was possible with previous 3GPP technologies. The Mobility Management Entity (MME), which handles authentication (via the HSS), ciphering/integrity protection for network signaling, idle mode User Equipment (UE) tracking, paging, retransmissions and mobility to and from 2G/3G radio access networks. Logically adjacent to the MME is the Serving Gateway (SGW). Its function is to route data packets as well as to manage inter-eNodeB cell re-selections and handovers. It also manages LTE/GSM/UMTS mobility.

The Packet Data Network Gateway (PGW) provides connectivity to and from external data networks.

The Home Subscriber Server (HSS) is a database that contains the information of all registered UEs. It is consulted by the MME to authenticate UEs requesting connection.

The Policy charging and Rules Function (PCRF) controls the billing function and the rules governing the Quality of Service parameters experienced by each UE.

The connectivity between all these elements is generally based on MPLS over IP services. None of the interfaces is based over an E1 link, as was the case with previous 3GPP technologies. Security is based on 128 bits Advanced Encryption Standard (AES) for the air interface, as well as SIM card (IMEI) identification via MME and HSS. Optionally, the MPLS transmission network can implement IPsec protocol to further augment security.

4.2.2 Demand for LTE

Nowadays interest has grown in using Mobile Relay Station (MRS) system to provide cellular coverage to the onboard users in public transport, particularly in High Speed Trains (HSTs) due to high penetration rate of portable electronic devices such as smart phones, tablets and laptops. In the railway scenarios, when the signal propagates into the train, it suffers through the high order of Vehicle Penetration Loss (VPL) due to modern construction materials and techniques used for the train. Beside that rapid temporal variations in the radio channel and Inter-Carrier Interference (ICI) issues due to Doppler shift effects produce a quick battery drain or increased call drop rates indeed. Therefore users inside train will suffer worse channel propagation conditions, similar to cell-edge users. Thus the coverage and capacity at railway scenario remain relatively small due to low Signal-to-Noise Ratio (SNR).

The deployment of MRS system to transmit data between the Donor eNB (DeNB) and the User Equipments (UEs) through multi hop communication significantly improves the achievable throughput of onboard users as compared to direct transmission. Besides that, it also improves the throughput of the macro users located in cells that the train is passing through [15].

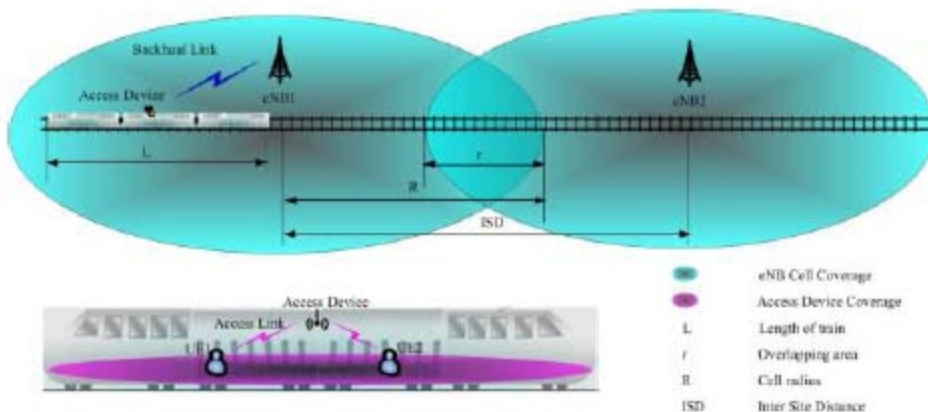


Figure 4.8: MRS Deployment in Railway Scenario

There are over several years of development separating GSM and LTE technologies, what makes them very different in many aspects. However, here, the focus is put on a few main advantages of LTE that could be highly beneficial from the railway perspective. The key element differentiating LTE from GSM-R is that an LTE network is based on packet-switched transmission. It is the first mobile technology adopting the all-IP approach abandoning circuit-switched transmission. Packet switched transmission is more flexible in managing available network resources. It increases network utilization and reduces waste of limited network resources. Despite the lack of circuit-switched mode, LTE includes Quality-of-Service mechanisms that provide packet differentiation.

Another advantage of LTE network is the reduced packet delay, which is one of the crucial requirements for providing ETCS messages. This is achieved by simplifying the network architecture. The LTE network has less logical and physical elements and they are all based on a common technology (IP).

Finally, LTE offers much higher throughput over its radio access. It consists of a number of improvements that increase spectral efficiency of LTE in comparison to older technologies (GSM and UMTS) [3, 8]:

- Advanced multiplexing – Orthogonal Frequency Division Multiplexing (OFDM).
- More advanced modulation – up to 64 Quadrature Amplitude Modulation (QAM).
- Sophisticated transceiver – Multiple Input Multiple Output (MIMO) technology.
- With a user-plane latency as low as 5 ms LTE supports a more capable CBTC system, leading to higher efficiency in train operation.
- Sophisticated QoS built into LTE guaranteed delivery of critical traffic over a multiservice network, leading to OPEX reduction.
- The all-IP architecture and superior broadband capacity performance of LTE opens up the possibility of supporting new kinds of operational or infotainment services and lowers the integration barrier.
- As the leading-edge mainstream mobility technology, LTE offers a platform for future evolution and growth. Its strong ecosystem support will deliver the best possible performance–value ratio in the long term.

- Despite its status as the newest of the 3GPP standards, LTE's evolutionary nature shares the benefits of many of the proven mobility technologies and architectural concepts defined in preceding standards.

The need to implement LTE to AALRT is:

- ✓ For safety and easily maintaining;
- ✓ Minimize the complexity of the system;
- ✓ Reliable and high capacity bandwidth;
- ✓ Reduce infrastructure cost;
- ✓ Minimize the need of wayside equipment;
- ✓ Reduce the effect of central conjunction;
- ✓ Flexibility of the system;
- ✓ Mobility supporting behavior;
- ✓ Low latency;
- ✓ Reduce the threat on fiber damage.

4.2.3 LTE System Planning

Radio network planning is a very vital step for a wireless communication technology. As standardization work of LTE is approaching the end line, it's high time to go for efficient radio network planning guideline for LTE. For the same reason, along with the fact that LTE radio network planning work just like other cellular technologies, initial stage plans is normally guided by various industries and vendors at their own discretion. Radio Network Planning contains number of series activities like Site survey-which includes collection of pre-planning information that will be used in the Link Budget preparation and Coverage and Capacity planning calculations; Frequency and spectrum planning- in this phase a variety of parameters' values will be chosen, and according to these parameters the rest of the calculation is processed; Link Budget and Coverage planning, and Capacity planning- these two steps involve propagation model tuning, defining thresholds from Link budget, creating detailed radio plan based on the thresholds, checking network capacity against more detailed traffic estimates, and configuration planning.

COST231 is the most important propagation prediction models. The predictions are based on the knowledge of topography, land usage and building height information. This section deals with

five different topics, modeling in urban areas, influence of vegetation, large-scale terrain effects, multipath prediction and the combination of the different aspects yielding more general models.

For the **COST 231 - Hata-Model** Path loss estimation is performed by empirical models if land cover is known only roughly, and the parameters required for semi-deterministic models cannot be determined. Four parameters are used for estimation of the propagation loss by Hata's well-known model: frequency f , distance d , base station antenna height h_{Base} and the height of the mobile antenna h_{Mobile} . In Hata's model, which is based on Okumura's various correction functions, the basic transmission loss, L_b , in urban areas is expressed as propagation loss Equation on Appendix A. the model restricted to frequency of between 150MHz to 1500MHz; h_{Base} between 30 to 200m ; mobile antenna height between 1 and 10 and coverage area up to 1.2Km. One of the limitations is not considering the barriers like vegetation and buildings.

COST 231 has extended Hata's model to the frequency band $1500 < f(\text{MHz}) < 2000$ by analyzing Okumura's propagation curves in the upper frequency band. This combination is called "COST-Hata-Model". The difference between Hata's model and COST-Hata-model is the special concentration for barriers like trees and building, frequency range, and coverage radius. Generally the models are summarized by equation 5.16 and 5.20.

Furthermore COST 231 proposed a combination of the Walfisch [M8] and Ikegami [M20] models. This formulation is based on different contributions from members of the "COST 231 Subgroup on Propagation Models" [M23]. It is called the COST-Walfisch-Ikegami-Model (COST WI). The model allows for improved path-loss estimation by consideration of more data to describe the character of the urban environment, namely. The special thing this model proposes the consideration of building roof height, distance between buildings and road width on the city.

The model distinguishes between line-of-sight (LOS) and non-line-of-sight (NLOS) situations. In the LOS case between base and mobile antennas within a street canyon - a simple propagation loss formula different from free space loss is applied [17].

4.2.3.1 Site Survey

The Addis Ababa Light Rail Transit Project is a semi-closed urban rail transit system. The planned line has a total length of about 75 km which is to be constructed in two phases. The scope of works implemented in this Project, Project Phase I (only), covers the main line in length of about 31.025km, including a common rail section of about 2.662km long, in downtown area,

to be run by both E-W line and N-S line. The main line of E-W line is about 16.998km in full length and the main line of N-S line is 16.689km in full length, with the starting point $8^{\circ}56'9''$, $38^{\circ}45'54''$ and $9^{\circ}1'17''$, $38^{\circ}51'7''$ respectively.

The E-W (Phase I) Project starts from the south of the gate of Tor Hailtoch Hospital in the west to Ayat which is the terminal end in the east, passing Mexico Plaza, Mesekel Plaza and Megenagna. The line passes through main roads such as Smuts St., Chad St., Ras Mekonen St., Jomo Kenyatta St., Haile GebreSilase St. and Equatorial Guinea St. It has the sub grade section about 12.891km in length, the elevated section about 3.91km in length (including a common rail section 2.662km in length), and the underground section 0.197km in total length. A total of 22 stations are designed on the line, among which there are 6 elevated stations (including 5 common rail stations), underground station and semi-underground station. The rest are built on the ground. The maximum and minimum intervals between stations are 1.26km and 0.435km respectively. The average station interval is 0.798km. However, according to the newest road planning of Addis Ababa City, three sections on the E-W line of the Light Rail Transit Project are adjusted to be designed as underway.

The N-S (Phase I) Project starts from the east of St. George Church in the north and turns towards the south after a section lay along the north of Mercato Market, then passes through the west of the market to Chad St. and integrates with the E-W line. Then the line is laid towards the east and turns towards the south after arriving at the west of Mesekel Plaza, and finally arrives at Kallti, which is the terminal end in the south, after crossing beneath Meshalokia Bridge and Sino-Ethiopian Friendship Bridge. The line passes through main roads such as Fitawrari Gebeyebu St., Gyorgis St., Central African Republic St., Dej. Mekonin Demisaw St. Dej. Bekele Weya St., Chad St., Ras Mekonen St., RasBiru St., Sierra Leone St., Beyene Aba Sebsib St. and Debre Zeit Rd. It has the sub grade section about 10.057km in length, the elevated section about 5.977km in length (including a common rail section 2.662km in length), and the underground section about 0.655km in length. A total of 22 stations are designed on the line, among which there are 8 elevated stations (including 5 common rail stations) and 1 underground station. The rest are built on the ground [2].

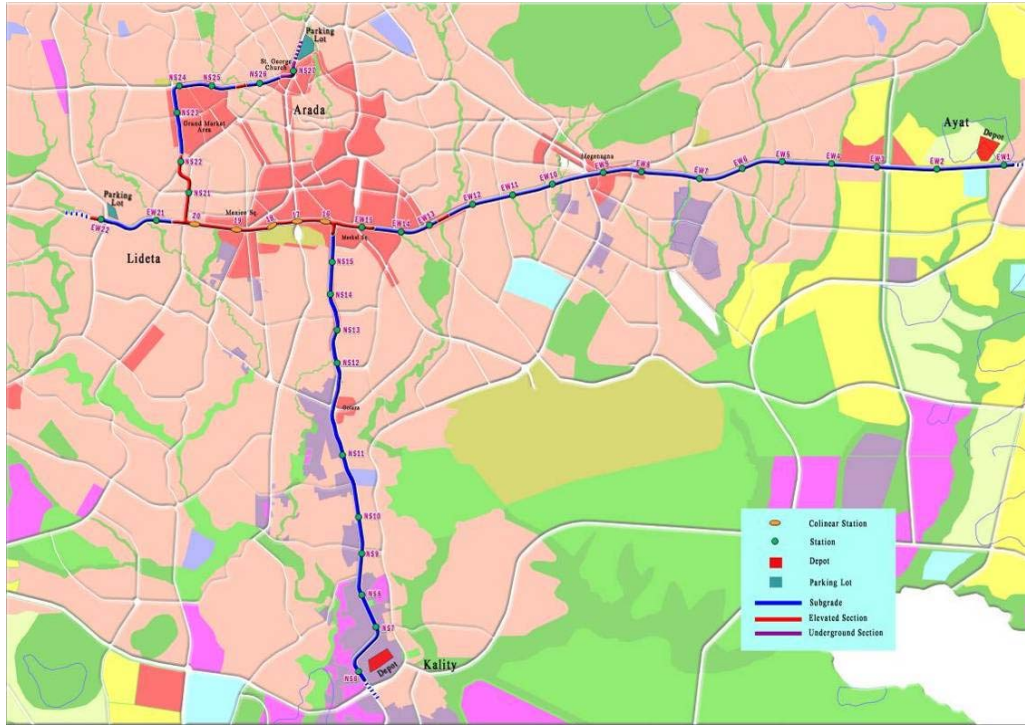


Figure 4.9: Alignment of E-W & N-S Lines (Phase I) Project

4.2.3.2 Link Budget and Coverage Planning

The link budget calculations estimate the maximum allowed signal attenuation, called path loss, between the mobile and the base station antenna. The maximum path loss allows the maximum cell range to be estimated with a suitable propagation model, such as Cost231–Hata model. The cell range gives the number of base station sites required to cover the target geographical area. The link budget calculation can also be used to compare the relative coverage of the different systems.

Radio Link Budget (RLB) is calculated in order to estimate the allowed path loss. Transmission powers, antenna gains, system losses, diversity gains, fading margins, etc. are taken into account in a RLB. RLB gives the maximum allowed path loss, from which cell size is calculated using a suitable propagation model.

For LTE, the basic RLB equation can be written as follows [1]:

$$PathLoss = \frac{TxPower \cdot TxGains \cdot RxGains}{TxLosses \cdot requiredSINR \cdot RxLosses \cdot RxNoise} \dots\dots\dots (4, 4)$$

Loss in dB:

$$PathLossdB = TxPowerdB + TxGainsdB - TxLossesdB - RequiredSINRdB + RxGainsdB - RxLossesdBs - RxNoised..... (4. 5)$$

In LTE, the basic performance indicator is ‘Required SINR’. Maximum allowed path loss is calculated according to the condition:

$$SINR = \frac{vRxPower}{interference+RxNoise} = \frac{AveRxpower}{ouwncellinterfarance+othercellinterference+RxNoise} (4, 6)$$

Parameter	Description
Path Loss	Total path loss encountered by the signal from transmitter to receiver (W)
Tx Power dB	Power transmitted by the transmitter antenna (dBm)
Tx Gains dB	Gain of transmitter antenna (dB)
Tx Losses dB	Transmitter losses (dB)
Required SINR dB	Minimum required SINR for the signal to be received at the receiver with the required quality or strength (dB)
Rx Gains dB	Gain of receiver antenna (dB)
Rx Losses dB	Receiver losses (dB)
Rx Noise dB	Receiver Noise (dB m)
SINR	Signal to interference and noise ratio.
Ave Rx Power	Average received power (W).
Interference	Interference power (W)
Own Cell Interference	Power due to own cell interference (W)
Other Cell Interference	Power received for neighboring cells (W).

Table 4.1: LTE parameters and its description

Required SINR is the main performance indicator for LTE. Cell edge is defined according to the Required SINR for a given cell throughput. Therefore, the accurate knowledge of Required SINR is central to the authenticity of the RLB and thus the process of dimensioning. Required SINR depends up on the following factors:

- Modulation and Coding Schemes (MCS);

- Propagation Channel Model.

Higher the MCS used, higher the required SINR and vice versa. This means that using QPSK $\frac{1}{2}$ will have a lower required SINR than 16-QAM $\frac{1}{2}$ [16].

LTE also exhibits soft capacity like its predecessor 3G systems. Therefore, the increase in interference and noise by increasing the number of users will decrease the cell coverage forcing the cell radius to become smaller.

The maximum allowed path loss can be used to calculate the cell radius (Cell Radius) by using a propagation model. COST231 model is use to compute the path loss for cell radius. This model is normally used for carrier frequencies between 1500 and 2000 MHz The same COST231 model can be used for carrier frequency of 2600 MHz, since we assume that the loss due to the higher frequency is compensated by the increase in the antenna gain. For the 900 MHz deployment option, the Hata model can be used instead. Given the cell radius, the cell coverage area (that we assume to be hexagonal) depends on the site configuration shown figure 4.8.

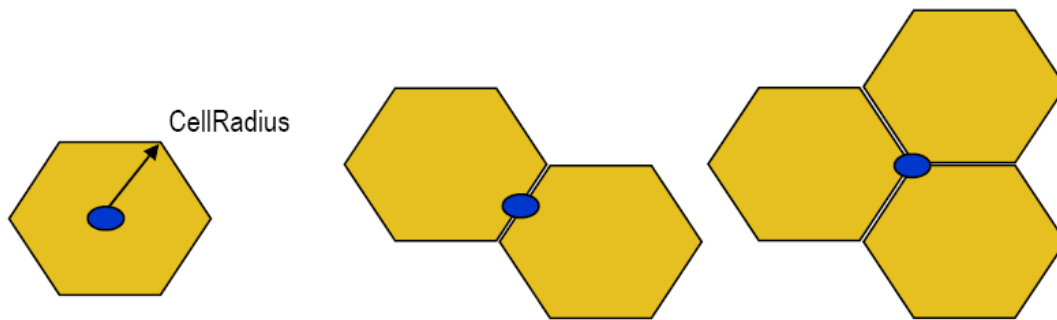


Figure 4.10: Three different types of sites (Omni-directional, bi-sector, tri-sector)

For three hexagonal cell models, site areas can be calculated as follows.

Omni-directional site Area = $2.6 * \text{CellRadius}^2$

Bi-sector site Area = $1.3 * 2.6 * \text{CellRadius}^2$

Tri-sector site Area = $1.95 * 2.6 * \text{Cell Radius} \dots \dots \dots (4. 7)$

The number of sites to be deployed can be easily calculated from the Cell Area and the input value of the deployment area.

Num Sites Coverage = $\frac{\text{deploymentArea}}{\text{sitearea}} \dots \dots \dots (4. 8)$

Link budget and coverage planning is calculated for each scenario separately, for both cases "UL & DL".

Procedures for path loss calculation [10]:

- **Step 1:** Calculate the Max Allowed Path Loss (MAPL) for DL and UL.
- **Step 2:** Calculate the DL and UL cell radiuses by the propagation model equation and the MAPL.
- **Step 3:** Determine the appropriate cell radius by balancing the DL and UL radiuses.
- **Step 4:** Calculate the site coverage area and the required sites number.

The next chapter consists of different analysis and calculation about maximum path loss.

Chapter Five

Simulation Analysis and Design

In this chapter, simulation results will be presented along with the underlying assumptions. The goal is to evaluate the performance of the simulator as well as to obtain a more accurate understanding of the operation and coverage area of the LTE system for Addis Ababa light rail transit. The analysis is starting from mathematical path loss model and then discusses the MATLAB graphical behavior of the path loss model. The coverage area simulate by Atoll wireless simulator. The best choice for the propagation path loss model of AALRT is **COST 231 - Walfisch-Ikegami-Model**. The model allows for improved path-loss estimation by consideration of more data to describe the character of the urban environment, namely:

- Heights of buildings h_{Roof} ,
- Widths of roads w ,
- Building separation b and
- Road orientation with respect to the direct radio path.

The model distinguishes between line-of-sight (LOS) and non-line-of-sight (NLOS) situations. There may be a question arises “why we use the ethio telecom network infrastructure? “Or “why we need to design the independent network?” The first motivation is the topography that we want to cover that has special zones like tunnels at St. George and underground stations require special in fracture. The other point is that the freedom utilization of the system during maintenance. For the next AALRT will have its own new services like advertizing for the customer and extension line so it needs independent modern system.

For the mathematical model we have different assumption for parameters which is internationally uses like transmission power, bode loss, transmission gain, receiver gain etc. some of the assumptions shown at the next table.

The overall work of simulation expresses by flow chart shown below. It includes the link budget calculation like coverage area and number of base station require for the Addis Ababa light railway. The first task priors to link budget calculation which allow as predict the number of enodeB cell radius and is coverage area. The evaluation includes Maximum allowed path loss and determine the optimum cell radius from UL and DL cell radius estimations. The other

calculation is the capacity planning calculation which determines the average capacity of the system.

Coverage planning is performed with a link-level calculation and propagation model. Since the coverage limiting factor for macro-cells is the uplink direction, the corresponding uplink link budget calculation needs to be done in advance to calculate the maximum allowable Path loss. The calculation also includes the total interference, a sum of all possible environment or system losses and gains and the hardware parameters of eNB and UE. Taking into account of the uplink cell load and maximum allowable path loss obtained, the next step will be to calculate the downlink signal to noise ratio and cell radius calculation based on the propagation model selected. The propagation model selection is done according to the planning parameters such as frequency, macro/micro cell environment, BTS antenna height. Real environmental information, standard empirical path loss models (such as COST231-Hata, COST231-W/I) and the maximum allowable Path loss obtained from link budget. The cell coverage area is usually calculated using the approximation of hexagonal or circular cells.

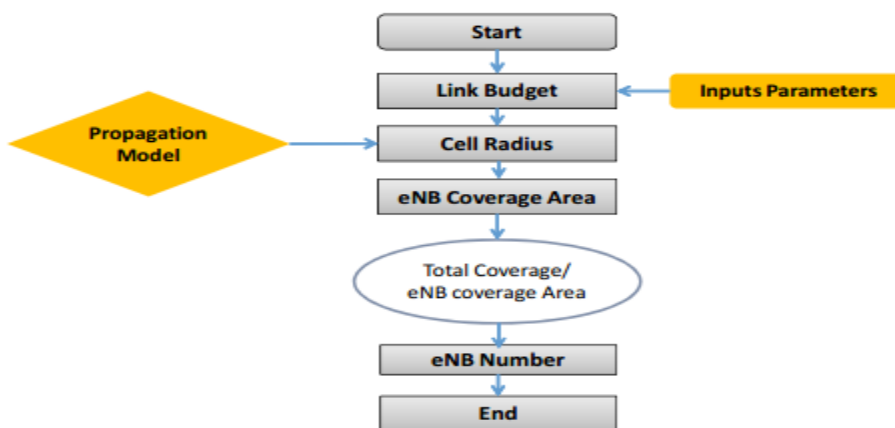


Figure 5.1: simulation structure

5.1 Link Budget and Coverage Planning Analysis

Maximum Allowed Path Loss (MAPL) has different values for dense urban, urban and suburban (UL &DL). So, the calculation must be done to every condition and scenario apart, and from these results the cell radius can be calculated for each case. At the end, the minimum cell radius from UL& DL cell radiuses is chosen. In case of Addis Ababa light railway, it has urban scenario since it deploys in the city. It has more of overhead structure at the dens area like

Lidetaa, Mexico, Merkato and Mesikel square area. Hence it reduces the effect of building height. Moreover, we have bidirectional antenna at the tunnel section mainly on St. George and at most of the line. Omni directional antenna only placed on the interlocking areas like Lideta and near Addis Ababa Stadium.

A link budget calculation evaluates the extent to which the transmitted signal weakens in the link before it is received at the receiver. The result accounts for all the gains and losses such as propagation loss and antenna gain in the path the signal takes to the receiver. The link budget gives the path loss estimate both for the uplink and the downlink which gives a chance of balancing the transmission and reception of data streams for selected criteria to increase both ways of QoS. The radio link budget equation in the LTE is expressed as:

$$\text{Path Loss}_{\text{dB}} = \text{TX Power}_{\text{dB}} + \text{TX Gains}_{\text{dB}} - \text{TX Losses}_{\text{dB}} - \text{Required SINR}_{\text{dB}} + \text{RX Gains}_{\text{dB}} - \text{RX Losses}_{\text{dB}} - \text{RX Noise}_{\text{dB}} \dots \dots \dots (5.1)$$

$$\text{SINR} = \frac{A_{\text{vRxPower}}}{\text{interference} + \text{RxNoise}} = \frac{A_{\text{vRxpower}}}{\text{owncellinterfarance} + \text{othercellinterference} + \text{RxNoise}} \dots \dots \dots (5.2)$$

in order to establish a starting point to be used as a reference for the LTE design activities a link budget analysis is carried out taking into consideration different bitrates, services and site configuration options[1]:

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.

The (eNB) maximum transmission power in LTE depends on the cell bandwidth, which can range from 1.25 to 20MHz. specifically, (eNB Power is 20 Watt (43 dBm) up to 5 MHz and 40 Watt (46dBm) above this limit [16].

Antenna Gain: Is mainly dependent on the carrier frequency, on the size of the antenna and device type. Diversity antenna gain can as well be included. Typical base station antenna gain is 15 -18 dBi. Similarly, depending upon the type of the device, UE antenna gain varies from -5 dBi to 10 dBi.

Losses: The MaxUETxPower can be either 0.125 W or 0.25 W (21 or 24 dBm) .The Link loss UL includes the distance-dependent Path loss and all other gains and losses at the transmitter and the receiver. The gains include antenna gains and amplification gains (e.g. Mast Head Amplifier (MHA) in the UL direction). The above gain does not need to be considered explicitly, in case antenna configuration is taken into account in link level simulations (i.e., the effect is included in the Required SINR value). The losses include body loss at the terminal side, cable losses Head Amplifier noise figure at the eNodeB and finally some margins (Other Losses) needed to take into account shadow fading and indoor penetration loss.

Cable loss is loss between the equipment antenna and the low noise amplifier which depends on the cable length, cable type and frequency band. The cable loss value depends on the cable length, cable type and frequency band. It varies from 1-6 dB for eNB and also 0 dB for UE. Body loss occurs when UE is held close to the user’s head and in practical planning it is considered to be 0 dB.

EIRP: Is an acronym for effective isotropic radiated power; the term is used to express how much transmitted power is radiated in the desired direction. It takes into account the losses in transmission cables and connectors and includes the gain of the transmitter antenna as:

$$EIRP = \text{Transmitter power} + \text{Antenna Gain} - \text{Transmitter loss} \dots\dots\dots (5.3)$$

Operation frequency and Bandwidth selection: LTE operates in different carrier bandwidths including 1.25 MHz, 2.5 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz in both the uplink and downlink. Bandwidth selection is directly connected to the capacity of the base station, the higher the bandwidth the more traffic it can support.

Interference: In LTE link performance, this refers to the total interference between the transmitter and the receiver. Generally, the interference can be caused by own cell users which is called intra-cell interference; or by other cell users and the eNB to be referred as inter-cell interference and additionally by other system operating on the same frequency. In the case of LTE, however, it’s assumed that the use of OFDM “fully” eliminates interferences caused by own cell uses. Furthermore, in practical planning and optimization cases, interference due to others systems may not be considered as a result of its rare occurrence and also the limited effect

on the process; thus only inter-cell interference is considered and the total interference to the receiver signal will be the sum of inter-cell interference and the thermal noise at the receiver.

$$I_{total} = I_{other\ cell} + N_{Thermal\ noise} \dots \dots \dots (5.4)$$

Required SINR: Required SINR is the main performance indicator for LTE. Cell edge is defined according to the Required SINR for a given cell throughput. Therefore, the accurate knowledge of required SINR is central to the authenticity of the link budget and thus the process of dimensioning. Required SINR depends up on the following factors:

- Modulation and Coding Schemes (MCS)
- Propagation Channel Model

Higher the MCS used, higher the required SINR and vice versa. This means that using QPSK ½ will have a lower required SINR than 16-QAM ½. From [16] the value of SINR is 7.0 for 16-QAM ½.

Required SINR can be estimated by two different methods.

1. By using the ‘Throughput vs. average SNR’ tables these tables are obtained as an output of link level simulations. For each type of propagation channel models and different antenna configurations, different tables are needed. One important thing to note here is that noise is modeled as AWGN noise; therefore, SNR is used instead of SINR.
2. By using the Alpha-Shannon formula [16] Alpha-Shannon formula provides an approximation of the link level results. Thus, in this case, no actual simulations are needed, but factors used in Alpha-Shannon formula are needed for different scenarios.

Thermal noise $N_t = K.T.\Delta f$ where $\Delta f = 10\text{MHz}$, $k = 1.38 \times 10^{-23}$ and T at normal 27°C or 300K

$$N_t = 4.14 \times 10^{-14} \text{ or } -113.8\text{dB}$$

$$N_t = 300 * 1.38 * 10^{-23} * 10^7$$

$$SINR = \frac{AveRxPower}{Interference + RxNoise} \dots \dots \dots (5.5)$$

$$AveRxPower = \frac{AveTxPower}{cellloss} \dots \dots \dots (5.6)$$

$$AveRxPower = 40 / 1.58 = 25.31645$$

Consider the interference value $4\text{dB} / 2.511$

$$\text{SINR} = 25.31645 / (2.511 + 4.14 \times 10^{-14}) = 10.07866 / 10.034 \text{ dB}$$

In order for calculating the cell radius, some basic parameters are considered as shown in Table 5.1 [1, 9].

Parameter	Up link	Down link
Transmission power	23dB	43-46
Transmitter antenna gain	15-10 dB	8dB
Receiver antenna gain	10dB	-5_10 dB
Transmitter body loss	0	2dB
Base station height	30m	30m
Mobile antenna height	2m	2m
Carrier Frequency	2000MHz	2000MHz
Bandwidth	10MHz	10 MHz
Average building height	20m	20m
Road width	15m	15m
Received noise	-102dB	10dB
SINR	-8dB	0

Table 5.1: Radio link budget parameter

Let us take some consideration values like base station height 30, average of roof height 20 and the mobile antenna 2m from the project. The maximum carrier frequency of 2000MHz since we have scattered building distribution on the way let us take the average distance between building 100m. There is no dense long building distribution at the railway line. However, there is partially dense building around stadium, 22 and global. The allocations of base station are mostly in stalled at AALRT Building and at the elevated topography to minimize the diffraction and barriers. The environment is metropolitan centers.

5.1.1 Mathematical Analysis

The Maximum path loss calculations by using *propagation* models as follow [17]:

1. COST 231 - Walfisch-Ikegami-Model

To cover 1500 MHz to 2000 MHz

- Frequency f between 800 MHz and 2000 MHz
- TX height h_{Base} between 4 and 50 m
- RX height h_{Mobile} between 1 and 3 m
- TX - RX distance d between 0.02 and 5 km

Line of site:

$$L_{LOS} [dB] = 42.6 + 26 \log_{10} d [km] + 20 \log_{10} f [MHz] \dots \dots \dots (5.7)$$

None line of site:

$$L_{NLOS} [dB] = L_{FS} + L_{rts} (w, f, \Delta h_{Mobile}, \alpha) + L_{MSD} (\Delta h_{Base}, h_{Base}, d, f, bS) \dots (5.8)$$

$$L_{FS} = \text{free space path loss} = 32.4 + 20 \log_{10} d [km] + 20 \log_{10} f [MHz] \dots \dots \dots (5.9)$$

L_{rts} = roof-to-street loss

L_{MSD} = multi-diffraction loss

$$L_{rts} = -16.9 + 10 \log_{10} (f [MHz]) + 20 \log_{10} (\Delta h_{Mobile} [m]) - 10 \log_{10} (w [m]) + L_{ori} \dots \dots \dots (5.10)$$

L_{ori} = street orientation function

$$L_{ori} = \begin{cases} -10 + 0.35\alpha & 0 \leq \alpha \leq 35^\circ \\ 2.5 + 0.075 (\alpha - 35) & 35^\circ < \alpha \leq 55^\circ \\ 4.0 - 0.114 (\alpha - 55) & 55^\circ < \alpha \leq 90^\circ \end{cases}$$

$$L_{MSD} = L_{bsh} + ka + kd \log_{10} (d [km]) + kf \log_{10} (f [MHz]) - 9 \log_{10} (b) \dots (5.11)$$

Where

$$L_{bsh} = \begin{cases} -18 \log_{10} (1 + \Delta h_{Base}) & h_{Base} > h_{Roof} \\ 0 & h_{Base} \leq h_{Roof} \end{cases} \dots \dots \dots (5.12)$$

$$K_a = \begin{cases} 54 & h_{Base} > h_{Roof} \\ 54 - 0.8 h_{Base} \geq 0.5 \text{ km}, h_{Base} \leq h_{Roof} & \dots\dots\dots (5.13) \\ 54 - 0.8 \Delta h_{Base} \cdot \frac{d[Km]}{0.5} < 0.5 \text{ km}, h_{Base} \leq h_{Roof} \end{cases}$$

$$k_d = \begin{cases} 18 & h_{Base} > h_{Roof} \\ 18 - 15 \Delta h_{Base} / h_{Roof} & h_{Base} \leq h_{Roof} \end{cases} \dots\dots\dots (5.14)$$

$$k_f = \begin{cases} 0.7 (f / 925 - 1) & \text{medium sized city} \\ 1.5 (f / 925 - 1) & \text{metropolitan center} \end{cases} \dots\dots\dots (5.15)$$

From the above equations

$$K_f = 1.5 \left(\frac{f}{925} - 1 \right) \text{ for metropolitan center}$$

$$K_f = 1.5(2000/925-1) = 1.74324$$

Since h_{base} greater than h_{roof}

$$K_d = 18, k_a = 54 \text{ and } L_{bsh} = -18 \cdot \log(1+18) = -23.01756$$

$$L_{MSD} = -23.01756 + 54 + 18 \cdot \log_{10}(d [km]) + 1.74324 \log_{10}(2000) - 9 \log_{10}(100)$$

$$= 18.7368 + 18 \cdot \log_{10}(d [km])$$

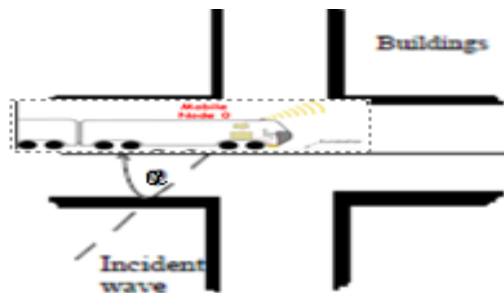


Figure 5.2: incident wave angle

The angle α from figure 5.2 is the Angle of incident wave with respect to street (use 90° if no data) [25].

The street orientation function L_{ori} :

$$L_{ori} = 4.0 - 0.114(\alpha - 55^\circ)$$

$$L_{ori} = 4.0 - 0.114(90 - 55) = 0.01$$

$$L_{FS} = 32.4 + 20 \log_{10} d[\text{km}] + 20 \log_{10} f [\text{MHz}]$$

$$L_{FS} = 32.4 + 20 \log_{10} d + 20 \log_{10} (2000) = 98.42 + 20 \log_{10} d [\text{km}]$$

$$L_{rts} = -16.9 + 10 \log_{10} (f[\text{MHz}]) + 20 \log_{10} (\Delta h \text{ Mobile}[m]) - 10 \log_{10} (w[m]) \\ + L_{ori}$$

$$L_{rts} = -16.9 + 10 \log_{10} (2000) + 20 \log_{10} (18m) - 10 \log_{10} (20) + 0.01$$

$$L_{rts} = 28.21545;$$

$$L_{NLOS}[\text{dB}] = L_{FS} + L_{rts}(w, f, \Delta h \text{ Mobile}, \alpha) + L_{MSD}(\Delta h \text{ Base}, h \text{ Base}, d, f, bS)$$

$$L_{NLOS} = 18.7368 + 18 * \log_{10} (d [\text{km}]) + 98.42 + 20 \log_{10} d[\text{km}] + 28.21545$$

$$= 145.3668 + 38 * \log_{10} (d [\text{km}])$$

From the above equation 5.1 and parameters from table 5.1:

$$\text{Path Loss}_{\text{dB}} = \text{Tx Power}_{\text{dB}} + \text{Tx Gains}_{\text{dB}} - \text{Tx Losses}_{\text{dB}} - \text{Required SINR}_{\text{dB}} + \text{Rx Gains}_{\text{dB}} - \text{Rx Losses}_{\text{dB}} - \text{Rx Noise}_{\text{dB}}$$

$$\text{Path Loss}_{\text{dB}} = 46 + 18 - 2 + 8 - 10.034 + 10 + 0 + 102 = 171.966$$

Relating the above results:

$$171.966 = 145.8568 + 38 * \log_{10} (d)$$

$$26.5992 = 38 * \log_{10} (d)$$

$$d = 5.0116 \text{Km}$$

- ✓ From mathematical view we can implement the cell radius up to $d = 5.0116 \text{Km}$. But our assumption is taken the average height of buildings. There are buildings which are more than 20 meters and vegetation. There are also other factors like topography. So taking the radius of 2km is the best choice and the optimum value to this work since we have high mobility behavior on receivers. The other propagation models also expressed as follow.

2. Okumura-Hata model:

To cover 150 MHz to 1500 MHz

- TX height hb between 30 and 200 m
- RX height hm between 1 and 10 m
- TX - RX distance r between 1 and 10 km

Urban areas: $LdB = A + B \log_{10} R - E$ (5.16)

Suburban areas: $LdB = A + B \log_{10} R - c$ (5.17)

Open areas: $LdB = A + B \log_{10} R - D$ (5.18)

Where

$$A = 69.55 + 26.16 \log_{10} fc - 13.82 \log_{10} hb$$

$$B = 44.9 - 6.55 \log_{10}(fc / 28))^2 + 5.4$$

$$D = 4.78 (\log_{10} fc)^2 + 18.33 \log_{10} fc + 40.94$$

$$E = 3.2 (\log_{10} (11.7554 hm))^2 - 4.97 \quad \text{for large cities, } fc \geq 300\text{MHz}$$

$$E = 8.29 (\log_{10} (1.54 hm))^2 - 1.1 \quad \text{for large cities, } fc < 300\text{MHz}$$

$$E = (1.1 \log_{10} fc - 0.7) hm - (1.56 \log_{10} fc - 0.8) \quad \text{for medium to small cities}$$

3. COST 231-Hata model:

- To cover 1500 MHz to 2000 MHz (1999)

$$L_{dB} = F + B \log_{10} R - E + G$$
..... (5, 20)

$$F = 46.3 + 33.9 \log_{10} fc - 13.82 \log_{10} hb$$
..... (5.21)

E designed for medium to small cities

$$G = \begin{cases} 0 & \text{medium sized cities and suburban area} \\ 3dB & \text{metropolitan area} \end{cases}$$

5.1.2 Graphical Performance Analysis

Three different receiver antenna heights are used for calculation of path loss, with a varying distance between transmitter and receiver. The main reason to consider these receiver antenna heights is the condition when the train runs at the elevation and at the ground section. The maximum and minimum elevated height is 12m and 5.4m respectively that obtained from the project design of AALRT. The graphical analysis for different models in urban area corresponding to certain distance value illustrate in figure 5.3. The path loss at maximum and minimum elevated sections and at normal ground section are shown on figure 5.4 next. The simulation at figure 5.3 comes from the *COST-WI* model and parameters. Some parameters are

standards and the others are the current situation in Addis Ababa. The building height, distance between building, road width and other parameters are taken from the Addis Ababa existing situation. These are inputs for the graphical analysis.

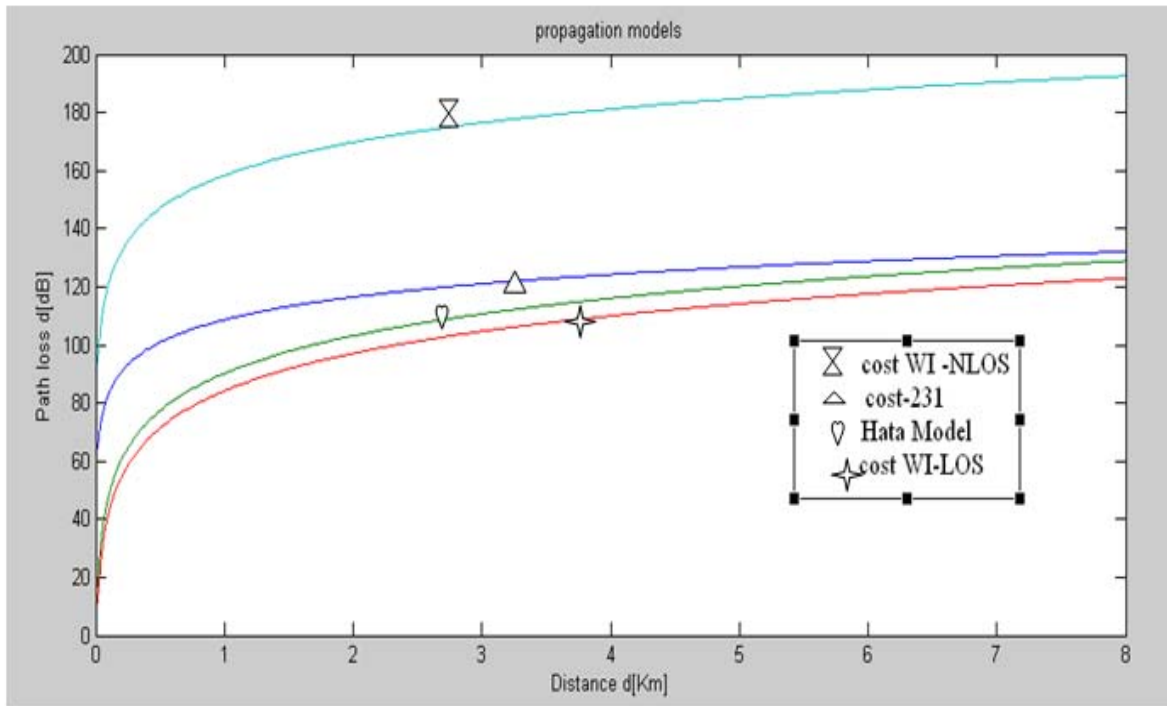


Figure 5.3: Path loss at normal ground for different model

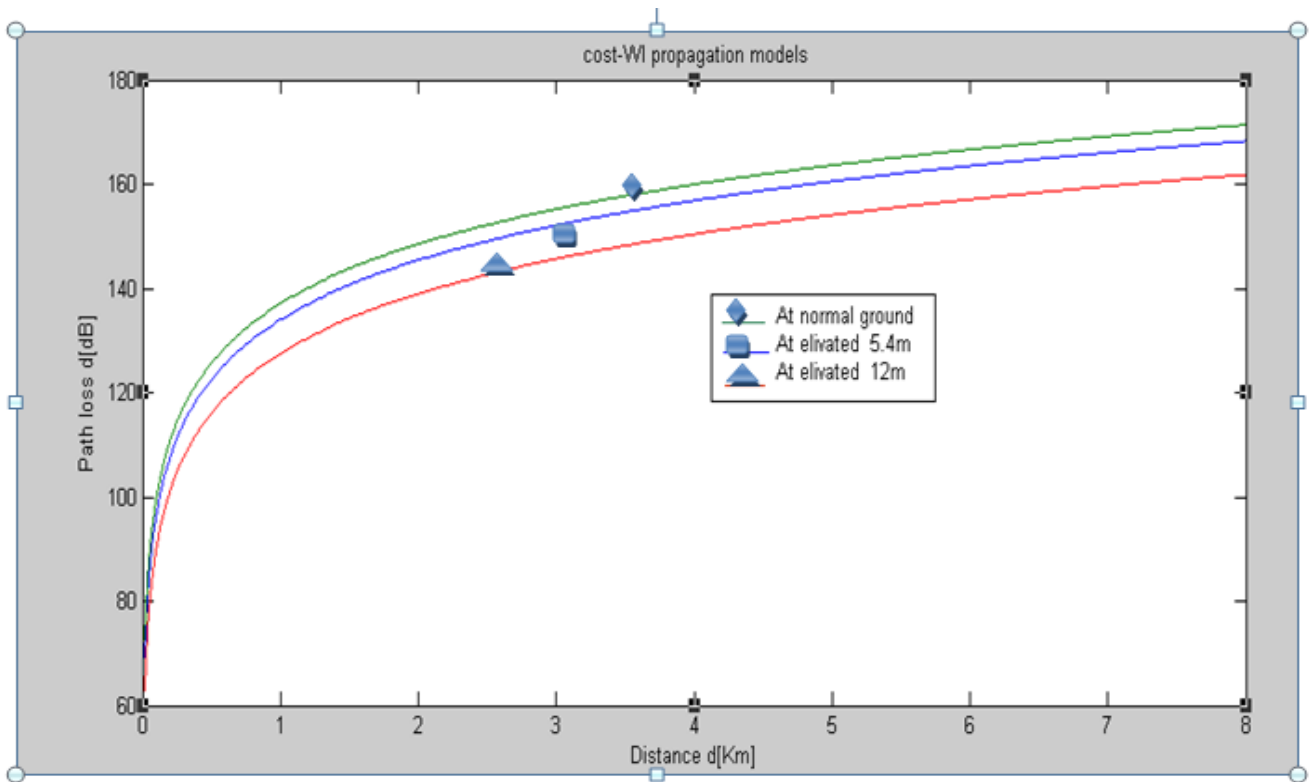


Figure 5.4: Path loss difference at elevated and ground section

From the above figure 5.4 as the elevated height increase there is decreasing path loss. The merit to have such properly is reducing the effect of path loss at high building areas found at Mexico, stadium and other places. Beside to that we can say if we increase the receiver antenna and transmitter heights we have less value of path loss. But while we increase the antenna height leads to increasing the cost of infrastructure. So we have to take the optimum value that requires to the project.

5.1.3 Atoll Coverage Area Design Analysis

Atoll is simulation software which helps to design the wireless communication systems like LTE, GSM, Wi-Fi, CDMA2000 and UMTS. The software requires very accurate data input or digital input. It needs great effort since there is no digital. We have to change the Google earth map to digital map format. First it must be change to CAD format. The next procedure shows the conversion of Google earth to digital map and coverage design.

Procedure 1: Obtain the path

1. Install the google earth setup on the computer.
2. Search Addis Ababa city from the google earth.
3. Find the railway root from the google earth.
4. Open the new path folder and select the color of the line and measurement unit.
5. Mark a path on the google earth following the railway line.

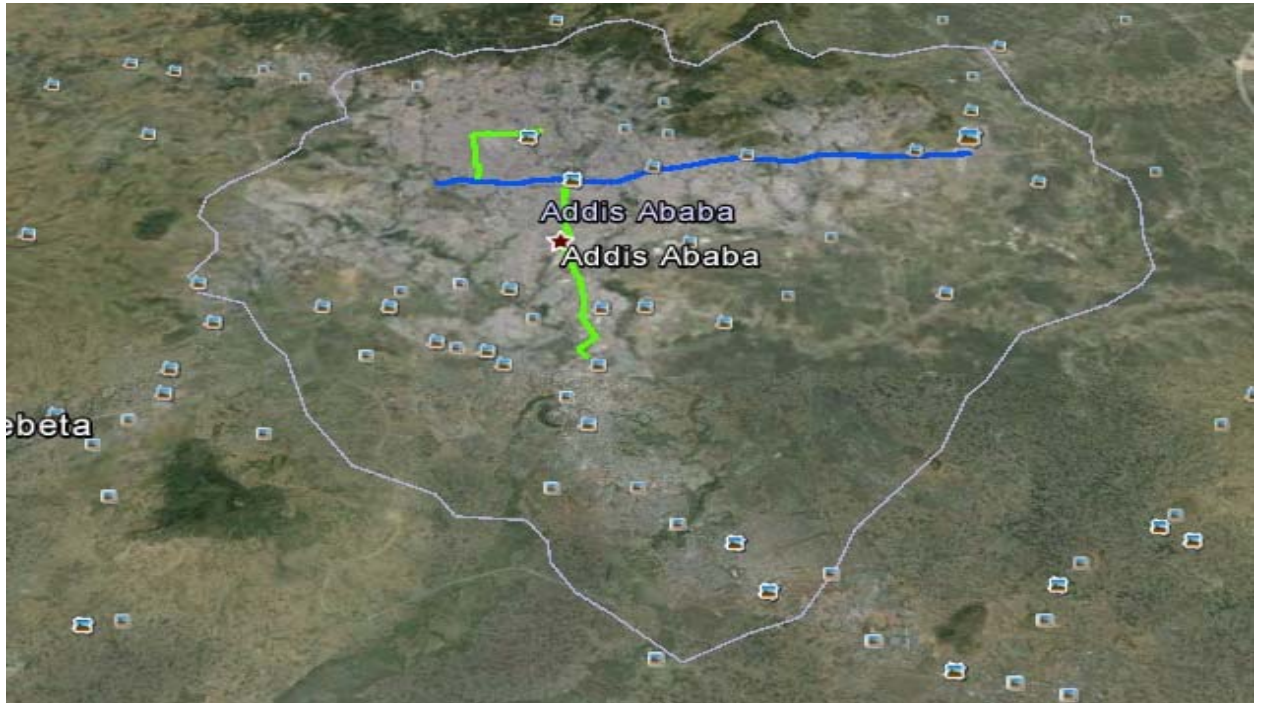
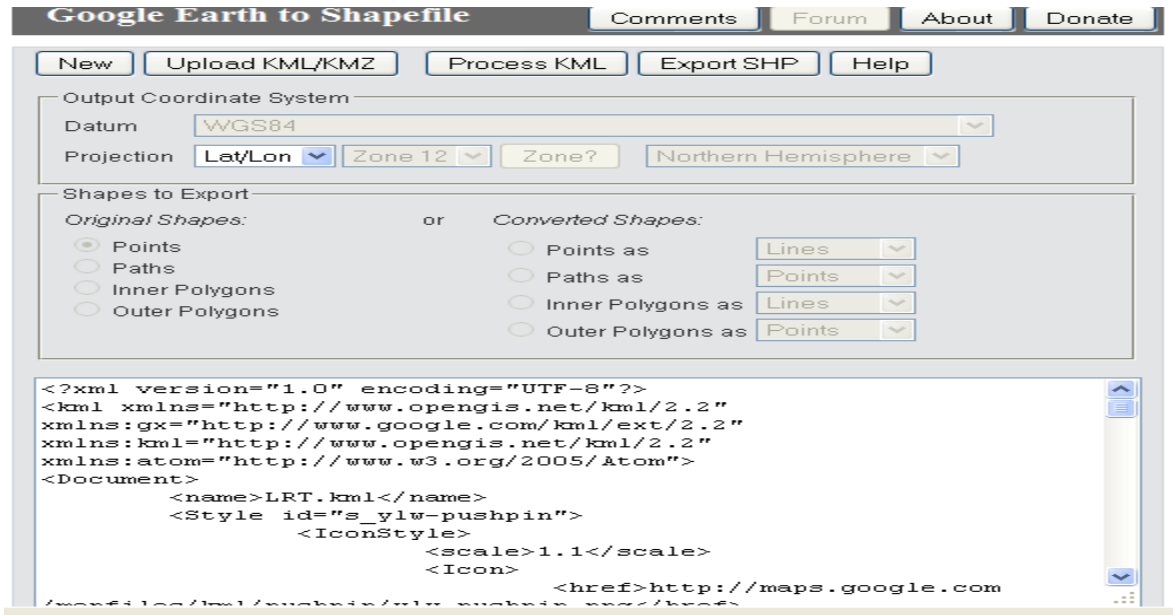


Figure5.5: AALRT line

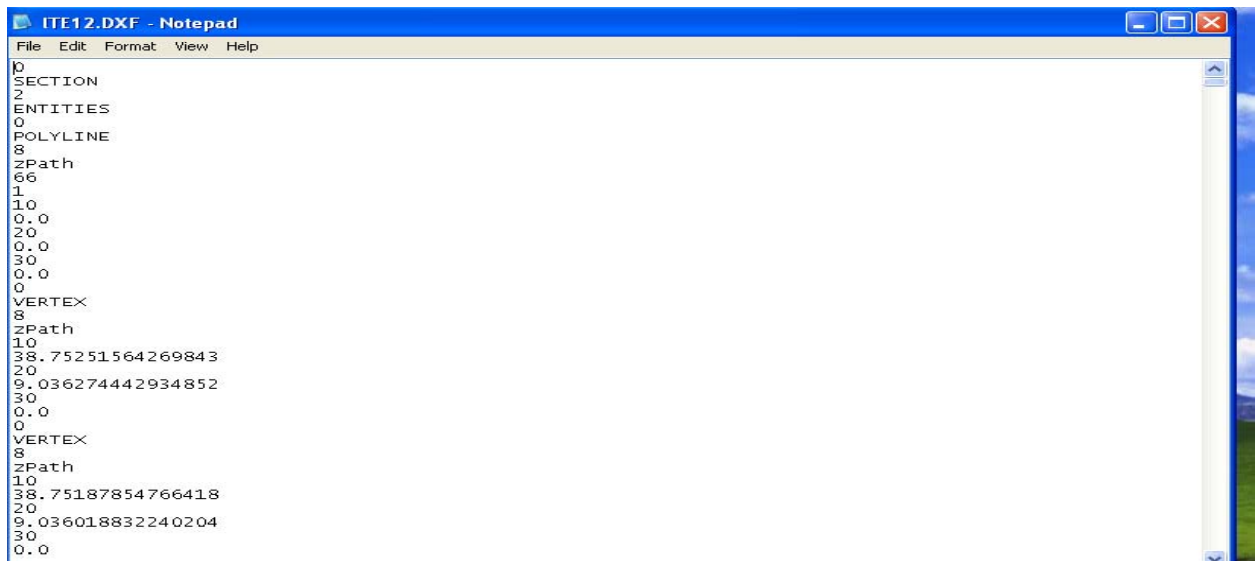
6. Save the path in the form of kMZ, KKML

Procedure 2: converting from KML/KMZ to Tab.

1. Prepare your KML/KMZ file consist path.
2. Go to <http://www.zonums.com/online/kml2shp.php> then Select **Kml2cad**.
3. A new page will be loaded. Then click on **Open KML File**.
4. Locate your KML file on your hard drive by Choose File and Accept. This will upload your KML to the server.
5. A new page consist the XML code will be displayed. Change the **Projection** into **Lat/Lon** and make sure the **File Format** is **DXF – AutoCAD**.



6. For **Data Type to Export**, you have to choose according to your KML data.
7. Click **Export** to generate the output
8. A new window consist some code will appear. Just simply copy all and paste it in a Notepad. Save it as a .DXF file.



9. Open Map info and select **Table -> Import**.
10. Locate your data and select the File type = **AutoCAD DXF (*.DXF)**
11. A warning message will appear. Select **No Warnings**

12. Click on Projection and select **Longitude – Latitude WGS 84** then OK. Save the TAB somewhere.
13. Open TAB file then Finish

Procedure 3: simulation results on Atoll

1. Open atoll software and import the TAB file.
2. Adjust the position in terms of degree, minute and seconds.
3. Place the enodeB on the path and adjust the direction
4. Fill the parameters from the calculated values like radius=2Km, height=30m, loss, propagation model etc
5. Display the strength of the coverage area in different colors. The colour indicates the signal strength.

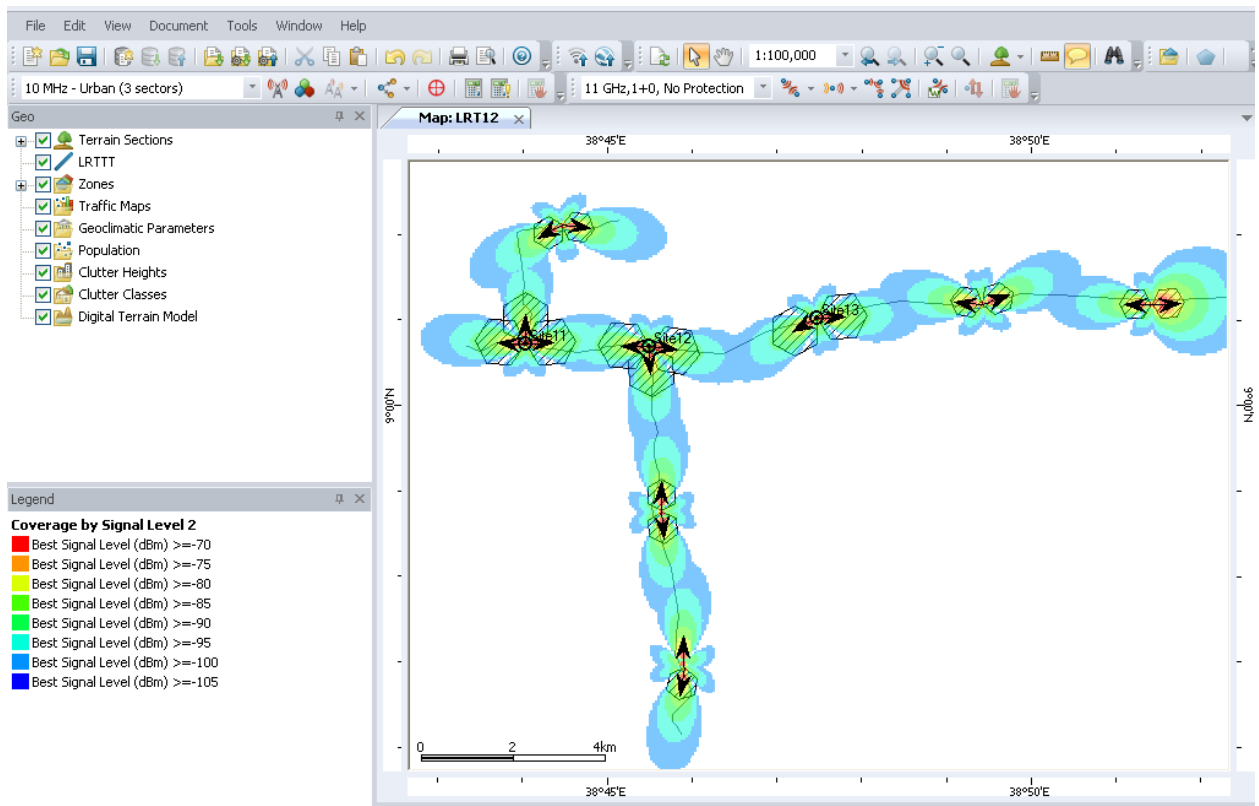


Figure 5.6: coverage area and strength color representation

6. Display the coverage area on the google Map.

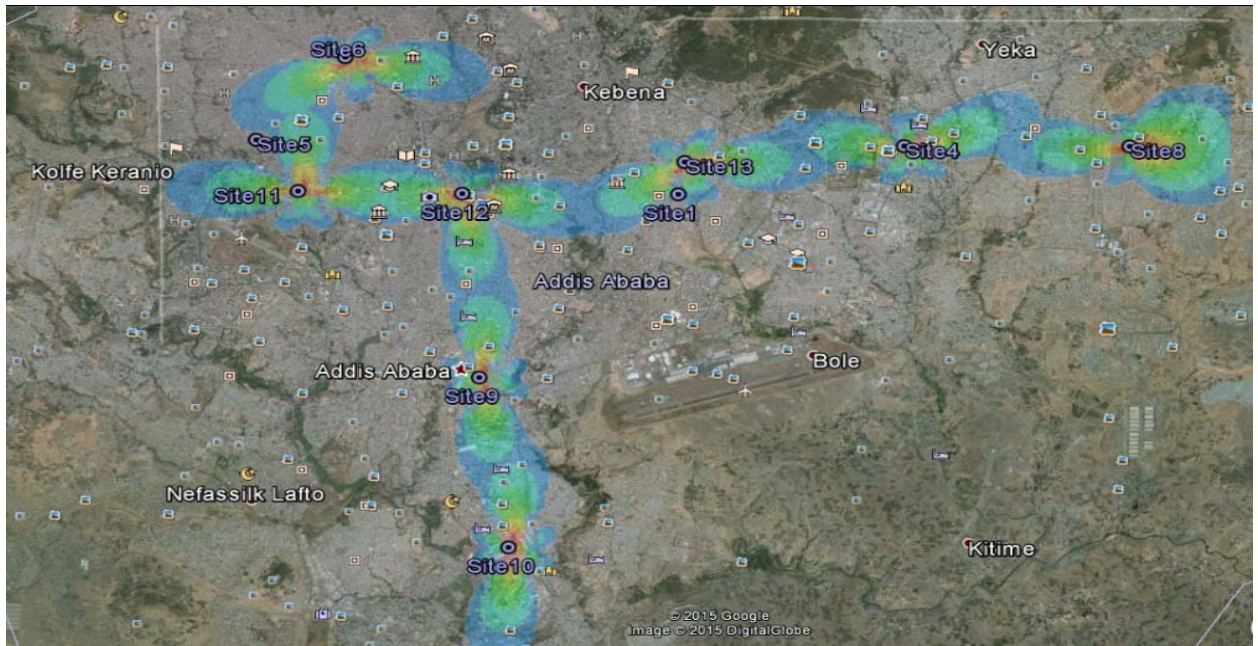


Figure 5.7: Signal strength and coverage area on Google earth map

7. Obtain the area vs signal strength Histogram result

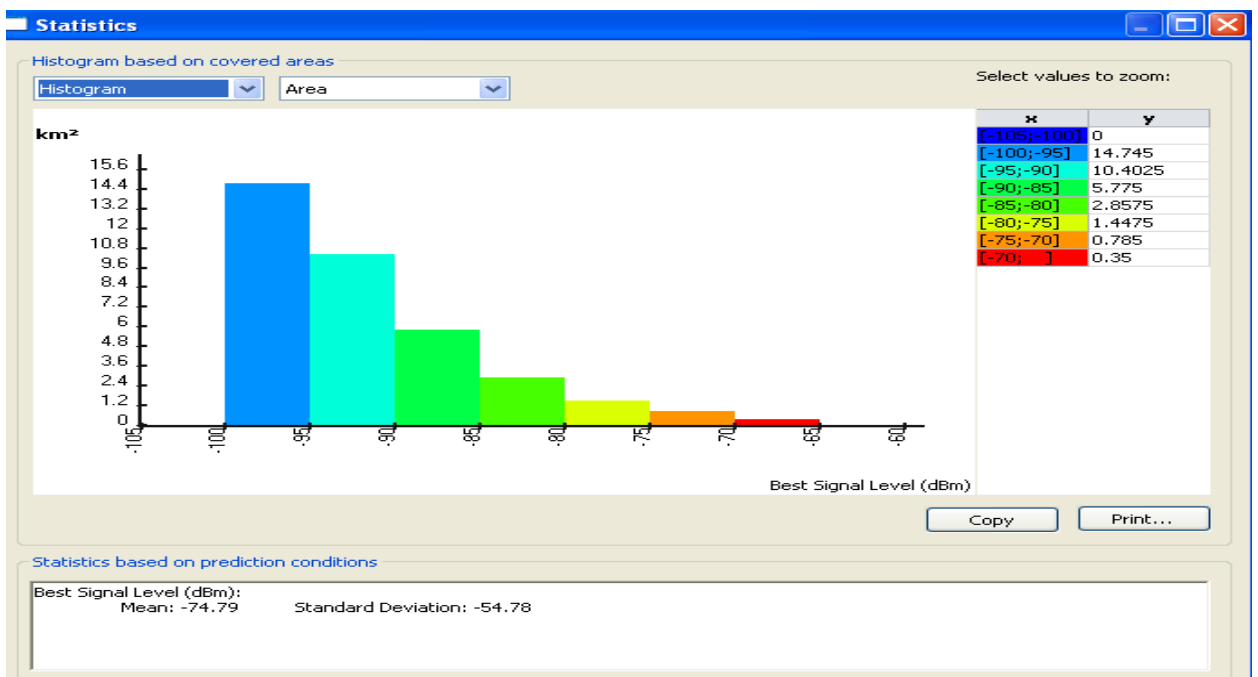


Figure 5.8: Signal level and covering area

The area cover for the bidirectional and omnidirectional antenna is calculated as:

$$\text{Omni-directional site Area (A}_o\text{)} = 2.6 * \text{CellRadius}^2$$

$$\text{Bi-sector site Area (A}_b\text{)} = 1.3 * 2.6 * \text{CellRadius}^2$$

$$\text{Tri-sector site Area (A}_t\text{)} = 1.95 * 2.6 * \text{CellRadius}^2$$

We have bidirectional and tri directional antenna. The above histogram obtains from the bidirectional antenna which has total area of $14.4+10.8+6+2.4+1.2+.6+.3=35.7\text{Km}^2$.from the formula we also get 54.08km^2 .

From the above figure 5.6 the system can be deploy with eight enodeBs. But there is a Tunnel section at St. George church. The tunnel height is 5200mm hence we need to have another system which express the existence of train in the tunnel. We have to make a communication between equipment from the gates and train. We can use normal track circuit to determine the existence of train in the tunnel. But we can design the communication between the outside train and gate equipment to make an action on the outside tunnel train.

Chapter Six

Conclusion and Future work

6.1 Conclusion

The study focuses on the deployment of LTE technology in Addis Ababa light rail train. The system implementation will help for train to train, train to ground and local communications. It reduces the deployment of complicated and old systems which are telephone and microwave technologies.

The propagation models for the prediction of coverage area and path loss or the budgeting calculations LTE on AALRT have been developed.

The deployment of LTE system for Addis Ababa light rail has the advantages based on the safety, mobility, capacity, latency and preferred QoS behavior. Especially The requirement of LTE mainly focuses on the safety movement and channel capacity. The study also slightly focuses on the speed since we have moderate speed of the train.

The simulation analysis present based on the Hata different models with varying receiver height since we have certain elevation path. The simulation made by the atoll simulator software helps to know the strength of signals for a certain radius of antenna and coverage areas of the path.

The paper shows the number of enodeB antennas require on the path to have a better train communication system.

We can implement this system for Addis Ababa light rail project and for the next projects that will be constructing. Instead of deploy the GSMR and telephone system to gather, we can implement only the LTE system. Another suggestion is on the signaling system. We can deploy the wireless LTE train to train communication as movable block instead of fixed block signaling system. There is no need of extra way side equipments on the track.

6.2 Future Work

Here are list of recommendations to the possible extensions of the works of this research:

- The LTE system designed in this thesis consider only train to train and train to ground communication. Further works can extend the system to provide additional service like the communication at station area, advertisement, passenger services like internet access.
- Conceder services like mobile ticketing service and ticket order.
- Design for the future newly implemented projects.

- Real statistical data such as number of telephone users and train allocate require having capacity planning, for the next study it easy to obtain this parameters.
- Any interested person who wants to study further may accomplished the remaining works:
 - Making capacity analysis from real data ;
 - Design the sub system at the cross over and departures;
 - Design sub systems for communication between signaling equipment at the tunnel and the nearest train.
 - Consider the passenger value added services like internet and other advertizing services.

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Appendix

I. AALRT path from Google earth

No.pt	Degree Decimal		Degree-Minute		Zone
	Latitude	longitude	Latitude	Longitude	
1	9.021481	38.875731	9 ⁰ 1'17"	38 ⁰ 51'7"	Hayat round about
2	9.020945	38.852052	9 ⁰ 1'15"	38 ⁰ 51'7"	Samit roundabout
3	9.020155	38.834531	9 ⁰ 1'12"	38 ⁰ 50'43"	CMC Michael church
4	9.019865	38.825981	9 ⁰ 1'11"	38 ⁰ 49'34"	Salitemihiret
5	9.020532	38.808214	9 ⁰ 1'14"	38 ⁰ 48'30"	Israel embassy
6	9.019632	38.801616	9 ⁰ 1'11"	38 ⁰ 48'6"	Megenagna
7	9.017639	38.795173	9 ⁰ 1'04"	38 ⁰ 47'43"	Lem hotel
8	9.015814	38.787342	9 ⁰ 0'57"	38 ⁰ 47'14"	Golagol
9	9.014341	38.781687	9 ⁰ 0'52"	38 ⁰ 46'54"	Haile St.
10	9.011041	38.774748	9 ⁰ 0'40"	38 ⁰ 46'30"	Urael church
11	9.011053	38.762814	9 ⁰ 0'40"	38 ⁰ 45'46"	Estifanos Church
12	9.011694	38.759058	9 ⁰ 0'43"	38 ⁰ 45'32"	interlocking point stadium
13	9.011796	38.753086	9 ⁰ 0'42"	38 ⁰ 45'11"	Legahr
14	9.010354	38.744446	9 ⁰ 0'37"	38 ⁰ 44'40"	Mexico Square
15	9.011252	38.736569	9 ⁰ 0'40"	38 ⁰ 44'12"	Lideta church
16	9.011633	38.734160	9 ⁰ 0'42"	38 ⁰ 44'3"	Interlocking at lideta
17	9.012016	38.727662	9 ⁰ 0'43"	38 ⁰ 43'40"	AAU Architecture campus
18	9.011653	38.722278	9 ⁰ 0'42"	38 ⁰ 43'20"	Torhayiloch

No.pt	Latitude	longitude			Area
1	9.018331	38.734976	9°1'5"	38°44'6"	K.Azimachmrkonrn D. St
2	9.020331	38.733256	9°1'13"	38°44'00"	Abinet Round about
3	9.027112	38.733154	9°1'38"	338°43'59"	Sebategna junction
4	9.033721	38.732266	9°2'1"	338°43'56"	Bus station
5	9.034582	38.736930	9°2'4"	38°44'13"	GojamBerenda
6	9.034215	38.742968	9°2'3"	38°44'35"	AtikilitTera
7	9.035383	38.749645	9°2'7"	38°44'59"	AbunePetros round about
8	9.035855	38.752384	9°2'9"	38°45'9"	Minilik Round about
9	9.007166	38.758906	9°0'26"	38°45'32"	Tilahun Round about
10	8.999116	38.758585	8°59'56"	38°45'31"	
11	8.994620	38.759790	8°59'41"	38°45'35"	
12	8.991615	38.758975	8°59'30"	38°45'32"	
13	8.987535	38.759816	8°59'15"	38°45'35"	
14	8.993807	38.759662	8°59'38"	38°45'35"	
15	8.980691	38.760160	8°58'50"	38°45'36"	Ring Road
16	8.977226	38.759593	8°58'38"	38°45'35"	
1718	8.968774	38.762450	8°58'8"	38°45'45"	
18	8.958581	38.794030	8°57'31"	38°47'38"	
19	8.951386	38.763415	8°57'5"	38°45'42"	
20	8.947922	38.765310	8°56'53"	38°45'55"	
21	8.945272	38.766398	8°56'43"	38°45'59"	
22	8.938848	38.762701	8°56'20"	38°45'46"	
23	8.935949	38.765002	8°56'9"	38°45'54"	Kality Roundabout

Table B.1 GPS position of the AALRT

II. MATLAB code for different propagation model

```

% MATLAB code for propagation modelmodel
% Loss based on measurements in Addis ababa light rail d>=20m
% f [MHz], d[km], w[m]=20, b [m]
% w: width of roads, b: building separation
% recommendable: b[20-100] m, phase=30
% hb, hr, hm [m] : base station, roof, mobile
% phase [degrees]
% LbLo,Lrts, Lori, Lmsd [dB]
% This model is restricted to:
% f: [800-2000] MHz
% hb: [4- 50] m
% hm mobile receiver hieght
% d: [0.02-5] km
hm=2;
hr=20;
hb=30;
AHm=hr-hm;
AHb=hb-hr;
b=100;
w=20;%street width
f=2000;
f1=1500;
d=[0.02:0.02:8];
phase=90;
Lo=32.4+20.*log10(d)+20.*log10(f);%free space loss
if (0<=phase<35)
Lori=-10+0.354.*phase;
elseif (35<=phase<55)
Lori=2.5+0.0075.*(phase-35);%street orentation function loss
else
Lori=4-0.114.*(phase-55);

```

```

end
Lrts=-16.9-10.*log10(w)+10.*log10(f)+20.*log10(AHm)+Lori;%roof to street loss
if (hb>hr)
Lbsh=-18.*log10(1+AHb);
else
Lbsh=0;
end
if (hb>hr)
ka=54;
elseif (d>=0.5 &&hb<=hr)
ka=54-0.8.*AHb;
else
ka=54-0.8.*AHb.*(d./0.5);
end
if (hb>hr)
kd=18;
else
ka=18-15.*(AHb./hr);
end
ifstrcmp('urban_type','Suburban area')==1
kf=-4+0.7.*((f./925)-1); % Suburban area
else
kf=-4+1.5.*((f./925)-1); % Metropolitan area
end
Lmsd=Lbsh+ka+kd.*log10(d)+kf.*log10(f)-9.*log10(b);%multi difraction
if (Lrts+Lmsd>0)
Lb=Lo+Lrts+Lmsd;%cost 231 WI none line of site
else
Lb=Lo;
end
am=(11.*log10(f)-0.7).*hm-(1.56.*log10(f)-0.8);

```

```

am1=(11.*log10(f1)-0.7).*hm-(1.56.*log10(f1)-0.8);
LM=69.55+26.16.*log10(f1)-13.82.*log10(hm)-am1+(44.9-6.55.*log10(hm)).*log10(d);%Hata
Lp=46.3+33.9.*log10(f)-13.82.*log10(hm)-am+(44.9-6.55.*log10(hm)).*log10(d)+3;%cost hata
231
LLOS = 42.6 + 26.*log10 (d) + 20.*log10 (f);%line of site
plot(d,LLOS,d,Lp,d,LM,d,Lb)
xlabel('Distance d[Km]')
ylabel('Path loss d[dB]')
title('propagation models')

```

III. MATLAB code for Walfich-Ikegami model at different environment

```

% COST 231 Walfich-Ikegami model for elevated and normal ground
% Loss based on measurements in Addis ababa light rail d>=20m
% f [MHz], d[km], w[m]=20, b [m]
% w: width of roads, b: building separation
% recommendable: b[20-100] m, phase=30
% hb, hr, hm [m] : base station, roof, mobile
% phase [degrees]
% Lb,Lo,Lrts,Lori,Lmsd [dB]
% This model is restricted to:
% f: [800-2000] MHz
% hb: [4- 50] m
% hm: [1-3] m
% d: [0.02-5]
%hm=2;
hr=14.6;
hr1=20;
hr2=8
hb2=18
hb1=30;
hb=24.60;
AHm=hr-hm;
AHm1=hr1-hm;
AHm2=hr2-hm;
AHb=hb-hr;

```

```

b=100;
w=20;%street width
f=2000;
d=[0.02:0.02:8];
phase=90;
Lo=32.4+20.*log10(d)+20.*log10(f);
if (0<=phase<35)
Lori=-10+0.354.*phase;
elseif (35<=phase<55)
Lori=2.5+0.0075.*(phase-35);%street orientation function loss
else
Lori=4-0.114.*(phase-55);
end
Lrts=-16.9-10.*log10(w)+10.*log10(f)+20.*log10(AHm)+Lori;%roof to street loss
Lrts1=-16.9-10.*log10(w)+10.*log10(f)+20.*log10(AHm1)+Lori;%roof to street
loss1
Lrts2=-16.9-10.*log10(w)+10.*log10(f)+20.*log10(AHm2)+Lori;%roof to street
loss2
if (hb>hr)
Lbsh=-18.*log10(1+AHb);
else
Lbsh=0;
end
if (hb>hr)
ka=54;
elseif (d>=0.5 &&hb<=hr)
ka=54-0.8.*AHb;
else
ka=54-0.8.*AHb.*(d./0.5);
end
if (hb>hr)
kd=18;
else
ka=18-15.*(AHb./hr);
end
if strcmp('urban_type','Suburban area')==1
kf=-4+0.7.*((f./925)-1); % Suburban area
else

```

```

kf=-4+1.5.*((f./925)-1); % Metropolitan area
end
Lmsd=Lbsh+ka+kd.*log10(d)+kf.*log10(f)-9.*log10(b);%multi difiraction
if (Lrts+Lmsd>0)
Lb=Lo+Lrts+Lmsd;%cost 231 WI none line of site
Lb1=Lo+Lrts1+Lmsd;
Lb2=Lo+Lrts2+Lmsd;
else
Lb=Lo;
end
plot(d,Lb,d,Lb1,d,Lb2)
xlabel('Distance d[Km]')
ylabel('Path loss d[dB]')
title(' cost-WI propagation models')

```