



Addis Ababa University

Addis Ababa Institute of Technology

AAiT

School of Electrical and Computer Engineering



***GSM-R Network Design for ATP System of Addis
Ababa-Djibouti route***

By: Teklebrhan Aregawi Weldegebreal

April, 2015/2007

Addis Ababa, Ethiopia



Addis Ababa University

Addis Ababa Institute of Technology

AAiT

School of Electrical and Computer Engineering

***GSM-R Network Design for ATP System of Addis
Ababa-Djibouti route***

By: Teklebrhan Aregawi Weldegebreal

Advisor: Dr. Yalemzewd Negash

A thesis submitted to the School of Electrical and Computer Engineering
at AAU in partial fulfillment of the requirements for the Degree of
Master of Sciences in Railway Electrical Engineering

April, 2015/2007

Addis Ababa, Ethiopia

Addis Ababa University

Addis Ababa Institute of Technology

AAiT

School of Electrical and Computer Engineering

GSM-R Network Design for ATP System of Addis Ababa-Djibouti route

By: Teklebrhan Aregawi Weldegebreal

Approved by Board of Examiners

Dr. Yalemzewd Negash

Chairman

Signature

Dr. Yalemzewd Negash

Advisor

Signature

Dr. Murad Ridwan

Internal Examiner

Signature

Ato Tezazu Bireda

External Examiner

Signature

Declaration

I, my name and my signature noted bellow declare that this thesis is my original work; there is no the same work submitted both in AAU and other universities. All materials used in this work are also acknowledged and referenced with honorable respect.

Name: Teklebrhan Aregawi Weldegebreal

Signature: _____

Place: Addis Ababa, Ethiopia

Date: April-03-2015

I certified that the above statement made by the student is correct to the best of my knowledge and it has been submitted for examination with my approval as university advisor.

Name: Dr. Yalemzewd Negash

Signature: _____

Date: April-03-2015

Acknowledgments

I would like to express my deepest gratitude to **Dr. Yalemzewd Negash** for his guidance, support and provision of important materials for this thesis work.

I would like also to express my sincere gratitude for the ERC design team engineers for their bright and generous help when I collect data from their office.

I am thankful to all my friends to their interesting and constructive ideas in our science and technology related discussions.

Lastly, I wish to express my special thanks to my parents especially my brother **Gebrehiwet Aregawi** for his irreplaceable support, love and encouragements throughout this work.

Abstract

Railway transport system hauls huge commodities and passengers from one location to another. Thereby, protection of the freight, passenger and the train itself from collisions and hazards is the pillar of railway system. There have been plenty of methods created to solve train protection problem all over the world so far. This thesis is also focused on solving protection problem in the route from Addis Ababa to Djibouti border (Deweale).

Addis Ababa-Djibouti route has both single and double tracks, serves to both freight and passenger trains. Moving Trains at this track have different speeds, passenger trains are relatively run at high speed. Another problem within this track is head-on conflict of outward and inward running trains at the single track. This situation needs an effective train control and protection system in order to protect train collision, increase route capacity and supply proper power distribution.

This thesis deals with designing proper, efficient and cost effective GSM-R radio coverage network for automatic train protection (ATP) system. Train detection mechanism is within GPS system. This work inspected the geographical and morphological nature of Addis Ababa-Djibouti (Deweale) route in detail.

In this thesis the appropriate radio coverage is done depending on the real geographical nature of the route. The data rate load and dimension of each train, whole line and other communication services are calculated. This thesis has been using an appropriate path loss model to estimate the link budget of the network. The appropriate path loss model is selected with MATLAB software simulation.

GSM-R radio network design parameters and appropriate algorithms are selected. Required mathematical calculations and analysis are defined on this thesis work. Then, lastly the network optimized with Atoll software.

Keywords: Automatic train protection (ATP), GSM-R, Global Positioning system (GPS)

Table of Contents

Acknowledgments.....	i
List of figures.....	v
List of tables.....	vi
List of acronyms	vii
Chapter one.....	1
1 Introduction.....	1
1.1 General Background	1
1.2 Statement of the problem	2
1.3 Objectives	2
1.3.1 General objective	2
1.3.2 Specific objective.....	3
1.4 Literature review	3
1.4.1 Historical development of train protection	3
1.4.2 Literature review of related works	5
1.5 Methodology	6
1.6 Scope of the thesis	7
1.7. Train control mechanism proposed by Chinese companies	7
1.8. Thesis outline	8
Chapter two.....	9
2.1. Addis Ababa-Djibouti route.....	9
2.2. Generalized description of Topographical and morphological nature of the route.....	9
2.3. Design standards of the route.....	11
2.4. Goods and passenger conveyance.....	11
2.5. Total train traffic and personnel of the whole line.....	12
2.5.1. Composition and function of information system.....	14
Chapter three.....	15
3. GSM-R radio communication system.....	15
3.1. Overview of GSM-R radio communication.....	15
3.1.2. Basic GSM-R services	17
3.2. GSM-R network requirements.....	17

3.3.	Carrier frequency band selection	20
3.4.	Modulation technique	21
3.5.	Multiple access technique	23
3.5.1.	Efficiency of TDMA frame.....	25
3.6.	Information type and GSM-R network dimension calculation	25
3.6.1.	Data traffic load of a stations	27
3.7.	Empirical Path loss models	28
3.7.1.	Okumura propagation model	29
3.7.2.	Okumura – Hata Path Loss Model.....	30
3.7.3.	COST 231 – Hata Model	31
3.7.4.	Stanford University Interim (SUI) Model.....	31
3.8.	Selection of an empirical models	32
3.9.	Cell radius Calculation.....	33
3.10.	Channel arrangement and frequency reuse	38
3.11.	Tunnel radio network coverage.....	39
3.12.	BTS antenna selections	40
3.13.	Handover algorithm in GSM-R network	40
Chapter four		43
4.1.	Simulation result and analysis.....	43
4.1.1.	Overview of Atoll software.....	43
4.1.2.	GSM-R network design using Atoll.....	43
4.1.3.	Simulation results of the route	45
Chapter five		51
5.	Conclusion and recommendations	51
5.1.	Conclusion and limitations.....	51
5.2.	Recommendations.....	51
References		52
Appendix-1:		55

List of figures

Figure 1.1	Addis Ababa-Djibouti route
Figure 2.1	Sample shut from Mieso-Diredawa
Figure 2.2	Sample shut from DireDawa-Adigala section
Figure 2.3	Sample shut from Dawanle Ngad section
Figure 3.1	End to end GSM-R network diagram
Figure 3.2	GMSK modulation and demodulation block diagram
Figure 3.3	FDMA/TDMA media access
Figure 3.4	TDMA frame structure
Figure 3.5	Pass loss comparison of different models
Figure 3.6	frequency reuse
Figure 3.7	signal coverage system of a tunnel
Figure 3.8	handover signal level
Figure 4.1	simulation steps block diagram
Figure 4.2	Addis Ababa-Meiso section
Figure 4.3	Meiso-Dewele Section
Figure 4.4	signal level coverage indication with different colors
Figure 4.5	Addis Ababa-Meiso BTS's signal level simulation
Figure 4.6	point analysis and performance result of chosen sites - (a), (b),(c)
Figure 4.7	Meiso-Dewele BTS's signal level simulation
Figure 4.8	point analysis and performance result of chosen sites for Meiso-Dewele section
Figure 4.9	area coverage of each signal level

List of tables

Table 2.1	Number of stations in each term stages
Table 2.2	General technical standards of the route
Table 2.3	Freight Flow Density of Each Section
Table 2.4	Freight flow density of each section
Table 2.5	Number of pair trains per day of each section
Table 2.6	Total personnel of the whole line
Table 2.7	Application of GSM-R network
Table 3.1	GSM-R system parameters standards
Table 3.2	GSM450MHz frequency allocation
Table 3.3	Information transfer between train and BTS
Table 3.4	Value for Erceg model parameters in various terrain categories
Table 3.5	personnel and trains of the most stations
Table 3.6	Radius of cells for different terrains
Table 3.7	route coordinate from AA-Meiso with their required BTS
Table 3.8	route coordinate from Meiso-Deweile with their required BTS

List of acronyms

ATP	Automatic Train Protection
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATS	Automatic Train Supervision
BTS	Base Transceiver Stations
CTCS	Chinese Train Control system
GPS	Global Positioning System
ETCS	European Train Control system
GSM-R	Global System for Mobile Communications-in Railway
MSK	Minimum Shift Keying
GMSK	Gaussian Minimum Shift Keying
BSC	Base Station Controller
MS	Mobile Station
BSS	Base Station Subsystem
NSS	Network Station Subsystem
ITU-R	International Telecommunication Union - Railway
GoS	Grade of Service
ETSI	European Telecommunication Standard Institute

SMG	Special mobile Group
SDH	Synchronous Digital Hierarchy
DC	Direct Current
AC	Alternative Current
FRS	Functional requirements specification

Chapter one

1 Introduction

1.1 General Background

Safe and reliable transportation system is crucial for economic, social and political development of a country. It is also one of the supporting mechanisms in eliminating poverty and initiating sustainable development.

Railway system is one of the important transport facilities that is needed in the achievement of effective development; and provides an efficient, cost-effective and environmental friendly transport system which can quickly haul large volumes of goods and passengers which are not easily convoy through other motor vehicles for long distances. It is also safe and cost effective relative to some other transportation systems.

Since train is moving in a guided path and running through many interlocking and level crossings, it needs appropriate protection of collision and derailment hazards. Automatic train protection (ATP) system is the best solution to eradicate safety problems of railway system. Moreover, GSM-R based ATP system consumes less equipment and infrastructures; hence, it isn't costly to invest and maintain the system. ATP is the latest technology in railway transport system protection.

At this time our country is investing railway transport system; thereby we have to use latecomer's advantage of technology development. No need to start from the beginning i.e. we have to use the latest GSM-R radio network technology in ATP system.

Addis Ababa-Djibouti route is the fundamental gate of our country; 75% of the total import and export goods are conveyed through this route. This route will also serves as passenger transportation. About 20,000,000 people lives across the path. It covers about 661.245km distance, and it comprises tunnels, bridges and level crossings.



Figure 1.1: Addis Ababa-Djibouti route, red and blue color

1.2 Statement of the problem

Single and double tracks are incorporated in Addis Ababa- Djibouti route. Hence, protection and track usage inefficiency difficulties are followed due to the following reasons.

- Freight and passenger trains have different running speed
- Trains are moving both back and forth direction in the same track(i.e. moving at a single track)

In addition to the above constraints any railway system needs an efficient, reliable and cost effective protection system. Thus, in railway transport systems there are a lot of protection methods issued so far. This work is mostly focused on GSM-R network design for ATP system in the case of Addis Ababa Djibouti route.

1.3 Objectives

1.3.1 General objective

In the history of railway transport system, solving safety problems have been a headache in the past hundreds of years all over the world. To solve the problem, many scholars come up with different solutions. This work also adds a drop of solutions to protect train collisions and other hazards in the route. It is intended to develop affordable radio communication network in the route. Thus, this work is a milestone for safe, reliable and less maintenance and/or investment cost train protection system for the route.

1.3.2 Specific objective

More specifically, this thesis investigates the techniques how GSM-R network for automatic train protection (ATP) system can be designed and explored the parameters concerned with. This work developed GSM-R radio communication network for Addis Ababa (Sebeta)-Djibouti border (Dewele) route.

1.4 Literature review

1.4.1 Historical development of train protection

At the beginning of industrial era, mankind had suffered with transportation problems; there was no any system of transport except animal transport. Meanwhile, they have developed different kind of transportation system. One of the most widely used and comfortable nodes of transportation system was train.

Since railway transport system is in a guided path, one train move at a time, if other train came in rear or front end, accident may occur due to collision. It is very difficult to stop such collisions because of the speed of moving trains and low adhesive force between the rail and the wheel, which needs a principal distance to stop. Collisions will happen due to human errors and/or defective equipment. Railway has intricate and inter-dependence sub systems. Safety in Railways is the end product of the cohesive fusion of its myriad parts.

From the early birth of railway system, expertise developed different kinds of train protection methods; some of the developed systems are described below.

1.4.1.1 Time separation

In the early development of railway system ‘**time separation**’ was the only mechanism of controlling train movement. It was not safe and reliable due to the following reasons.

- a. It assumes that, the first train isn’t delayed or broken
- b. Insufficient use of the route/decrease line capacity
- c. No schedule flexibility

1.4.1.2 Fixed signaling

Fixed signaling is a train protection scheme by dividing the track into different sections (blocks); each block has to be occupied with one train at a time. If a train enters a block, the block protected by a fixed signal placed at the entrance of the block, if a block is cleared, go-ahead indication signal displays with different caution level in the case of multiple signaling aspect. Fixed signaling can be manual or automatic depending on its operation. Automatic in this sense doesn’t mean all operation of the railway system is automated, but it is related to the signal display scheme.

At the early stage of railway development the fixed signaling system was operated by man power. He/She located at the entrance of the block having different flags to show the indication either the

block is occupied or not. It was bulky and needs vast number of people to operate the system, and then, scholars come up with semaphore signaling system.

Semaphore signaling system uses a moving arm mounted in a mast; its position conveys the status of the block ahead. It was operated with manual mechanical or an automated electro-mechanical system. This system also has some difficulties, it wasn't fast to respond the change about the block ahead relative to the fast moving trains and it was not economical.

Electrical signaling system had come with some remedy to semaphore limitations. As the electrical system develops, track circuit signaling system has been created in the train protection system. It uses either DC (battery) or AC input power supply. If it uses a battery, nearby blocks must be isolated of each other, but if it uses AC source the current flow in a successive blocks differ in its frequency. Track circuit and interlocking systems used electronic equipment in its operational system.

Axel counter is also used in a fixed signaling system. Its operation is by comparing the number of axel enters to a block and leaves out of the block. Axel counter and track circuit signaling systems have been using in some countries of the world till now.

1.4.1.3 Automatic train control (ATC) systems

Efficient mass transit systems that can be easily adapted or upgraded to the increasing transport capacities are required for maximum mobility. The public transportation systems in long line and urban areas must support the growing demand of urban and suburban services.

The performance of mass transit systems is largely dependent on the performance of the automatic train control (ATC) system deployed. An ATC system incorporates functions for the monitoring, operation and control of the entire operational process. It can feature different degrees of automation such as manual train operation with a driver, semi-automated train operation and driverless operation. An ATC system displays the current driving instructions on the cab console and supervises the permissible train speed continuously. Color-light signals can be dispensed with in the higher levels of automation. The functional scope of ATC systems is focusing more and more on cost reduction.

The ATC system should be designed on the basis of the latest technologies available and comply with international standards. Only if this approach is integrated into the system development, can be guaranteed that, ATC system will be future-proof and support the operators, municipalities and governments in fulfilling their obligation to provide an attractive transportation system for day-to-day travelers [1].

Major subcomponents of the ATC network include automatic train operation (ATO), Automatic train Protection (ATP) and Automatic train supervision (ATS). This thesis focused on Automatic train Protection (ATP).

There are many national, institutional and even continental standards (conventions) on the subject of ATC systems all over the world. European Train Control System (ETCS), American Railway Engineering and Maintenance of way Association (AREMA), Chinese Train Control System (CTCS) and East Japan Railway Control System (E-JRCS) are the most known train control and management system agencies.

1.4.2 Literature review of related works

There have been related works and standards done so far, some of the published related works are reviewed as follows.

a. Corneliu Mihail ALEXANDRESCU, Lăcrămioara-Mihaela NEMȚOI (2011)

They described the GSM-R radio planning parameters for Bucuresti –Constanța railway corridor (225 km) according the ETSI-GSM-R standard and compliant with the requirement of mandatory demands specified by the International Union of railway (UIC). They designed everything in detail about every parameters of GSM-R radio communication. They setup minimum and maximum value of the parameters used in their design (i.e. coverage threshold $= -95\text{dB}$, $S/I > 14\text{dB}$, $S/I_A > -6\text{dB}$). The handover and network coverage status are described with graphical simulation software. The clutter signal propagation loss was modeled by Fresnel's ellipsoid formula for different type of terrain structure in the route deployed with GSM-R network [2].

b. Jørgen & Binningsbø (2006)

These people had studied about the guide lines of GSM-R network planning for Norwegian National Rail Administration. They set all the needed parameters to GSM-R radio network communications (i.e. $C/I_c > 14\text{dB}$ and $C/I_A > -6\text{dB}$, -95dB signal sensitivity). Procedures, steps and other required materials to radio planning had been elaborated and specified. Cell sectorisation, antenna tilting and polarization, BTS site selection, handover mechanism, quality and coverage calculation, capacity analysis, link budget and propagation loss, frequency allocation, fading margin analysis, minimum RxQual setting and other parameters had been carried out in this paper [3].

c. Valentin I. Popov, Andrei J. Baranovskii (2010)

This group of people had examined the basic principles of GSM-R network planning. This paper described the method of frequency channel distribution and frequency channel reuse techniques. The procedure of an operational planning is proposed. The principles of even radio coverage are considered for cells with mainly free radio propagation and for urban areas. Link budget was calculated encompassing all of the technical factors associated with the uplink and downlink transceiver to determine the maximum permissible air interface path loss [4].

d. Jan Magne Tjensvold (2007)

Even though my work is on GSM-R radio network, it is interrelated with domestic GSM network and it is advisable to take some important points about the nature of the overall structure. This

design is GSM radio network for the cities of Stavanger and Sandnes in Norway. It provided an estimate cost of the required infrastructure in these two cities. The designer set the minimum required signal to noise ratio of 14dB for the GSM network of the design. He also stated the bandwidth of the channel to 200 kHz and he used time division multiple access (TDMA) media access system. He assumes 1% GoS of the service quality. Signal to noise ratio (SNR) had calculated for both Omni-directional and sectored antennas of the system and he got 27.55dB and 17.62dB respectively which satisfied to the minimum requirement. He calculated traffic capacity of each city, number of cells, cell size etc. [5].

1.5 Methodology

This thesis is conducted as an applied research. This work used reference materials from ETCS standards and specifications. Data collection, reviewing related works and standards, route investigation, planning and designing are the most important tasks of this thesis. Then finally, atoll software simulation configuration and result analysis is also done in this work. The following flow chart shows the main activities of this thesis work.

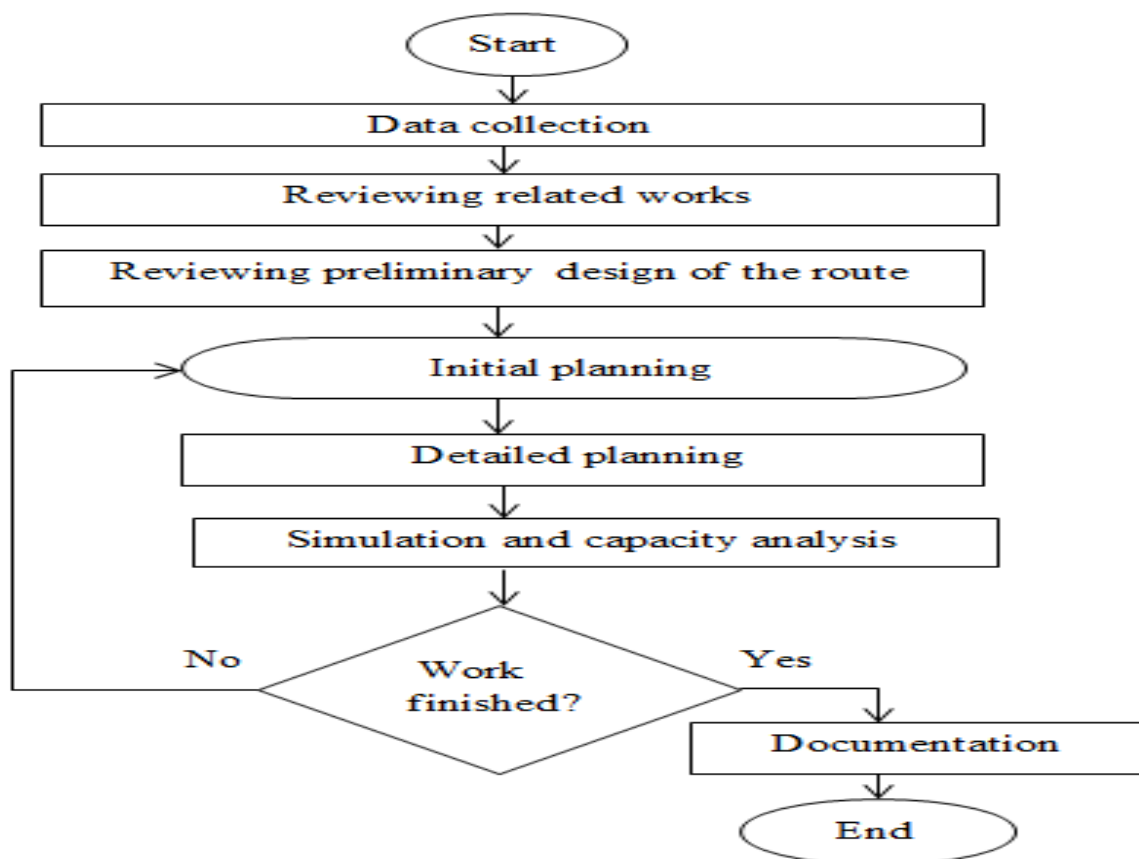


Figure 1.2: work flow chart

1.6 Scope of the thesis

This thesis covers the route from Addis Ababa (Sebeta)-Djibouti (Dewele). It is contingent on many other expected civil and mechanical design input figures. This work emphasized mostly on how automatic train protection (ATP) system is designed with GSM-R radio communication scheme and GPS based train detection mechanism of Addis Ababa-Djibouti route. The scopes and tasks of this work are described as follows.

- Investigating geographical nature of the route and calculates the distance between consecutive GSM-R antenna poles and base stations.
- Formulating parameters needed in designing GSM-R based ATP system.
- Estimating transmitting and receiving data rate of each user and the system at large
- Selecting frequency bands for this GSM-R radio network
- Handover algorithm selection and discussion
- Calculating signal transmission power, signal to noise ratio, channel capacity, data rate flow of the network...
- Putting and calculating all empirical models with their detail mathematical analysis
- Signal strength checking analysis using software simulation by taking the mathematical results as an input.

1.7. Train control mechanism proposed by Chinese companies

In the feasibility study report, it is stated that the main system of centralized traffic control (CTC) is located in Addis Ababa; subsystems will be installed in the other stations along the line and will be connected to the CTC system. According to the evaluation, the computer interlocking equipment configured in the study can realize remote control on turn out, signal and route within the station in the station control room. The section axle counter and centralized traffic control (CTC) may be postponed in the preliminary stage of construction according to the Chinese design standard for single track railway of semi-automatic blocking to save project investment cost. If the operation management organization needs to carry out remote centralized control on the field turnout, train route and shunting route in Addis Ababa the supporting equipment such as section axle counter, field equipment and office equipment of centralized traffic control (CTC) should be provided correspondingly [6].

Communication mechanism used in the whole line is through SDH 2.5GHz (1+1) and SDH 622MHz (1+1) managed service provider access layer transmission system will be deployed. Fiber optic cable is used as a transmission media in communication system. Mobile communication network will also be used in some functionality of the system.

This train protection system uses semi-automatic block signaling system. This system controls railroad communication and remote control of train traffic and guarantees safety of the whole operation. Some participant personnel will be required to oversee the signaling system in each block of the line. Therefore, the system distinguishes from fully automatic block signaling system and it is called semi-automatic system.

97 types of 25Hz phase detecting track circuits will be used in the stations and nearby sections [7].

1.8. Thesis outline

This thesis report consists of five chapters. Each chapter's content describes as follows briefly.

Chapter 1: introduces some background information, the methodology followed in this work, objectives and scope of the thesis, statement of the problem and some reviewed literatures, relevant for this work are described in this chapter.

Chapter 2: deals with general overview of the route, number of employees and personnel in the train control system and other services will be given in the route, number of train running in peak hour and free hour of the short and long terms, type of track and general specifications, general geographical and morphological nature of the route are noted in this chapter.

Chapter 3: explains GSM-R coverage planning. This chapter includes the Radio Link Budget and related calculations and factors taking into consideration on designing GSM-R radio network. This section also describes the capacity planning for GSM-R Network elaborating the methods used and factors impacting the capacity planning process. Traffic demand estimation and access network dimensioning have been derived in this chapter.

Chapter 4: this chapter reported the GSM-R radio network planning tool simulation analysis. It explains the structure and functionalities of the software and discussed the prediction and performance results of the designed simulation network results.

Chapter 5: concludes the thesis with summary of the entire project and possibilities of future researches and recommendations.

Chapter two

2.1. Addis Ababa-Djibouti route

Addis Ababa-Djibouti route is located in the mountain areas between the central plateaus of Ethiopia and Djibouti border, the line originates from Sebeta at southwest of Addis Ababa and runs eastward through LABU, INDODE, GELAN, DUKEM, BISHOFTU, MOJO, ADAMA, WELENCHITI, METEHARA, AWASH, ASEBOT, MIESO, MULU, AFDEM, BIKE, GOTA, DIRE DAWA and DEWELE. The total distance of the route is 661.245km. The section from Sebeta to Mieso covers a distance of 327.245km and the route from Mieso-Deweile section covers 334km.

SEBETA, LABU, BISHOFTU, MOJO, ADAMA, AWASH, MIESO and DAWANLE will be arranged to deal with passenger transport business at preliminary stage.

Five stations will be arranged to deal with freight transport business at preliminary stage, including INDODE, MOJO, ADAMA, MIESO and DIRE DAWA. Others are general intermediate stations or crossing stations. The number of stations in each term is described as follows.

The section from SEBETTA~ADAMA is double track railway; with a distance of 113.836km has seven stations with an average distance of 16.26km between consecutive stations. The section from ADAMA~MIESO is single track, with a distance of 213.418km having 12 stations with an average separation distance of 17.78km. The section from MIESO~DEWELE is single track with a distance of 334.014km having 21 stations with an average distance separation of 15.91km. The total numbers of station are summarized in Table 2.1 for all term of stages.

s/n	terms	Number of stations
1	Initial stage	16
2	Short term stage	21
3	Long term stage	40

Table 2.1: Number of stations in each term [8]

This work depends on the long term requirement of all aspects of the feasibility study. The total number of receiving-departure tracks and marshaling yards of all stations are about 260 and 80 level crossings in the long term stage.

2.2. Generalized description of Topographical and morphological nature of the route

Addis Ababa-Djibouti route passes through different topographical areas. It comprises suburban and rural areas with hilly and flat geographical reliefs. The route also has different forest coverage statuses, some part of the route has moderate vegetation and some has no vegetation.

The section from Sebeta to Mieso is relatively hilly section with moderate forest coverage and it comprises many cities. This section has a tunnel with 380m distance around awash. The section from Meiso to Dire-Dawa has small hills with moderate vegetation coverage.



Figure 2.1: sample photo from Mieso-Dire-Dawa

The section from Dire-Dawa to Adigala has a flat topographical relief with almost no vegetation coverage.



Figure 2.2: sample photo from Dire-Dawa-Adigala section

Adigala-Dawanle section has small hills with no vegetation coverage.

In general, the overall nature of the route is sectioned into two parts and summarized in the following two paragraphs.

The section from sebeta-mesio belongs to the landform of the Ethiopian plateau platform having small mountains and shallow hills. The terrain type is wide and open, the topographical relief is not good for civil works, and part of the zone has low mountains and river valley landforms. The elevation of road surface ranges between 850~2300m.

The section from Meiso-Dewele is also belongs to the Ethiopian plateau and it has shallow hilly landforms. Part of the zone has low mountains with river valleys and the ground is open and wide landforms. The elevation of track surface is ranging from 700m to 1200m, and the relative elevation difference is ten to twenty meters. Its climate is hot and the surface tropical plants are scarce with coverage of approximately 10% to 30%.

2.3. Design standards of the route

Design standard of the newly developing railway system is described in the following table.

	Sebeta-Adama	Adama-Djibouti
Gauge	1435mm	1435mm
Number of main lines	Double track	Single track
Target speed value	Passenger train: 120km/h Freight train: 80km/h (max)	Passenger train: 120km/h Freight train: 80km/h (max)
Minimum radius of curves	800m	800m
Maximum grade	Ruling grade 9%, pusher grade 18.5‰	Ruling grade 9%,pusher grade 18.5‰
Algebraic difference of maximum grade	3500T	3500T
Type of traction	Electric power	Electric power
Locomotive type	Passenger train: SS9; freight train: SS4	Passenger train: SS9; freight train:SS4
Length of arrival and departure line	850m (880m for dual-locomotive)	850m (880m for dual-locomotive)
Distance between centers of tracks	4m	
Block type	Semi-automatic block	Semi-automatic block

Table 2.2: General technical standard of the route [9]

2.4. Goods and passenger conveyance

Freight and passenger transportation of the route is shown in the following tables (table 2.3 and table 2.4) for each term. Load traffic of each sub-station is forecasted according to the current and future load development status of the corridor.

station	Direction	2020	2025	2035
Indode ~Adama	Up direction	530	780	1610
	Down direction	190	290	420
Adama~Awash	Up direction	439	697	1503
	Down direction	136	211	314
Awash~Dire Dawa	Up direction	456	775	1653
	Down direction	144	238	351
Dire Dawa~Dewele	Up direction	479	800	1700
	Down direction	148	242	358

Unit: 10⁴t

Table 2.3: Freight Flow Density of Each Section

The up direction (i.e. Dewele~ Addis Ababa) of cargo transport is heavy loaded. This forecast is according to the situation of the future resources mobilization and current transport condition of our country. Dewele~DireDawa section possesses the maximum cargo traffic volume; freight flow density of short and long terms are eight and seventeen million tons respectively [10].

Annual passenger movement along the route is shown in the following table. Addis Ababa-Adama section has a heavy passenger transport.

Section	Single direction	2020	2025	2035
		Density of passenger flow (10,000 persons/year)		
Addis Ababa-Adama		137.5	165	275
Adama-Diredawa		55	55	82.5
DireDawa - Dewele		27.5	27.5	55

Table 2.4: passenger flow density of single direction [11]

2.5. Total train traffic and personnel of the whole line

The route comprises both double and single tracks. Passenger and freight trains will move in the line at the same time. According to the freight and passenger traffic load forecasted in Table 2.3 and Table 2.4, corresponding freight and passenger trains are shown in the following table for each term stages.

Terms/s tages	sections	Pair of trains per day (train/day)				Required passing capacity
		Passenger trains	Freight trains	Pickup & drop rains	Sub total	
Initial stage	Sebeta~Adama	5	5	1	11	17
	Adama~Awash	2	5	1	8	11
	Awash~Dire dawa	2	5	1	8	11

	Dire-Dawa-~Nagad	1	5	1	7	10
Short term stage	Sebeta~Adama	6	7	1	14	21
	Adama~Awash	2	8	1	11	15
	Awash-~Dire dawa	2	9	1	12	16
	Dire-Dawa-~Nagad	1	9	1	11	15
Long term stage	Sebeta~Adama	10	16	1	27	38
	Adama~Awash	3	17	1	21	27
	Awash-~Dire dawa	3	19	1	23	30
	Dire-Dawa-~Dewele	2	19	1	22	28
Total		39	124	12	175	239

Table 2.5: number of pair trains per day [11]

There will be sixty (60) trains moving in the whole route from Addis Ababa to Djibouti every day. Half of them move up wards and the rest in the downward direction. Twenty of the trains are passenger trains, two are pick-up trains and the rest 38 are freight trains [8].

Ethiopian Railway Corporation (ERC) sets up rolling stock depot management institution in LABU to take charge of the administrative management of stations inside Ethiopia, education and work management of personnel in operation, passenger and freight transportation. The number of operating passenger trains is limited. ERC sets up passenger transport department at the rolling stock depot of LABU, in charge of education and work management of the crew. Due to lack of deep understanding about the local custom and living habits in Ethiopia and Djibouti, the accommodation or rest arrangement for the crew in the places, such as ADAMA, is not considered in the initial time, which will be determined by ERC during railway operation period, based on scheme of operating passenger train and the crew's demands [12]. The total number of personnel will be hired in the whole line is accounted in Table 2.6. The total number of personnel needed in the line may be increased to a small deviation due to some additional tasks from the list in the following table.

s/n	Department	Qty
1	Company management staff	76
2	Rolling stock depot in Addis Ababa(Labu)	54
4	Personnel of all stations in total	403
5	Dispatching center staff (in Labu)	63
Total		536

Table 2.6: total personnel of the whole line

2.5.1. Composition and function of information system

- a. **Composition of system:** The information system consists of freight transport management information system, electronic ticket system, GPS and cab signaling system. The passenger service information system includes integrated display system, clock system and passenger transport broadcast system.
- b. **System function:**
 - i. **Freight transport management:** The freight transport management information system mainly provides three module functions, including freight transport planning, freight transport ticketing and train idle time reporting.
 - ii. **Electronic ticket system:** The electronic ticket system can fulfill the functions of ticket selling, fare adjustment and statistics collection.
 - iii. **Integrated display system:** The integrated display system provides relevant information service for passengers and station management personnel.
 - iv. **Integrated system:** The clock system can satisfy the demands of timing by the passengers and the staff of the station with the functions of automatic time checking and automatic synchronization; in addition it holds the function of clock synchronization and can help relevant systems to achieve clock synchronization.
 - v. **Passenger transport broadcast system:** The passenger transport broadcast system provides audio information, issued by the railway station for the passengers, organizes passenger transport, evacuates passenger flow, ensures traffic safety and implements effective passenger transport management and service [13].

Services given in advanced GSM-R communication comprises the following functions specified in the following table:

Driver operation communication	Emergency Area Broadcast
Wide Area Communications	Train Support Communication
Passenger Service	Local Communication at Stations and Depots
Trackside Maintenance	Shunting
Automatic train control	Remote control like door opening and other tasks

Table 2.7: Application of GSM-R network

Chapter three

3. GSM-R radio communication system

3.1. Overview of GSM-R radio communication

GSM-R is built on the proven GSM standard for cellular wireless communication. This means all sorts of existing hardware can be easily modified by vendors and manufactures in order to work on GSM-R platform[14].GSM-R is an international wireless communication standard for railway communication and applications. It is used for communication between train and railway regulation control centers. GSM-R is typically implemented using dedicated base station towers close to the railway [15].

GSM-R is an international wireless communications standard for railway communication and applications. Its performance is guaranteed till train movement of 500km/h speed. GSM-R is part of the standard and carries signaling information directly to the train driver, enabling track efficiency and traffic density increases with a high level of safety. GSM-R is a secure platform for voice and data communication between railway operational staff including drivers, dispatchers, shunting team members, train engineers, and station controllers[16].

Railway companies chose the wireless GSM-R radio network since the maintenance of cables and/or overhead lines had become costlier in wired networks. Moreover, emergency communication becomes easier and farther more prompt against cable communications which have sockets placed at fixed intervals. It eliminates the problem of stealing network equipment like cables, it also avoids infrastructure for radio patching covering breaks in cable [17].

GSM-R technology is applied to rail way system, Since it developed from GSM, in addition to basic GSM functions, it has other functions, such as broadcasting call and group call, location-based connections, and call pre-emption in case of an emergency. This will support applications such as cargo tracking, video surveillance in trains and at stations. So the following factors to be considered in GSM-R design [18]:

- Fast fading of signals caused by fast-moving trains
- Frequency shift
- Coverage in tunnel and valleys
- Handover times

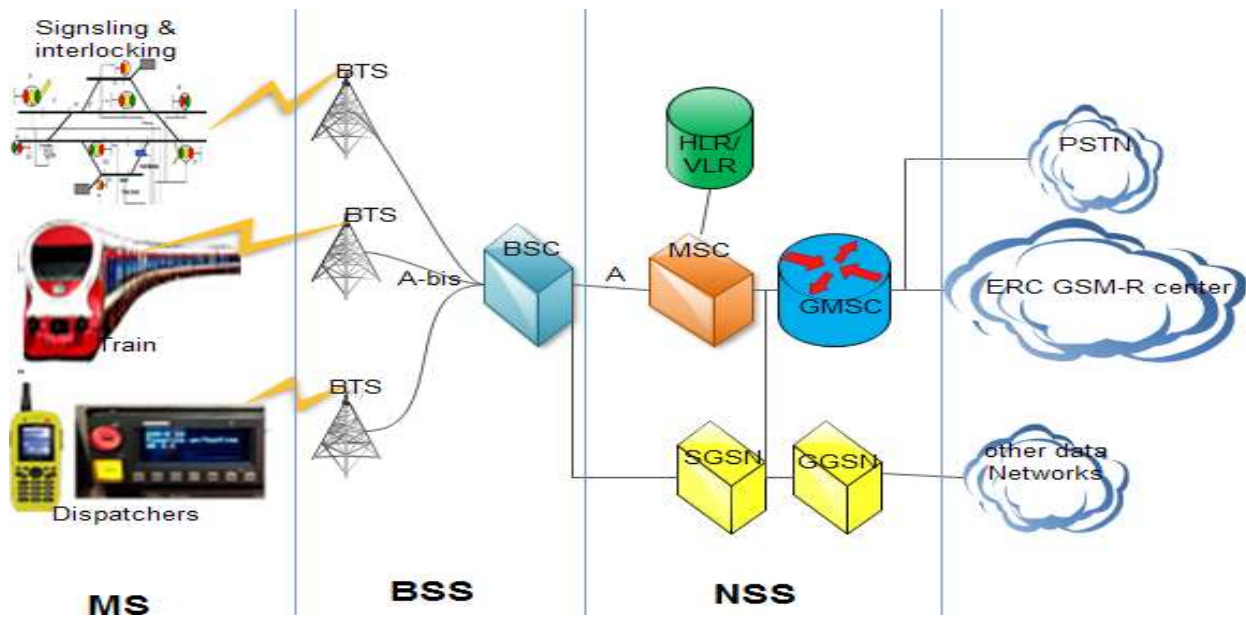


Figure 3.1: End to end GSM-R radio network

End to end communication of GSM-R network is shown in the above figure, but this work is focused on the mobile station (MS) and base transceiver station (BTS) communication part. Each subsystem has its function and it is described briefly as follows.

- a. **Mobile station (MS):** this section includes CAB radio signaling, dispatcher portable mobiles and other signaling & interlocking systems. All systems communicate with base transceiver station in wireless mode of networking.
- b. **Base station subsystem:** base transceiver station (BTS) and base station controller (BSC) are subsystems of BSS. BTS is a piece of equipment that facilitates wireless communication between user equipment (UE) and network. Radio interface control, diversity control, channel encryption and media access control is executed by BTS. BSC is a critical mobile network component that controls one or more BTS, also known as base stations or cell sites. The key functions of BSC include radio network management (such as radio frequency control), BTS handover management and call setup [19].
- c. **Network switching system (NSS):** this part includes many subsystems. Mobile switching center (MSC) which controls calls between base station subsystem and other networks like PSTN. Gateway MSC (GMSC) enables an MSC to interrogate a HLR in order to route a mobile terminating call. Executes gateway functionalities for MSC. Home Location Register (HLR) is a database that contains the subscribers of the system itself. Visitor Location Register (VLR) is also database that contains information of visiting subscribers. There have to be one VLR per one MSC station. Serving GPRS Support Node (SGSN) is the main component of the GPRS network, which handles all packet switched data within the network. Gateway GPRS Support Node (GGSN) is responsible for internetworking

between SGPRS network and external packet switched networks, like Internet and X.25 networks.

- d. **Basic GSM-R interfaces:** the interface between user equipment and BTS is Um interface with TDMA media access control and the interface between BTS and the BSC is A-bis, which can be channeled by DS-1, E1 or T1 data network carriers. 'A' interface is used to carry signal and traffic data between BSC and MSC subsystems.

3.1.2. Basic GSM-R services

UITC (Union Internationale des Chemins de Fer) designated GSM as the platform for railway communication services. To meet the communication requirements on railways, ETSI SMG introduced eMLPP (enhanced Multi Level Precedence and Pre-emption Service), VBS (Voice Broadcast Service), and VGCS (Voice Group Call Service), to the existing domestic GSM network standards [18]. Description of each service given in GSM-R communication is:

- a. **eMLPP:** This part has precedence and pre-emption services. Precedence involves assigning a priority level to a call in accordance with their priority level. But pre-emption involves in seizing of resources which are in use by calls of a lower precedence with a higher level of precedence calls in the absence of idle channel resources [20].
- b. **VGCS:** These are group calls, similar to the walky-talky communication used in some railway communications even nowadays. A number of users can take part in a conversation. Listeners become talkers by pushing the PTT (Push-to-Talk) button. When many users are located in the same cell they can't use more than one frequency for all listeners and two for the talker [21].
- c. **VBS:** One person speaks while the others are listening. A specific type of broadcast call is the railway emergency call. This is a broadcast call with the highest priority which is used in case of an emergency [21].
- d. **Location dependent addressing (LDA):** is an effective and efficient addressing method in GSM-R, which needs information on the location of the mobile station in order to forward the call to the correct called party [22].
- e. **Shunting mode service:** For users working on the tracks, the application will regulate and control user access to shunting communications. A link assurance signal gives reassurance to the driver that the radio link is working [21].
- f. **Point to point calls:** A point-to-point call is a call between two people (like a normal telephone call) where one person dials another and both people can speak at the same time. The call will continue until either person ends it [23].

3.2. GSM-R network requirements

GSM-R is a system relying on the definition of the domestic GSM system and uses any operating band defined for GSM could also be utilized by Railway systems. GSM-R is a very robust standard since it is defined for very high blocking performance, and wide dynamic range. Such qualities are the key to deliver a reliable communication, especially in terms of resistance to blocking

interferers, or in terms of required carrier over interference ratio which is very low and thus profitable for frequency reuse pattern. Finally GMSK modulation defined for GSM/GSM-R is very robust to system linearity and this allows wide receiver dynamic range [24].

GSM-R networks have to fulfill tight availability and performance requirements of the railway radio services. The special conditions and requirements of a railway communication system such as linear train movement along the tracks are laid down in EIRENE SRS V15 specification. Both line oriented GSM-R network and ERTMS requires a very high quality of service. Especially ETCS application needs a permanent connection with a traffic load of 1 ERLANG per train and a permanent radio link availability of 100% in a time. These requirements of GSM-R and ETCS for continuous radio link availability are in accordance with the UIC/EC/EIRENE definitions [25].

There are many factors limiting the power signal path loss in GSM-R radio networking. These factors are described in the following paragraphs.

Receiver selectivity is the ability to isolate and acquire the desired signal from all undesired signals that may be present on other channels. It is a central factor in the control of adjacent channel interference. It is also the measure of a receiver's ability to receive signals of low strength. More sensitivity means a receiver can pick up lower level of signals [26].

Receiver blocking is the effect of a strong out-of-band interfering on the receiver's ability to detect a low level wanted signal. Receiver blocking response (or performance level) is defined as the maximum interfering signal level expressed in dBm reducing the specified receiver sensitivity by a certain number of dB's [27].

Noise figure and **noise factor** are measures of degradation of the signal to noise ratio (SNR), caused by components in a radio frequency signal chain. It is a number by which the performance of an amplifier or a radio receiver can be specified, components with lower values indicating better performance [28]. The noise factor is the ratio of actual output noise to the input noise signal or the ratio of the input SNR to the output SNR of the device. The noise figure is simply the noise factor expressed in decibels [28].

Noise floor is the measure of the signal created from the sum of all the noise sources and unwanted signals within a measurement system, where noise is defined as any signal other than the one being monitored (i.e. undetermined noise created through the measurement) [29].

Feeder loss indicates the signal loss caused by various devices that are located on the path of the antenna to the receiver. Any loss created from external antennas for service provision at either base station side or terminal side must consider feeder loss [30].

Thermal noise is the electronic noise produced by the natural motion of the electrons in a receiver's or transmitters atoms. It largely affects the receiver's quality. If your receiver is made out of atoms, then it will automatically produce thermal noise [31]. Thermal noise is approximately

white Gaussian noise, meaning that its power spectral density is nearly equal throughout the frequency spectral. The amplitude of the signal has very nearly a Gaussian probability density function [32].

Antenna gain is defined as the ratio of the power produced by antenna from a far-field source on an antenna's beam axis to the power produced by a hypothetical lossless isotropic antenna, which is equally sensitive to signals from all directions [33]. It is an antenna's ability to direct or concentrate radio frequency energy in a particular direction or pattern [34].

Spectrum mask and spurious Emissions: nonlinear amplification of a signal may cause the signal to spread in the frequency domain into the adjacent frequency bands. This creates extraneous emissions. Every communication standard has to limit on the spectral emissions of transmitters and receivers. This spectral masking is carried out by different modulation techniques [35].

Maximum path loss is the algebraic sum of all the above behavioral effect of equipment and/or the medium by itself on signal strength of the power transmitted from the transmitter.

Details of GSM-R RF performance and system parameters are described in 3GPP technical specification TS45.005. The main GSM-R system characteristics are summarized in the following table [25].

s/n	Parameters	Upper link	Down link	
		BS	Portable mobile station	Train mounted MS
1	Max Transmitter power	30W (14.77dB)	2W (3.01dB)	8W (9.03dB)
2	Terminal noise (dBm)	-121	-121	-121
3	Noise figure (dB)	5	9	7
4	Noise floor (dBm)	-116	-112	-114
5	Receiver sensitivity (dBm)	-110	-112	-114
6	Receiver protection ratio(dB)/ blocking ratio	9	9	9
7	Antenna height (m)	20 (rural areas) 45 (urban areas)	1.5	4.5
8	Antenna gain (dBi)	18	0	2
9	Feeder loss (dB)	3	0	0 to 3
10	Spectrum mask and spurious Emissions (dB)	3	3	3
11	Maximum path loss	-79.23dBm	-96.99dBm	-93.97dBm

Table 3.1: GSM-R system parameters and standards

The maximum path loss occurs due to the portable mobile station (i.e. 96.99dBm) and it is taken as a limiting factor for this network design. But the European Integrated Radio Enhanced Network (EIRENE) functional specification that governs GSM-R technology defines forward link requirements as follows:

Functional specification required with a minimum of coverage probability of 95% based on a coverage level of 41.5 dB μ V/m (-95 dBm) on lines with ETCS levels 2/3 for speeds lower than or equal to 220km/h [3]. This specification is guaranteed to Addis Ababa-Djibouti route since the maximum train speed of the route is 120kmph.

3.3. Carrier frequency band selection

GSM-R networks with lower frequencies are cost-effective, because a cell covers wide area coverage and then needs small number of base stations [36]. Operation in the 450MHz band offers an advantage in coverage over other systems operating in higher frequencies. Signal attenuates lesser at lower frequencies than at higher frequencies. Then, fewer cell sites are required to cover large areas with less network traffics. With its inherent of better propagation characteristics, GSM 450 offers more efficient coverage than the higher frequency variants of GSM networks [37].

In particular, 450 MHz band in comparison to 900 MHz and higher frequency bands has the following valuable features [38]:

- Lower propagations losses, usable to give improved range of coverage
- Not used for dense communication system traffic(i.e. it has small capacity)
- Lower multipath effects, which provides lower possibility margins for network engineering.
- Lower losses in RF cables, which improves link budget or reduce site cost

According to the ECC decision (04)06 specification duplex spacing of 450MHz is 10MHz. (i.e. the spacing between uplink and down link frequency is 450-460 MHz and 460-470 MHz respectively) [39].

GSM 450MHz has small frequency spectral (i.e. its capacity is small relative to higher GSM frequencies). But it is enough to support the Addis-Ababa-Djibouti GSM-R radio network (see section 3.6). Table 3.2 shows the spectral band allocation of the route.

Frequency allocation	450 – 452.8MHz uplink
	460 – 462.8 MHz downlink
Frequency spectrum	2.8MHz
Duplex separation	10MHz
Carrier spacing	200MHz
Number of channels	13 communication channels + 1 guard channel (100kHz at both ends)

Table 3.2: GSM450 frequency allocation

Large cells are suited for applications especially in coastal areas, deserts, mountain tops, rural areas, and in low-traffic areas where the terrain is flat [40].

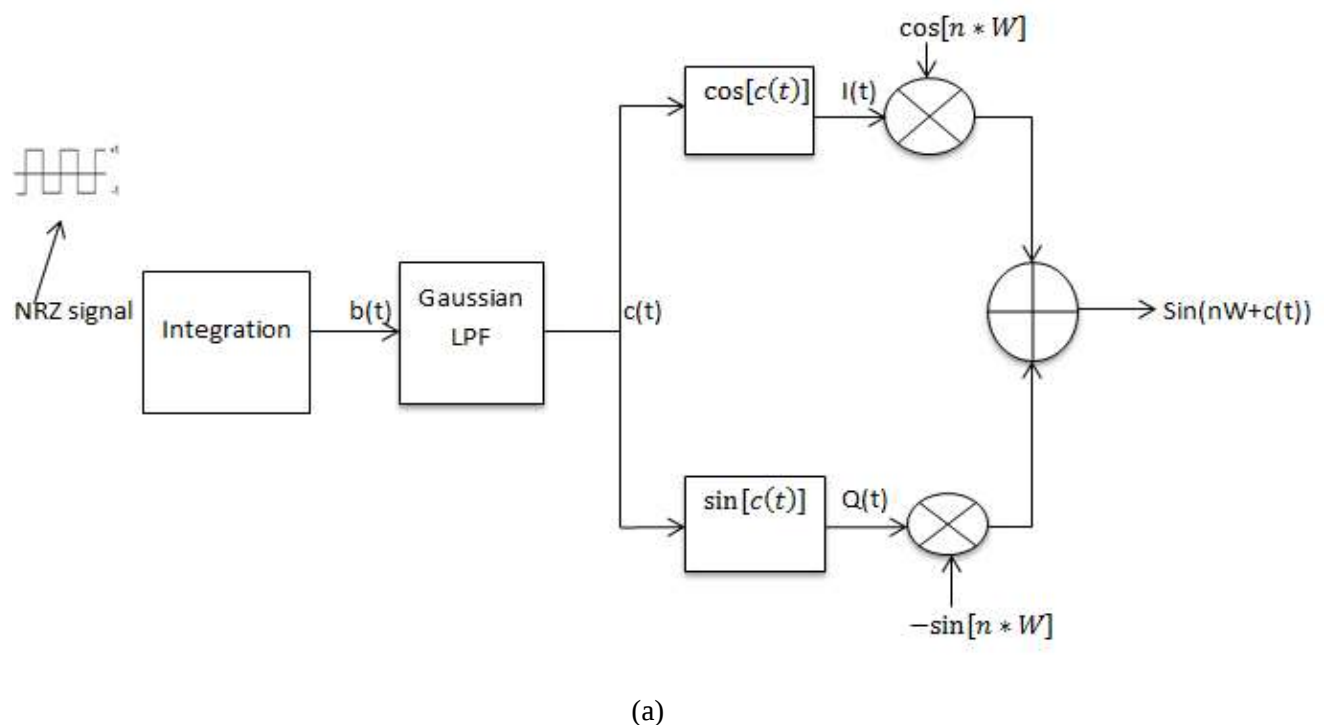
Each frequency channel is divided into eight time-slots. One time slot is required per base station to serve as a control channel. The other seven time slots are available to be used as traffic channels to support voice or circuit switched data calls. The composition of larger number of frequency channels by the addition of more transceivers to each base station will add up to a further eight traffic channels [4].

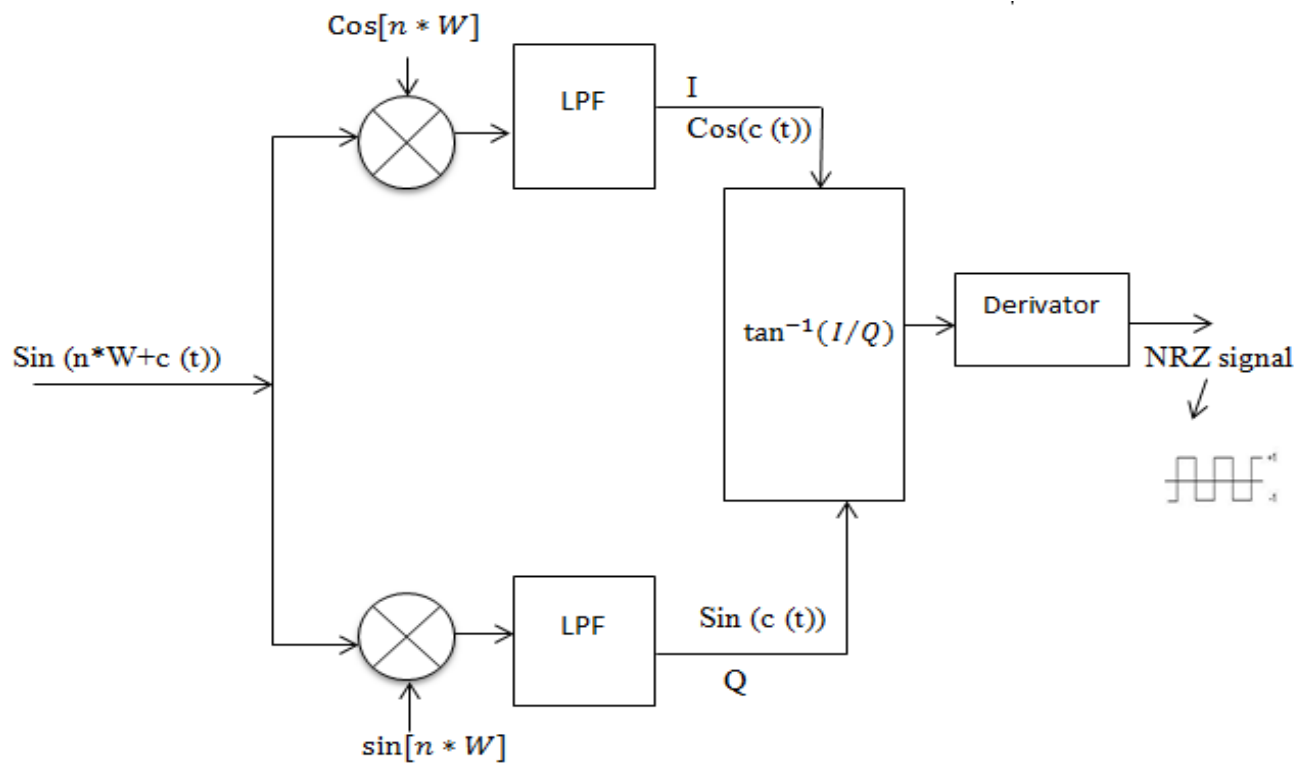
3.4. Modulation technique

Modulation is the process of encoding information from message source into a suitable manner for transmission [41].

It is necessary to analyze which modulation scheme is best suited for GSM network. There are a number of factors that taken into consideration to select modulation scheme for using in a wireless application, power and spectral efficiencies have been taken into consideration. Performance of a cellular system is dependent on the efficiency of the modulation scheme in use [42].

GMSK is a simple binary modulation scheme which may be viewed as a derivative of MSK. In the GMSK, the side-lobe levels of the spectrum are further reduced than MSK side-lobes. In GMSK,





(b)

Figure 3.2: GMSK modulation and demodulation block diagrams, (a) & (b)

digital signal is first passed through a pre-modulation Gaussian pulse shaping filter and the filter generates a signal which is used to shift the carrier phase. This process has an effect on reducing the side-lobes level in the transmitted spectrum. Pre-modulation Gaussian filter converts full response message signal into a partial response scheme where each transmitted symbol spans several bit periods. GMSK is most attractive for its excellent power and spectral efficiency [8]. Figure 3.2 shows the modulation and demodulation of GMSK modulation technique.

$$\begin{aligned}
 \text{Frequency shift } (\Delta f) &= \text{Higher frequency (FH)} - \text{Lower frequency (FL)} \quad (3.1) \\
 &= 0.5 \times \text{date rate (R)} \\
 &= 0.5 \times 270.83 \text{ kHz} \\
 &= 135.415 \text{ kHz.}
 \end{aligned}$$

This is less than the 200 kHz carrier band spacing. If we take the center carrier frequency (F_c) band as 451MHz, the maximum and minimum frequency shift of this band is:

$$\begin{cases} F_H = F_c + 0.5 \times 270.83 \text{ kHz} = 451.1354 \text{ MHz} \\ F_L = F_c - 0.5 \times 270.83 \text{ kHz} = 450.8646 \text{ MHz} \end{cases} \quad (3.2)$$

$$\text{Bandwidth efficiency} = \frac{\text{data rate}}{\text{bandwidth}} = \frac{270.83 \text{ kbps}}{200 \text{ kHz}} = \frac{1.35415 \text{ bps}}{\text{Hz}} \quad (3.3)$$

And probability of bit error (P_e) is given in equation 3.4:

$$P_e = \text{erfc} \left(\sqrt{2 \times \beta \times \frac{E_0}{N_0}} \right) \quad (3.4)$$

Where:

$$\text{erfc}(u) = \frac{2}{\sqrt{\pi}} \times \int_u^{\infty} e^{-y^2} dy \quad (3.5)$$

$$u = \sqrt{2 \times \beta \times \frac{E_0}{N_0}} \quad (3.6)$$

β is a degradation factor due to pre-modulation filter of GMSK, ($\beta = 0.97$) and value of $\frac{E_0}{N_0}$ is 6dB

From equations 3.4, 3.5 and 3.6 probability of bit error (P_e) is $\sim 10^{-5}$.

3.5. Multiple access technique

There are 13 pairs of frequency channels with an additional one pair guard channel of both uplink and downlink directions. Each of the frequency channels has eight time slots serving for seven users at a time and the remaining one is used for channel control.

Figure 3.3 shows an FDMA/TDMA channel used in cellular GSM networks. It examines an 8 time slot TDMA scheme used in GSM system. Forward and reverse channels used separate carrier frequency; each carrier supports 8 users using 13 kbps half rate and 22.8 kbps full rate encoded digital channels speech within 200 KHz carrier band width. A total of 13 channels frequency carrier channels are allocated in uplink and downlink directions, 100 KHz frequency band is allocated as a guard band at each edge of the overall allocated band. Figure 3.4 shows the TDMA frame structure showing a data stream divided into frames and those frames divided into timeslots. All carrier frequency is divided according to time slot using TDMA scheme. Each carrier frequency is further divided into a 120ms multi frame which is made up of 26 frames. In which two frames are used for control purpose while the remaining 24 frames are used for traffic purpose [43].

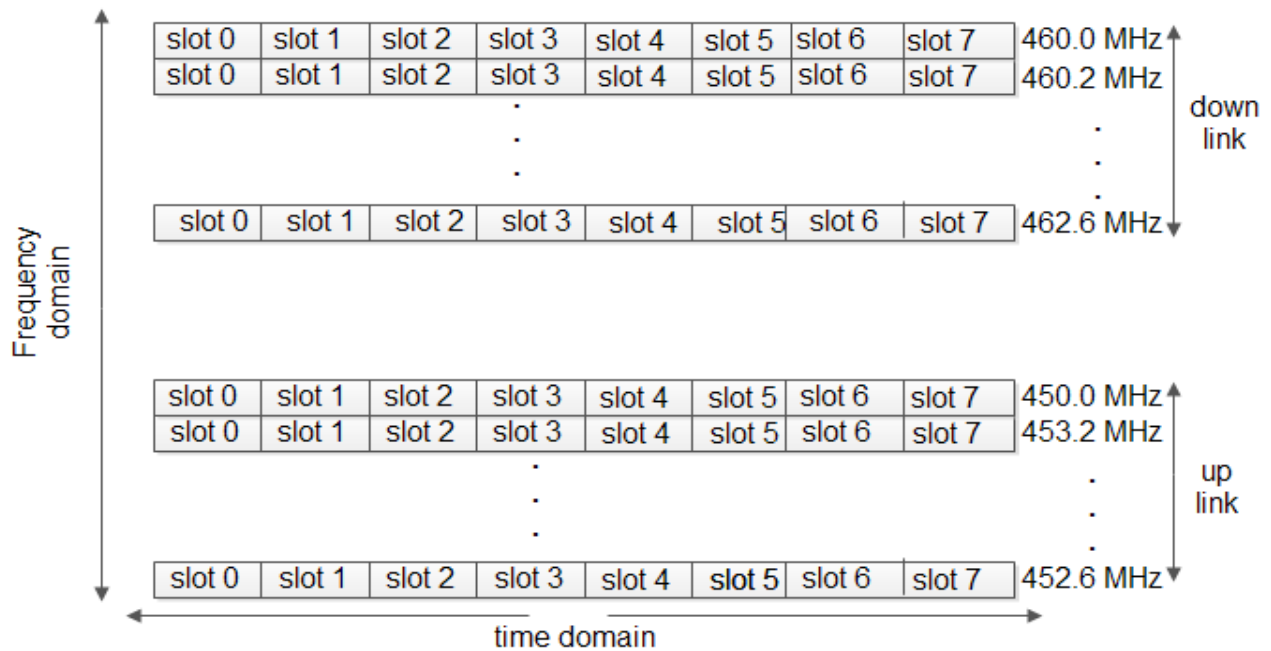


Figure 3.3: FDMA/TDMA media access

The information carried in one timeslot is called a burst. The timing of the burst transmission to and from the mobile is critical. Each time slot of a TDMA frame lasts for duration of 156.25 bit

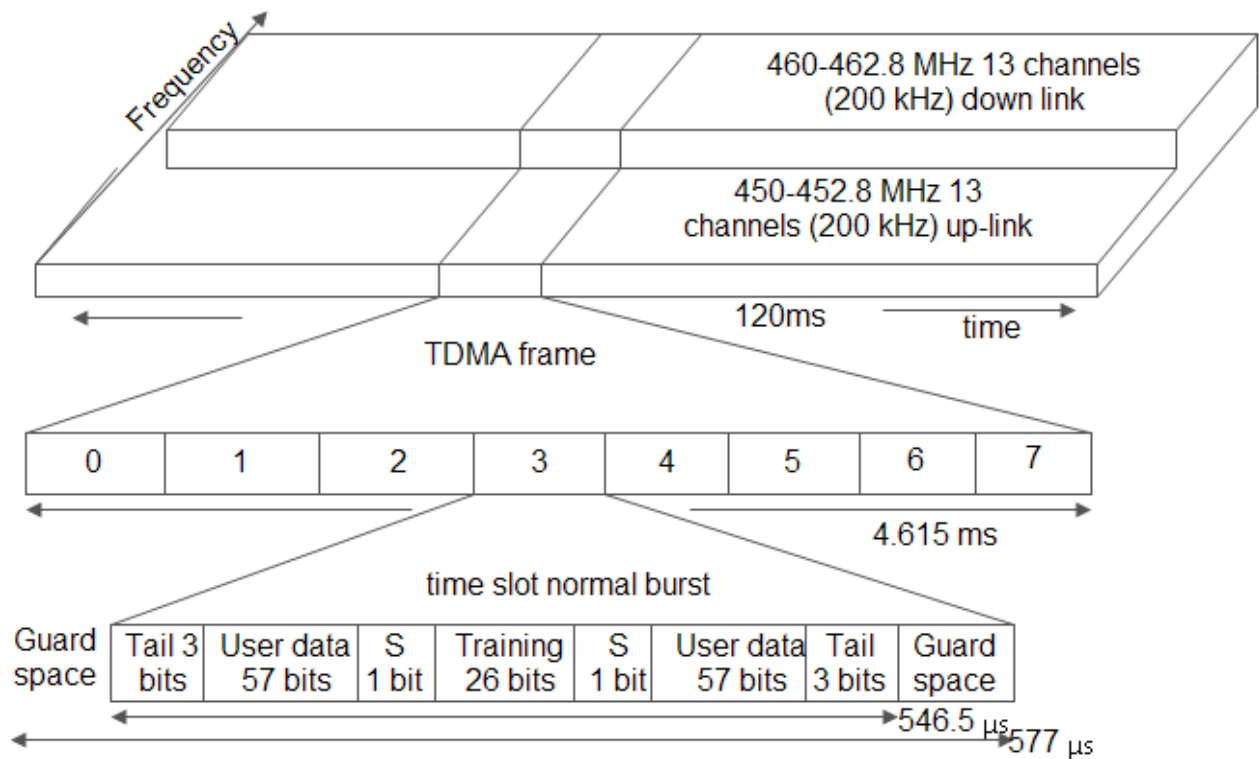


Figure 3.4: TDMA frame structure

periods or 576.9 μsec (0.576ms) so a frame takes 4.615ms GSM's data transmission rate is 270.83 kbps per carrier frequency. Therefore one bit duration is 3.692 μsec [44].

3.5.1. Efficiency of TDMA frame

The numbers of overhead and total traffic bits are given in the following formulas consecutively.

$$b_0 = N_r b_r + N_t b_p + (N_t + N_r) \times b_g \quad (3.7)$$

$$b_T = T_f \times R_{rf} \quad (3.8)$$

Where:

b_0 is total overhead bits per frame

N_r is the number of reference bursts per frame (2 in 120ms time frame)

N_t is the number of reference bursts per frame (24 frames of 120ms each with eight time slots per frame)

b_r is the number of traffic bursts (slots) per frame (148 bits in each of 8 time slots)

b_p is the number of overhead bits per reference burst (34 bits in each of 8 time slots)

b_g is the number of overhead bits per preamble per slot (8.25 bits in each of 8 time slots)

b_T is the total number of traffic bits per frame

T_f is the frame duration (120ms of 26 total frames)

R_{rf} is the bit rate of the radio frequency channel (270.8333333 kbps)

Having the above values, efficiency of TDMA frame is given by:

$$\eta = \left(1 - \frac{b_0}{b_T}\right) \times 100\% \quad (3.9)$$

$$\eta = 67.35\% \quad (3.10)$$

From equation 3.10 we can deduce that efficient data bit rate of the BTS is **182.405kbps**. This data rate is the product of the efficiency (η) and the total data rate of the BTS.

3.6. Information type and GSM-R network dimension calculation

There are critical (real-time) and non-critical (on-demand) communication systems in GSM-R network. Motor control, brake control, track signals, power electronics, GPS signals and related train commands and controls are with critical and hard real-time requirements. Audio and video passenger information, vehicle diagnostics that usually have soft or no real-time requirements and

they are called non-critical signals. The dimension of the exchanged information and time exchange is from a video image of hundreds of kilobytes sent once an hour to a GPS position sent every second.

The dimension and frequency of occurrence for a GSM-R radio network is listed in the following table.

s/n	Data(signal) transfer	Dimension	Transfer frequency
1	GPS location position signal	50 Byte	Send per second
2	SMS	140 Byte	Event driven
3	Passenger notification	500 Byte	Event driven
4	Alarms and signals	10 Byte	Event driven
5	Command like door open-close system	3 Byte	Event driven
6	Reservation, payment and baggage management	50 KB	Event driven
7	Train events like harsh brake, block authority violation, curve, etc...	50 Byte	Event driven
7	Average transfer data files	1200Byte	Event driven
9	Voice data communication	2850,1675 Bytes in full rate and half rate duplex respectively	Event driven

Table 3.3: information transfer of GSM-R network [45, 46]

As we can see from the above table, GPS data is only transferred in every second but other transferred data are event driven. The total event driven data transfer is 405624 bits and the total GPS position signal dimension is 400 bits. The capacity of frequency channel per minute is $182.4053\text{kbps} \times 60\text{second} = 10944318$ bits which is much greater than $434424(434024+400)$ bits.

There will be forty (40) total number of running trains in the long term stage at pick hour in the section from Addis Ababa-Dewele. Since the running trains location signal (GPS signal) communicate with the BTS continuously, traffic intensity per train is 1Erlang and therefore, the total traffic intensity is 40Erlang. In the event driven communication mode the traffic intensity of 40 trains is given by the following equation.

$$I(E) = \left(\frac{Tr_{total} \times call_{ph} \times call_{dura}}{3600} \right) \quad (3.11)$$

Where:

Tr_{total} is maximum number of trains in the section (40 trains)

$call_{ph}$ is call frequency per hour (40 calls)

$call_{dura}$ is call duration in second (30 second)

Inserting the above values to equation 3.11, traffic intensity (I (E)) is *equal to* 13.333Erlang

536 people will be employed and will use the GSM-R radio network. Then, the total traffic intensity is given by:

$$I(E) = \left(\frac{(536 - 0) \times 12 \times 25}{3600} \right) = 44.67 \text{Erlang} \quad (3.12)$$

where

25 is average call duration of each user

0 is blocking probability

12 is call frequency per hour.

There are total of 260 yards, blocks, interlocking and station signaling systems of the long term stage of the route, and the path also incorporated 80 level crossing signals. Thus, total signaling system of the route is 340. The traffic intensity for the signaling system of this value is:

$$I(E) = \frac{((340 - 0) \times 3 \times 15)}{3600} = 4.25 \text{Erlang} \quad (3.13)$$

Where

3 call frequency per hour

15 call duration.

The total data rate of GSM_R along the route is given as:

$$TDR_{bh}(R) = 44.67E \times DR_{doc} + 44.67E \times DR_{voi} + 4.25E \times DR_{s\&a} + 40E \times DR_{GPS} + 13.333E \times DR_{t\&tss} \quad (3.14)$$

Where

DR_{doc} is the data rate for document transfer (9.6kpps)

DR_{voi} is the data rate for voice communications (22.8kbps full duplex)

DR_{s&a} is the data rate for signaling and track side equipment transfer (80bps)

DR_{GPS} is the data rate for GPS location signaling transfer (0.4kbps)

DR_{t&tss} is the total data rate of train and track side operational commⁿ(373.224kbps)

Having these values the total data rate of the GSM-R network is given in equation 3.15

$$TDR_{bh}(R) = \mathbf{6.4385Mbps} \quad (3.15)$$

Equation 3.15 shows the overall data rate dimension to be afforded the communication services will be given in the route.

3.6.1. Data traffic load of a stations

The personnel and number of shunting, arriving and departing tracks for the three largest stations are tabulated as follows.

S/N	Stations	personnel	Number of passing Tracks and shunting tracks
1	Labu	43	4
2	Indode	53	23
3	Adama	33	8

Table 3.4: personnel and trains of the most stations

It is convenient to consider two trains would be communicates to the BTS at a time in the stations. Therefore the total traffic intensities of the stations are given as:

$$\left\{ \begin{array}{l} I_{perso}(E) = \frac{(53 - 0) \times 120}{3600} = 1.766E, \text{ ptp and other personal communication} \\ I_{tcs}(E) = \frac{(2 - 0) \times 30 \times 40}{3600} = 0.67E, \text{ train to central and train to signal man com}^n \\ I_{ts}(E) = \frac{(23 - 0) \times 2 \times 15}{3600} = 0.192E, \text{ centarl to track side communication} \\ I_{GPS}(E) = 23E, \text{ GPS location signal communication at Indode station} \end{array} \right. \quad (3.16)$$

$$TDR_{indo_st}(R) = 0.67E \times 0.4\text{kbps} + 1.7666E \times 22.8\text{kbps} + 0.192E \times 0.8\text{kbps} + 1.7666E \times 9600\text{bps} + 0.67 \times 405.624\text{kbps} + 23E \times 0.4\text{bps} = \mathbf{336.867\text{kbps}} \quad (3.17)$$

This data rate dimension is for Indode station and in a similar manner the data rate for Labu and Adama is 318.4914kbps and 307.7000kbps respectively.

From the above data rate results we can conclude that each station needs a BTS with double frequency channel but the other deployed BTS's on the whole line will fulfill its data rate requirements with a single frequency channel.

3.7. Empirical Path loss models

Path loss is the reduction in power density of an electromagnetic wave as it propagates through space [47]. There are fast (Rayleigh) and slow (log-normal) fading. Fast fading occurs due to fast movement of train, signal collusion with towers and trees. This effect is harsh in urban areas and fast moving trains [48]. Slow fading arises when the coherence time of the channel is large relative to the delay constraint of the channel. Slow fading can be caused by events such as shadowing, where large building obscures the main signal path between the transmitter and the receiver [49].

Path loss is influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height and location of antennas. Path loss is a major component in the analysis and design of the link budget of a telecommunication system. Propagation models have been developed as suitable, low cost and convenient system design alternatives since site measurements are costly. Channel modeling is required to predict path loss associated with the design of cellular network base stations, as this informs the design engineers how much power a transmitter need to radiate so as to service a given cell site. A typical network consists of a transmitter, a receiver and the surrounding environment. A model can be used for a certain frequency band to predict, to a high degree of accuracy, the behavior of radio signal in a particular environment/terrain. The performance of a communication system depends on design parameters whose values can be selected by the system designer and environmental parameters over which the designer has no control [47].

Empirical models are developed based on observations and measurements alone. These models are mainly used to predict the path loss, but models that predict rain-fade and multipath have also been proposed. The deterministic models make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location [47]. Some of the models are discussed as follows.

3.7.1. Okumura propagation model

Okumura's model is one of the most frequently used macroscopic propagation models. It was developed during the 1960's as the result of large-scale studies conducted in and around Tokyo. The model was designed for use in the frequency range 200MHz to 1920MHz and mostly in an urban propagation environment.

Okumura's model assumes that the path loss between the transmitter and receiver in the terrestrial propagation environment can be expressed as [50]:

$$P_{loss} = L_{fs} + A_{ul} + H_{txf} + H_{rxf} \quad (3.18)$$

Where:

P_{loss} - Median path loss between the transmitter and receiver expressed in dB

L_{fs} - Path loss of the free space in dB equated as follows

$$L_{fs} = 32.45 + 20 \times \log d/1km + 20 \times \log f/1MHz - 10 \times \log G_t - 10 \times \log D_r \quad (3.19)$$

d - Distance between the transmitter and receiver in km

f - Operating frequency in MHz (450MHz – 462.8MHz)

G_t, D_r - transmitter and receiver antenna gains (18 dB for transmitter, 0db for portable MS 2dBfor CAB radios)

A_{ul} - “Basic median attenuation”, additional losses due to propagation in urban environment in dB, in this thesis A_{ul} is equal to 0dB since there is no an urban area in the route.

H_{txf} - Transmitter height gain correction factor in dB (-18dB)

$H_{rx f}$ - Receiver height gain correction factor in dB (-2.8dB for portable MS and 2.5dB for CAB radios) [50].

3.7.2. Okumura – Hata Path Loss Model

One of the most extensively used empirical propagation model is the Hata-Okumura model, which is extended on the Okumura model. Okumura gives an illustration of correction factors for suburban and rural or open areas. Recently, through the ITU-R Recommendation P.529, the International Telecommunication Union (ITU) encouraged this model for further extension up to 3.5 GHz. Based on prior knowledge of Okumura model, an extrapolated method is applied to predict the model for higher frequency greater than 3 GHz. The tentatively proposed propagation model of Okumura-Hata model is referred to as ECC-33 model. In this model path loss is given by:

$$P_{l(\text{urban})} = 69.55 + 26.16 \log_{10} f + [44.9 - 6.55 \log(H_b)] \log_{10} R - 13.82 \log(H_b) - a(H_m) \quad (3.20)$$

Where,

f	–	Frequency	[MHz]
H_b	–	Base station antenna height	[m]
H_m	–	Mobile antenna height	[m]
R	–	Distance between transmitter and receiver antenna	[km]
		(H_m)	– Mobile antenna height correction factor

$$a(H_m) = \begin{cases} 3.2[\log_{10} 11.75 H_m]^2 - 4.97, & \text{for urban} \\ [1.1 \log_{10} f - 0.7] H_m - 1.56 \log_{10} f - 0.8, & \text{suburban and rural} \end{cases} \quad (3.21)$$

For typical suburban:

$$P_{\text{loss(suburban)}} = P_{\text{loss(urban)}} - 2 \left[\log \left(\frac{f}{28} \right) \right]^2 - 5.4 \quad (3.22)$$

For rural:

$$\begin{cases} P_{\text{lossrural semi-open}} = P_{\text{loss(urban)}} - 4.78 \times [\log(f)]^2 + 18.33 \times \log(f) - 35.94, [36] \\ P_{\text{lossrural open}} = P_{\text{loss(urban)}} - 4.78 \times [\log(f)]^2 + 18.33 \times \log(f) - 40.94 \end{cases} \quad (3.23)$$

3.7.3. COST 231 – Hata Model

Committee 231 of the European Cooperation in the field of Scientific and Technical Research (EURO-COST) extends the Hata model for scientific frequencies of interest (900MHz & 1800MHz). The model, which was renamed COST – Hata model, is applicable for only cases in which the antenna heights are above the rooftops of the surrounding buildings [47]. The distance from the base station to mobile station ranges from 1Km to 20Km. The height of base station antenna (h_b) ranges from 30m to 200m and the height of mobile antenna (h_m) ranges from 1m to 10m. Hata created a number of representative path loss mathematical models for each of the urban, suburban and open country environments, as illustrated in the following equations [51].

$$P_{l(\text{dB})} = 46.3 + 33.9 \times \log ht - 13.82 \times \log ht - a_{(hR)} + (44.9 - 6.55 \times \log ht) \times \log R + C \quad (3.24)$$

Where:

$$\begin{cases} a_{(hR)} = (1.1 \times \log f) \times hR - 1.56 \log f - 0.8 \quad [52] \\ C = \begin{cases} 0 \text{ dB for medium cities and suburban areas} \\ 3 \text{ dB for metropolitan areas} \end{cases} \end{cases} \quad (3.25)$$

3.7.4. Stanford University Interim (SUI) Model

The frequency bands below 11 GHz use the channel model which is proposed by Stanford University Interim (SUI) model. This model is derived for the Multipoint Microwave Distribution System (MMDS) frequency band from 2.5 GHz to 2.7 GHz. The model covers three most common terrain categories. This model is recommended by IEEE 802.16 Broadband Wireless Access Working Group [53]. The basic path loss formula with correction factors is given as [54]:

$$P_{\text{loss}} = A + 10Y + \log d/d_0 + X_f + X_m + S \quad (3.26)$$

Where:

$$d > d_0 \quad (3.27)$$

$$A = 20 \log_{10}(4\pi d_0 / \lambda) \quad (3.28)$$

$$\lambda = \frac{3 \times 10^8 \text{ m/s}}{4.6 \times 10^8 \text{ 1/s}} = 0.65 \text{ m} \quad (3.29)$$

d is the Distance between BS and receiving antenna [m]

d_0 is the reference distance , 100m

$$X_f(\text{Correction for frequency above 2 GHz}) = 6 \times \log_{10} \left(\frac{f}{2000} \right) \quad (3.30)$$

$$X_h(\text{Correction for receiving antenna in terrain A and B}) = -10 \times \log_{10} \left(\frac{f}{2000} \right) \quad (3.31)$$

$$X_f(\text{Correction for receiving antenna in terrain C}) = -20 \times \log_{10} \left(\frac{f}{2000} \right) \quad (3.32)$$

$$Y(\text{Path loss exponent}) = a - b \times h_b + \frac{c}{h_b} \quad (3.33)$$

Parameter	Terrain category		
	A (Hilly / moderate to heavy tree density)	B (Hilly / light tree density or flat / moderate to heavy tree density)	C (Flat / light tree density)
a	4.6	4.0	3.6
b (m ⁻¹)	0.0075	0.0065	0.0050
c (m)	12.6	17.1	20.0
S	10.6	9.6	8.2

Table 3.5: Values for Erceg model parameters in various terrain categories [55]

3.8. Selection of an empirical models

The selection of a suitable radio propagation model for GSM-R is of great importance. A radio propagation model describes the behavior of the signal while it is transmitted from the transmitter towards the receiver. It has a relation between the distance of transmitter & receiver and the path loss. From this relation, we can get an idea about the allowed path loss and the maximum cell radius. This thesis used MATLAB simulation to compare the amount of path loss for the different empirical propagation models. The result is shown in figure 3.5 and its MATLAB code is shown in Apendix-1. The route passes through different topographical areas (i.e. comprises rural & suburban, hilly & flat, forestry and bare lands).

From the simulation result shown in Figure 3.5, the maximum path loss is obtained in Okumura-Hata propagation model. From the planning perspective, it is better to assume the worst case scenario so as to avoid risks of inadequate coverage in a cell. Hence, Okumura-Hata model is selected as a tool to develop radio network planning in this thesis.

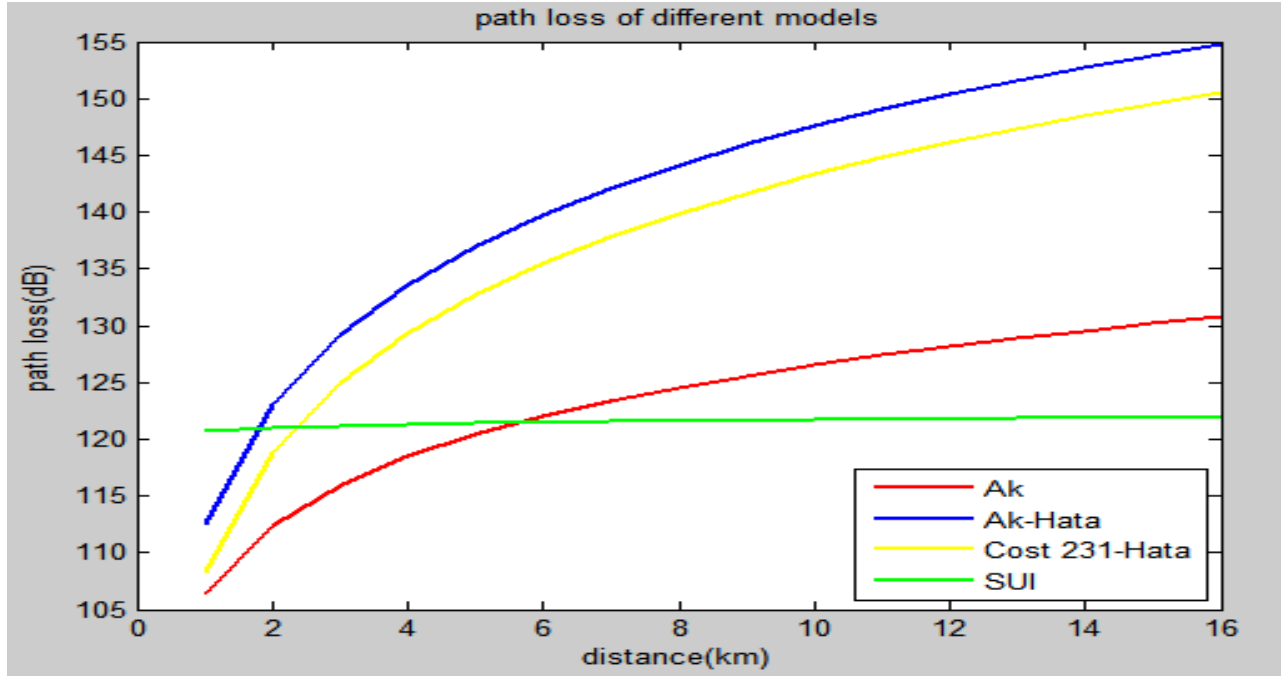


Figure 3.5: path loss comparison

Note: even though this simulation is for the frequency band 450 to 650MHz the Stanford University Interim (SUI) Model is mostly appropriate for the frequency band greater than 1900MHz. The other three models are appropriate for the selected frequency band (i.e. 450-465MHz)

3.9. Cell radius Calculation

There is no metropolitan area along the route since there is no city with very large and dense buildings. The route comprises suburban, rural, hilly, semi-hilly and flat topographical areas along the route. The route has grouped in to three cell radius according to the feature of the area passes through. According to the EIRENE specification -95dBm is the minimum received signal level (MRSL) for train speed running less than 220kmph. Since Okumura-Hata model is selected to plan the radio coverage of the route, MRSL of each topographical and morphological areas are calculated as per the following equations (equation 3.34, 3.35, 3.36).

$$\text{MRSL} = P_t + G_t - (69.55 + 26.16 \times \log_{10} f + [44.9 - 6.55 \times \log_{10} H_b] \times \log_{10} R_{su} - 13.82 \times \log_{10} H_b - a(H_m) - (-2[\log_{10} f / 28]^2 - 5.4)) \quad (3.34)$$

$$\begin{aligned} \text{MRSL} = P_t + G_t - (69.55 + 26.16 \times \log_{10} f + [44.9 - 6.55 \times \log_{10} H_b] \times \log_{10} R_{rso} - 13.82 \\ \times \log_{10} H_b - a(H_m) \\ - (-4.78 \times [\log_{10} f]^2 + 18.33 \times \log_{10} f - 35.94)) \end{aligned} \quad (3.35)$$

$$\begin{aligned} \text{MRSL} = & P_t + G_t - (69.55 + 26.16 \times \log_{10} f + [44.9 - 6.55 \times \log_{10} H_b] \times \log_{10} R_{ro} - 13.82 \\ & \times \log_{10} H_b - a(H_m) \\ & - (-4.78 \times [\log_{10} f]^2 + 18.33 \times \log_{10} f - 40.94)) \end{aligned} \quad (3.36)$$

Where:

- ✓ MRSL is -95dBm
- ✓ P_t is transmitted power in dBm (the minimum limiting value, 33.2dBm)
- ✓ G_t is transmitted antenna gain in dBi (2dBi, appropriate value)

$$a(H_m) = [1.1 \log_{10}(f) - 0.7] H_m - 1.56 \log_{10}(f) - 0.8 \quad (3.37)$$

- ✓ R_{su} is cell radius for suburban areas
- ✓ R_{rso} is cell radius for rural semi – flat and open areas
- ✓ R_{ro} is cell radius for flat and open areas

The limiting factor for the radio link of the route is the uplink communication of the portable mobile station which has the smallest transmitting power (33.2dBm). Working place of operators will be at stations and BTS will be deployed near/or at the stations. Therefore, taking CAB signaling antenna's gain (2dBi) is acceptable.

From the three equations and the values specified above, cell radiuses of the three topographical and morphological areas are shown in the following table.

s/n	Topographic type	Radius (km)
1	Suburban	5.53
2	Rural (semi-flat and open)	12.69
3	Rural (flat and open)	17.50

Table 3.6: radius of the cells for different terrains

Geographical and Morphological nature of the route is described in the following table. According to the calculation of cell radius and the nature of the terrain, corresponding required BTS quantity are described in the table below.

s/n	Distance (km)	Elevation difference	Geographical and morphological nature	Location of the BTS deployed	radius per BTS (km)
1	10	2107.93-2250.89	Scattered houses long trees, almost hilly(increasing altitude)	8°56'22.0524"N 38°44'3.0788"E-	5.53
2	10	2215.63-	scattered houses and trees, almost flat	8°53'21.3398"N	5.53

		2273.43	(up-down altitude nature)	38° 46'35.1012"E	
3	10	2054.90-2215.63	Small city with scattered long trees, almost hilly (decreasing altitude)	8° 51'16.1676"N 38° 48'12.7404"E	5.53
4	10	2055.80-2133.30	scattered houses and trees, almost flat (increasing altitude deference)	8° 46'16.1676"N 38° 56'12.7404"E	12.69
5	10	1976.00-2138.25	scattered houses and trees, almost flat (decreasing altitude deference)		
6	10	1894.23-1976.00	Scattered trees, almost flat (decreasing altitude deference)	8° 44'28.0848"N 39° 1'6.6216"E	12.69
7	10	1874.61-1903.56	Small city with Scattered trees, almost flat (decreasing altitude deference)		
8	10	1831.71-1873.65	scattered long trees, almost flat (decreasing altitude)		12.69
9	10	1780.01-1830.28	scattered long trees, almost flat (up-down structure)	8° 39'17.2800"N 39° 3'48.9816"E	
10	10	1680.99-1806.46	scattered short trees, almost hilly (up-down structure)	8° 32'46.8836"N 39° 12'58.9192"E	12.69,
11	10	1623.84-1687.97	Small city with scattered long trees, almost flat (up-down structure)		
12	10	1510.43-1686.97	scattered short trees, almost hilly (up-down structure)	8° 34'20.9388"N 39° 19'56.1216"E	12.69
13	10	1465.56-1510.10	Small city with scattered trees, almost flat (decreasing altitude structure)		
14	10	1403.36-1467.73	scattered trees, almost flat (decreasing altitude structure)	8° 38'38.7888"N 39° 24'51.5160"E	12.69
15	10	1277.33-1403.36	Huge trees almost flat (decreasing altitude structure)		
16	10	1277.30-1168.40	scattered trees, almost flat (decreasing altitude structure)	8° 41'51.8388"N 39° 31'43.7224"E	12.69
17	10	1153.30-1173.11	scattered trees, almost flat (up-down altitude structure)		
18	10	1071.12-1173.11	scattered trees, almost flat (decreasing altitude structure)	8° 46'31.5912"N 39° 37'52.0284"E	12.69
19	10	974.51-1071.12	scattered trees, almost flat (decreasing altitude structure)		
20	10	973.79-1025.05	small city, scattered trees, almost flat (up-down structure)	8° 50'57.6676"N 39° 44'27.5352"E	12.69
21	10	962.56-	scattered trees, flat (up-down		

		986.01	structure)		
22	10	953.99-984.91	scattered trees, flat (up-down structure)	8°54'28.9260"N 9°54'44.2800"E	12.69
23	10	981.96-1048.56	scattered trees, flat (up-down structure)		
24	10	909.23-981.96	scattered trees, flat (up-down structure)	9°0'20.5419"N 40°10'38.4428"E	12.69
25	10	853.98-950.05	scattered trees, flat (up-down structure)		
26	10	950.08-1027.00	scattered trees, almost flat (decreasing altitude)	9°0'33.5412"N 40°16'43.0500"E	12.69
27	10	1027.00-1108.04	scattered trees, almost flat (decreasing altitude)		
28	10	1108.05-1179.68	Scattered houses and trees, almost flat (increasing altitude)	9°1'11.3844"N 40°25'52.0416"E	12.69
29	10	1179.80-1288.33	scattered trees, almost flat (increasing altitude)		
30	10	1288.33-1399.92	scattered trees, almost flat (increasing altitude)	9°9'38.1408"N 40°38'41.1144"E	12.69
31	10	1399.92-1479.93	scattered trees, almost flat (up-down altitude structure)		
32	10	1307-81-1424.77	Small city, Heavy trees, almost flat (decreasing altitude)	9°13'50.3342"N 40°43'35.8944"E,	5.53

Table 3.7: route coordinates from Addis Ababa-Meiso with required BTS [56]

s/n	Distance (km)	Elevation difference (m)	Geographic status and Morphologic nature	Location of the BTS where it deployed	Cell radius per BTS (km)
1	14	1204.50-1313.81	Moderate forest, small city, hilly area (decreasing)	9°16'45.3792"N, 40°45'30.8064"E; 9°18'35.6352"N 40°49'30.8064"E	5.53 (x2)
2	10	1204.50-1029.35	Moderate forest, small city, hilly area (decreasing)	9°20'45.5452"N, 40°51'34.5664"E	5.53
2	22	1029.35-1168.88	Moderate forest, scattered houses and hilly areas	9°22'28.3710"N 40°54'24.8620"E	12.67

3	20	1020.30-1101.36	Moderate forest, dispersed houses, semi-hilly area	9°27'56.3620"N 40°59'43.7800"E; 9°29'50.3700"N 41°06'67.7680"E; 9°30'55.3254"N 41°08'54.2380"E	5.53 (x3) Three BTS's
4	21	1010.05-1177.45	Moderate forest, small cities, hilly area	9°32'52.2710"N 41°11'37.5080"E; 9°32'6.2580"N 41°21'27.1180"E; 9°34'33.4580"N 41°32'24.1120"E	12.69 (X3)
5	24	1025.04-1108.49	Moderate forest, small cities, semi-hilly area		
6	4	1098.83-1121.89	Moderate forest, scattered houses, semi-hilly area	9°36'31.8220"N 41°42'54.5400"E	5.53
7	10	1011.39-1104.38	Moderate forest, hilly area		
8	10	927.00-1011.39	No forest, semi-hilly area	9°36'14.8860"N 41°53'48.8030"E	12.69
9	10	838.77-927.00	No forest, semi-hilly area		
10	9.834	772.45-838.88	With no forest flat with continuously decreasing altitude	9°43'38.3900"N 42°03'05.5590"E	12.69
11	9.08	748.09-772.25	No forest, flat with continuously decreasing altitude		
12	9.898	716.82-748.12	With no forest, flat with continuously decreasing altitude	9°53'52.3530"N 42°13'6.3910"E	17.50
13	10	695.38-717.14	Almost no forest, flat with continuously decreasing altitude		
14	10	693.41-695.35	No forest, almost flat		
15	10	679.84-693.70	No forest, almost flat	10°2'50.2420"N 42°24'12.4200"E	17.50
16	10	648.64-705.45	No forest, almost flat		
17	11	705.33-760.00	No forest, almost flat		
18	10	759.45-770.23	No forest, almost flat	10°21'23.7270"N 42°33'48.5330"E	17.69
19	10	761.68-774.00	No forest, almost flat		

20	10	761.43-776.54	No forest, almost flat		
21	10	728.20-783.50	No forest, semi-flat	10°44'54.4563"N 42°35'30.9630"E	17.50
22	10	712.00-732.43	No forest, almost flat		
23	10	717.00-756.21	No forest, semi-flat		
24	10	712-752	No forest, semi-flat	11°1'24.2330"N 42°38'12.1440"E	12.69
25	9	717-821	No forest, hilly area		
26	8	797-857	No forest, hilly	11°3'12.4330"N 42°39'10.1320"E	12.69
27	6	797-833	No forest, semi-hilly		

Table 3.8: route coordinates from Meiso-Deweale with required BTS [57]

Note: Addis-Ababa (Sebeta) is starting point of the investigation and every word like increasing and decreasing referred from this point.

3.10. Channel arrangement and frequency reuse

Having many number of cells in a cluster reduces co-channel interference and improves the mean S/I ratio for a given cell reuse factor. However, it reduces network capacity since the channel resource is distributed more thinly among various sectors [58]. For reliable and good performance S/I must be greater or equal to 14 dB for GSM-R radio networks and 16dB has been chosen in this work. Since the cells are cascaded in a straight manner the effect of co-channel interference over one cell is negligible from the 3rd co-channel cell. Co-channel interference from two channels satisfied the performance for reliable communication.

$$N = \frac{1}{3} \times \left[2 \left(\frac{S}{I} \right)^{\frac{2}{Y}} \right] \quad (3.38)$$

Where

$$\begin{cases} 2 \leq Y \leq 5, 2 \text{ for free space and } 5 \text{ for urban areas} \\ \frac{S}{I} = 10^{1.6} \end{cases} \quad (3.39)$$

number 2 shows the most nearest co – channels to the selected cell

Taking 2.5 value of Y, the number of cells in a cluster is approximately 11. Thus, frequency reuse is after 11 cells. Signals which are adjacent to each other cause adjacent channel interference. Adjacent channel interference is brought primarily because of imperfect receiver filters which allow nearby frequencies to move into the pass band, and nonlinearity of the amplifiers. This effect can solve by using modulation scheme which have small out of band radiation and assigning adjacent channels to different cells in order to keep the frequency separation between each channel

in a given cell as large as possible. GSMK modulation technique is selected which has small out of band radiation comparing to QPSK, FSK and AFK. The total number of channels used in network is 13(see section 4.3), and eleven channels (cells) are grouped to one cluster. each separated by a interval of four from both side channels (1,5,9,13,4,8,12,3,7,11,2; 6, 10,1,5,9,13,4,8,12,...)

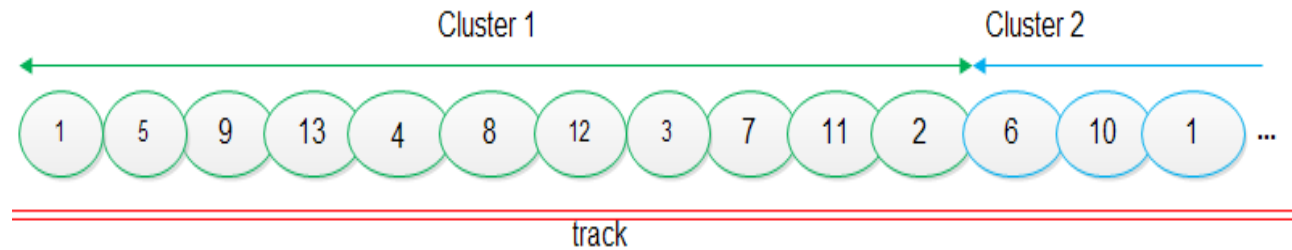


Figure 3.6: cluster size

In a cell there is only one frequency channel for most of the BTS's deployed in the stations and other part of the route, because the line has small data traffic load. A single frequency channel is enough to afford the load in its area coverage except for Indode, Labu and Adama stations which needs two frequency band channels.

3.11. Tunnel radio network coverage

The route includes 380m distance tunnel at Awashisht. The running train inside the tunnel must be communicated with the BTS deployed around. To get affordable signal in the tunnel, radio frequency (RF) repeater antenna and radiating cable is deployed inside and at the entrance of the tunnel. Radiating cables facilitate radio communication where the usual free space propagation of electromagnetic waves is hampered, undesired or impossible- in tunnels and other underground communications. It provides coverage for other technologies and GSM-R in band intervals ranging from 380 MHz to 2700MHz [59].

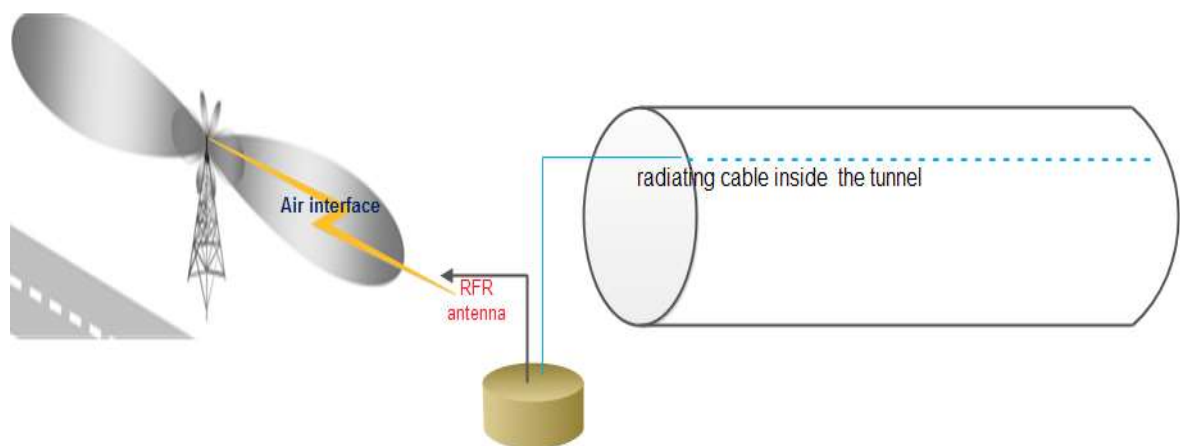


Figure 3.7: signal coverage system of a tunnel

Radio frequency repeater receive the radio signal coming from the BTS and this signal conveys to the radiating cable. The radiating cable serves the train in the tunnel both in receiving and transmitting information (duplex communication).

The positioning of the repeater antenna should typically be placed in a position where line of sight is at its best and the signal coming from the BTS has to be greater than -75dB . Both antenna and radiating cable should preferably not be mounted lower than ~4 .5m above the track.

3.12. BTS antenna selections

GSM-R antennas selection is according to the actual condition of the network to be built. Generally, antennas with high gain and narrow beams are required in GSM-R networks. There are different kinds of antennas used in different applications [18]. Some of them are discussed in brief as follows.

- a. **Omnidirectional antenna:** is a class of antenna which radiates radio wave power uniformly in all directions in one plane, with the radiated power decreasing with elevation angle above or below the plane [53]. This class of antenna is mostly used in rural areas. In all horizontal direction these antennas radiate with equal power and the vertical plane antennas radiate uniformly across all azimuth angles and have a main beam with upper and lower side lobes [60].
- b. **Isotropic antennas:** is an antenna that broadcasts power equally in all directions [61]. The isotropic radiator is used in antenna technology as a standard for the comparative evaluation of the directional characteristics of various antennas, particularly in determining the front-to-rear factor. A great deal of attention is being devoted to the design of antennas whose directional properties are close to those of an isotropic radiator [62].
- c. **Directional antennas (beam antennas):** is an antenna which radiates greater power in one or more directions. It has high performance on transmitting, receiving and reducing interference from unwanted sources. It provides increased performance over the other antennas when a greater concentration of radiation in a certain direction is desired [63]. Since Addis Ababa-Djibouti route has almost a straight path, directional type of antenna is more preferable in this design.

3.13. Handover algorithm in GSM-R network

In virtue of applying the frequency reuse to increase the GSM-R system capacity, the frequency handover problem during the user's movement should be considered. Handover process occurs between two cells (or sectors) overlapping area. If the instantaneous change of the signal strength for two cells is bigger within certain area, moving train will be handover between two cells backwards and forwards this creates "ping-pang effect". This effect increases the switching system's burden and call drop probability.

The criteria of determining one handover include average receiving signal strength, signal quality (bit error rate), and distance from the BTS. Running train handover is frequently decreases the

performance of GSM-R radio network [64]. In the case of this thesis average receiving signal strength determines the handover request. The margin of the handover signal level is from -82dB to -95dB.

$$\text{Handoff margin} = Pr_{\text{handoff threshold}} - Pr_{\text{minimum receiving sensitivit}} \quad 3.38)$$

Taking equation 3.38 and figure 3.8 handoff margin is from 0dBm to 8dBm (i.e. (-87dBm) – (-95dBm))

Handoff can be categorized as hard handoff, soft handoff, and softer handoff. The hard handoff can be further divided into intra-frequency and inter-frequency hard handoffs. During the handoff process, if the old connection is terminated before making the new connection, it is called a hard handoff whereas soft handoff is making a connection with the new BTS before terminating the connection with the old BTS. For 2G GSM technology hard handoff type is the most common [20]. Even though there is a short break in transmission, this is normally a very short and it can't noticeable by the user especially in the digital world.

Soft and softer handover techniques are used in sensitive communication services and there are expensive relative to hard handover. Soft handover technique is occurred when the mobile station is in the overlapping coverage area of two or more adjacent cells. But, softer handoff is the detail of soft handoff scheme, which occurred when user has two simultaneous connections to a single base station network using different air interface channels concurrently. In the case of soft handover the mobile station is in the overlapping cell coverage area of two or more sectors belonging to different base stations; softer handover is the situation where one base station receives two user signals from two adjacent sectors it serves. Due to reflections on buildings or natural barriers the signal sent from the mobile station reaches the base station from two different sectors and the strong signal will be selected [65].

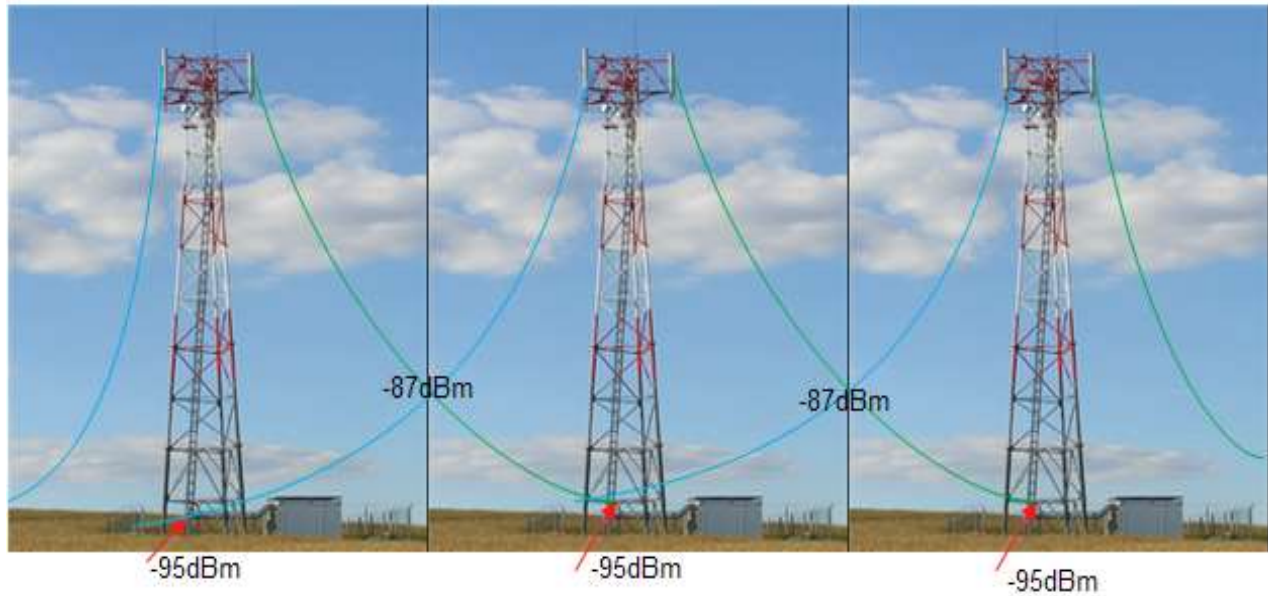


Figure 3.8: handover signal level

Hard handoff is the cheapest and simple to implement. User equipment (UE) is connected to only one BTS at a time. This type of handover is used in different adjacent frequency channels. It uses TDMA and FDMA media access technique [66]. Therefore, hard handover technique is selected in this thesis.

There are three basic handover processes. These are signal strength measurement, decision making and execution phases. The cab signaling system is measuring the signal strength of the new and the old BTSs continuously. The decision phase consists of an assessment of the overall quality of service (QoS), of the connection and comparing it with the requested QoS attributes and estimates from neighboring cells. Depending on the outcome of this comparison, the handoff procedure may or may not be triggered. The execution phase involves handoff signaling and radio resource allocation [66].

The length of handover zone depends on the proper handover execution elapsed time and the speed of the running train. The overall required time to carry out handover process is from 5 to 10 seconds and the maximum running train speed of the route is 120 kmph. Therefore, the overlapped handover zone is about 240m distance.

If one of the BTS fails it is guaranteed that the train will communicate with the BTSs ahead or rear since its signal strength at the location of the failed BTS is greater or equal to the MRSL (-95dB).

Chapter four

4.1. Simulation result and analysis

In this chapter we will discuss the simulation results done based on Atoll radio network planning tool using the design results calculated in chapter three. Performance analysis of the planned network is evaluated based on the designed values resulted in chapter three and simulation results.

4.1.1. Overview of Atoll software

Atoll is a scalable and flexible multi-technology network design and optimization platform that supports wireless operators throughout the network lifecycle, from initial design to deployment and optimization. It can be used to plan both radio and microwave links networks. Atoll can support the following technologies:

- GSM/GPRS/EDGE
- UMTS/HSPA
- Multi-RAT projects
- CDMA2000 1xRTT/EV-DO
- LTE
- TD-SCDMA
- WiMAX/BWA

The Atoll working environment is powerful and flexible. It provides a comprehensive and integrated set of tools and features that allows operators to create and define radio-planning project in a single application. Atoll includes advanced multi-technology network planning features, and a combined single-RAN, multi-RAT GSM/UMTS/LTE Monte Carlo simulator and traffic model. Operators can save the entire project as a single file, or you can link your project to external files.

The Atoll working environment uses familiar Windows interface elements, with the ability to have several document windows open at the same time, support for drag-and-drop, context menus, and support for standard Windows shortcuts, for example, for cutting and pasting. Atoll not only enables operators to create and work on their project planning, but also offers a wide range of options for creating and exporting results based on the project. The working environment provides a wide selection of tools to facilitate radio-planning, such as a search tool to locate either a site, a point on the map, or a vector.

4.1.2. GSM-R network design using Atoll

This thesis had planned to simulate the signal strength with the digital map of the route but I didn't get it, instead it used slightly different method but almost the same performance. The steps that are implemented to simulate the signal strength are shown in the following block diagram. Google

earth, online Zonum Solutions, MapInfo and Atoll software are the technologies used in the simulation process.

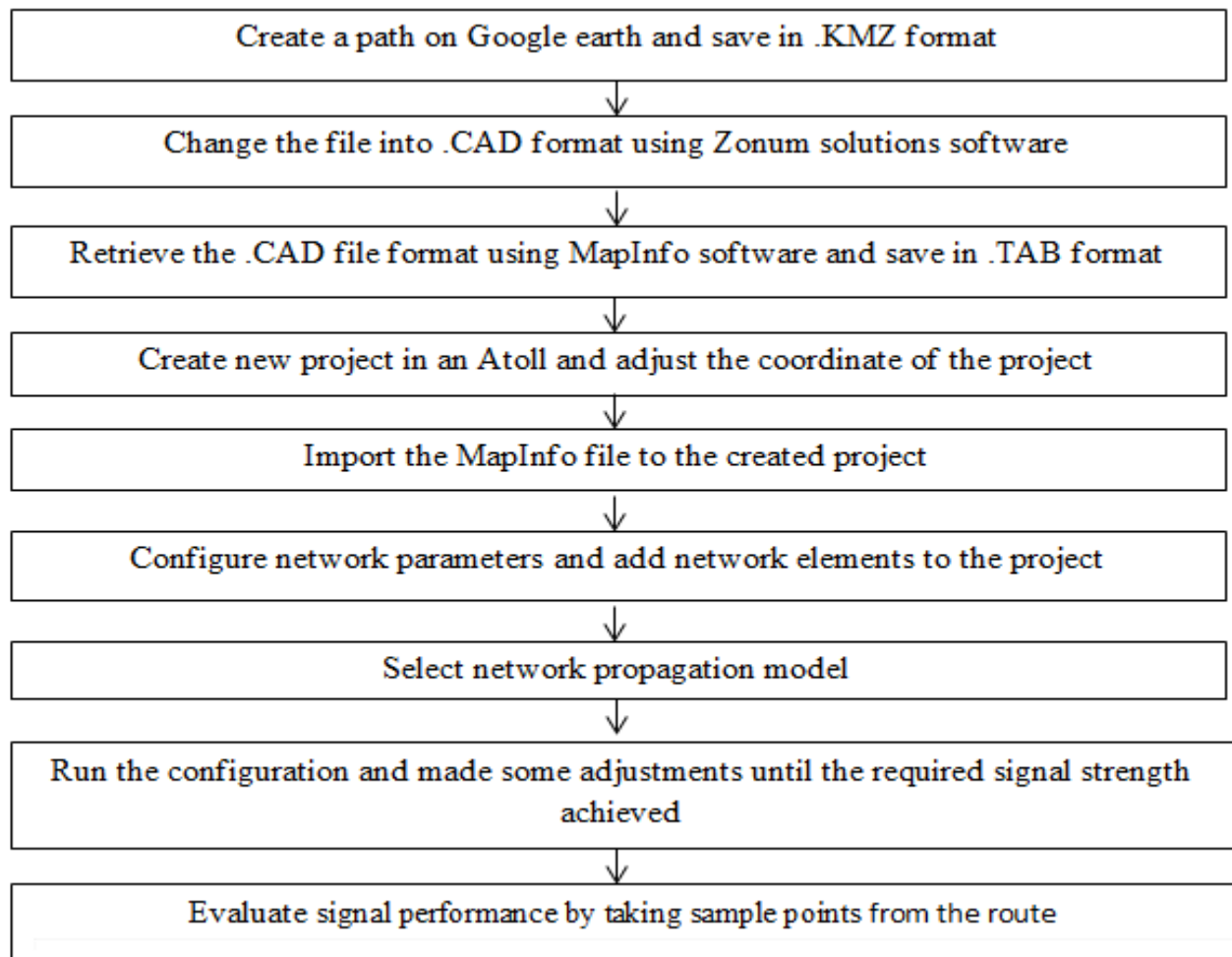


Figure 4.1: block diagram of simulation steps

The first task of the simulation configuration is creating an Atoll project file of having the Google earth map of the route with no base stations. BTS locations are defined in the Google earth with the created route. Afterwards, adding the transmitters and settings of the parameters which are calculated in the previous chapter.

The use of the Google earth map is to identify the nature of the route which affects the signal strength directly or indirectly. The route is divided in to two sections to simplify the simulation and result analysis.

The route from Addis Ababa to Meiso and Meiso to Dewele are shown in the following consecutive figures on Google earth. This figure shows only the path with no transmitters and/or stations.



Figure 4.2: path from Addis Ababa to Meiso section



Figure 4.3: Meiso-Deweile section

4.1.3. Simulation results of the route

The best signal level is shown in figure 4.4 with different colors. This legend shows the prediction property of each signal level.



Figure 4.4: signal level coverage indication with different colors

The route divided into two sections (i.e. Addis Ababa-Meiso and Meiso-Dewele sections). Figure 4.5 shows the simulation result of the signal coverage level for Addis Ababa - Meiso section and it covers 327.245km distance. There are 18 BTS's which are required in this section and the signal strength is confidential at every point of the route as we can see from figure 4.5.

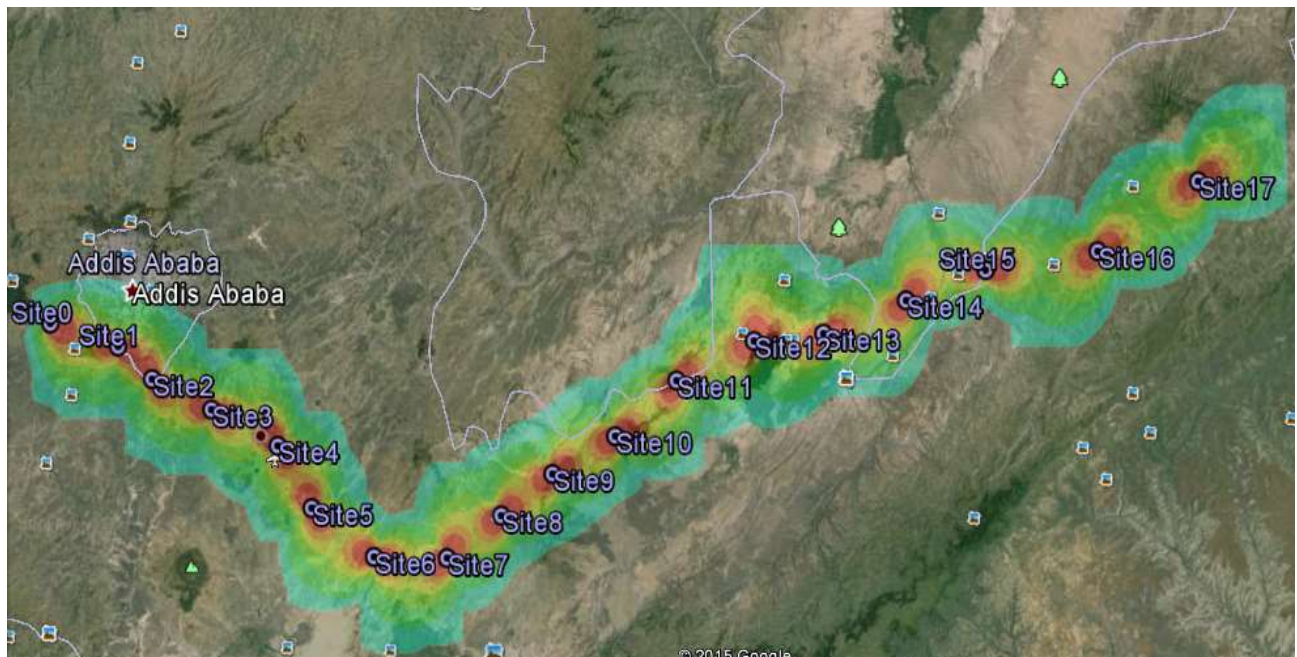
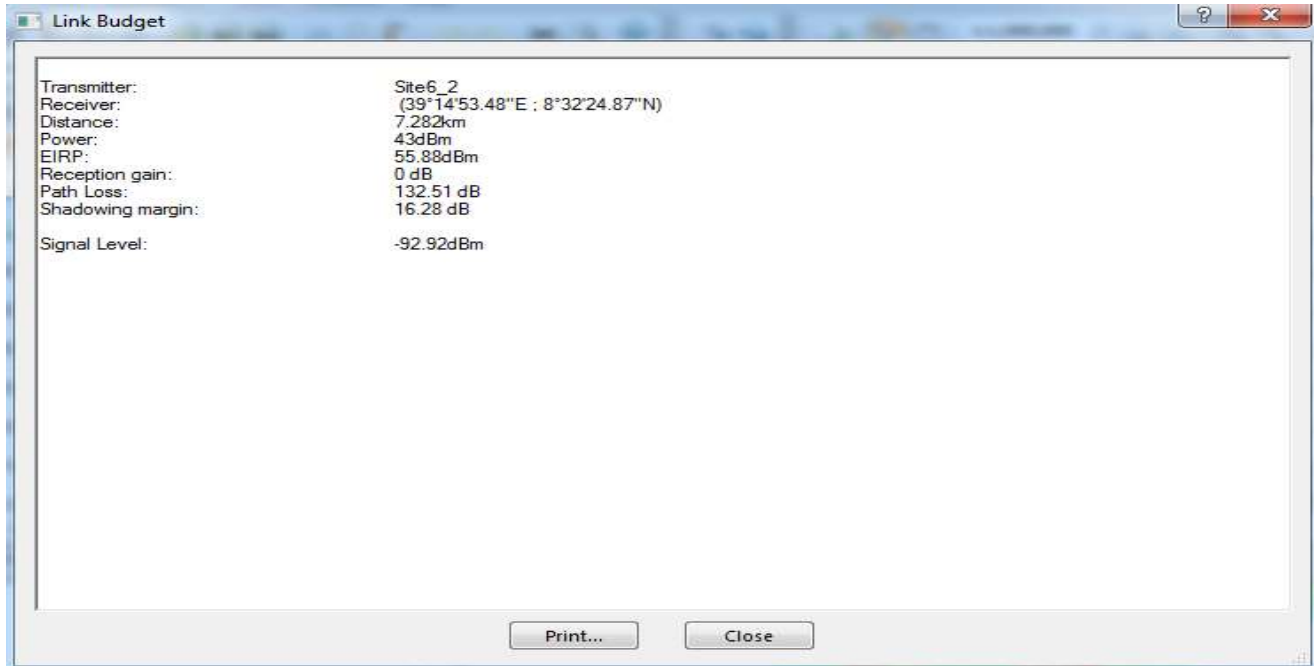


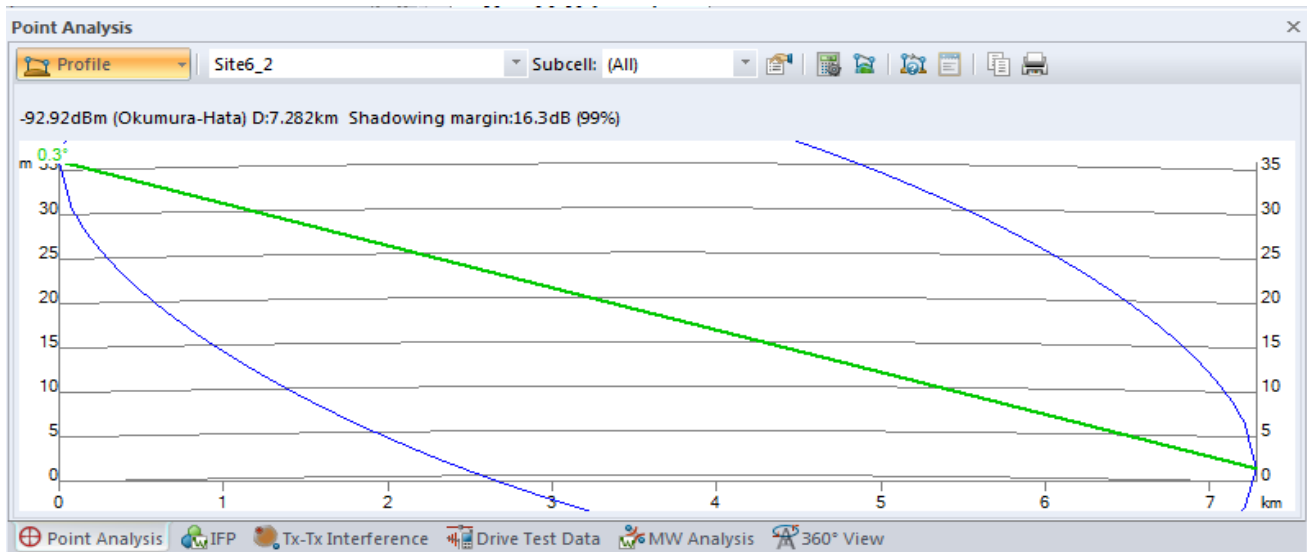
Figure 4.5: Addis Ababa-Meiso BTS's signal level simulation

4.1.3.1. Performance analysis of Addis Ababa-Meiso section

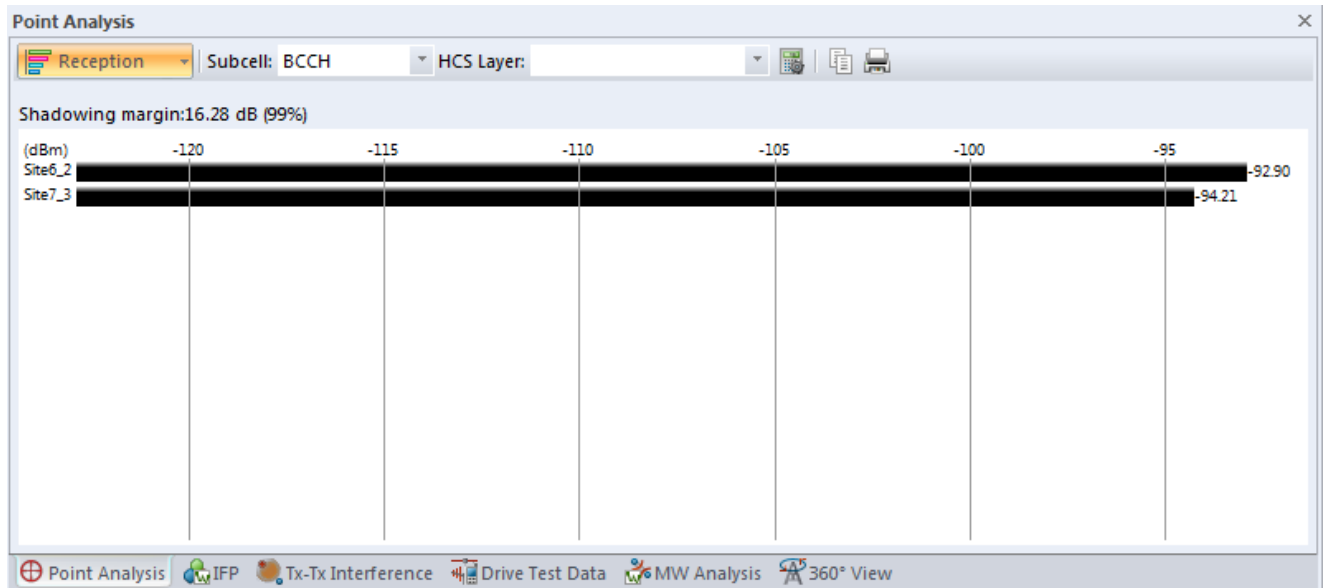
Using point analysis tool of Atoll software, a random point is chosen between site6_2 and site 7_3. The point is selected from Addis Ababa-Meiso section simulation result along with a receiver to analyze the cell edge throughput scenario. Link budget from site6_2 is shown as in figure 4.6 (a), geographical profile and reception signal level of the selected point is shown in figure 4.6 (b)&(c) respectively.



(a)



(b)



(c)

Figure 4.6: point analysis and performance result of chosen site -(a),(b) and(c)

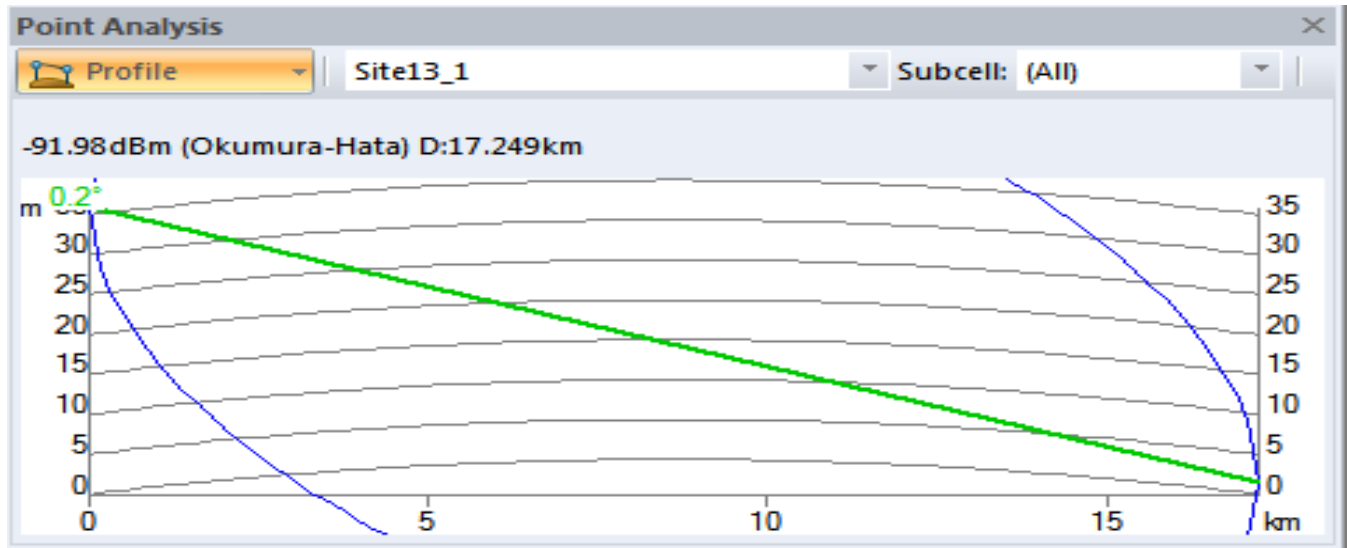
The following figure (figure 4.7) is also the section from Meiso to Dewele route and it covers a distance of 334km. 19 BTS stations are required in this section. The signal strength and performance is confidential at every point of the route. The BTS station antennas are configured in two sectors.



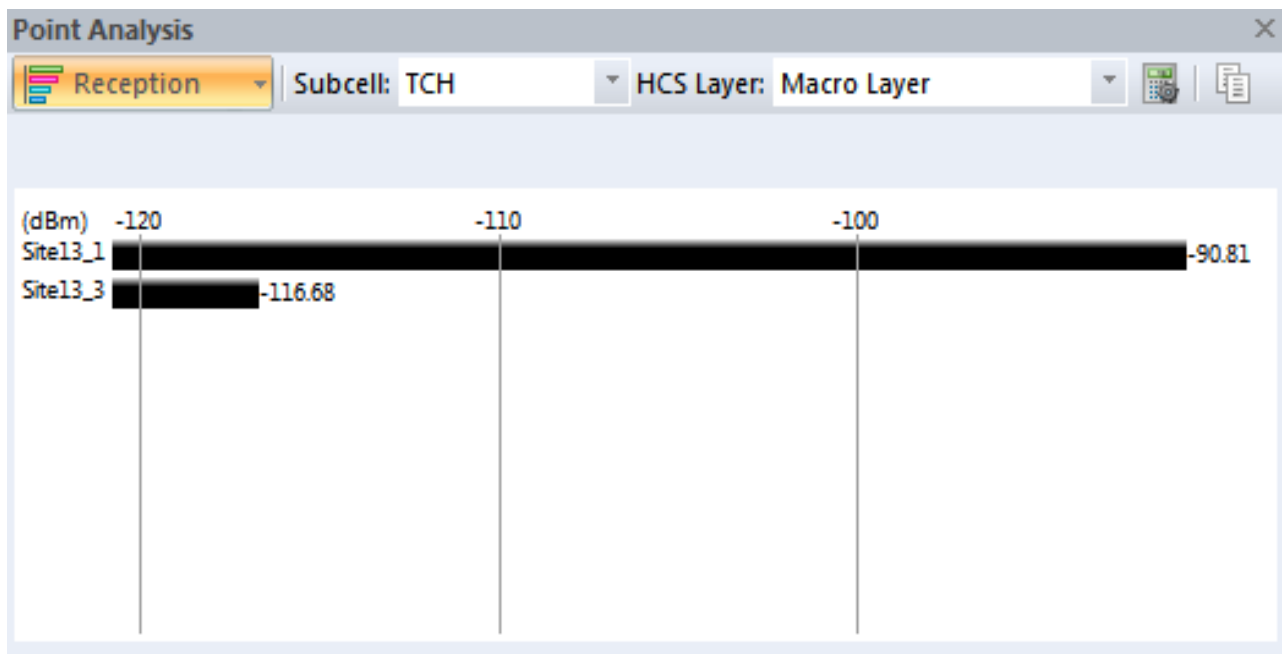
Figure 4.7: Meiso-Dewele BTS's signal level simulation result

4.1.3.2. Performance analysis of Meiso-Dewele section

A random point is chosen between site13_1 and site 14_2 from the Meiso-Dewele section along with a receiver to analyze the cell edge throughput scenario. Geographical profile and reception signal level of the selected point is shown in figure 4.8 (a) & (b) respectively.



(a)



(b)

Figure 4.8: point analysis and performance result of chosen sites for Meiso-Dewele section- (a), (b)

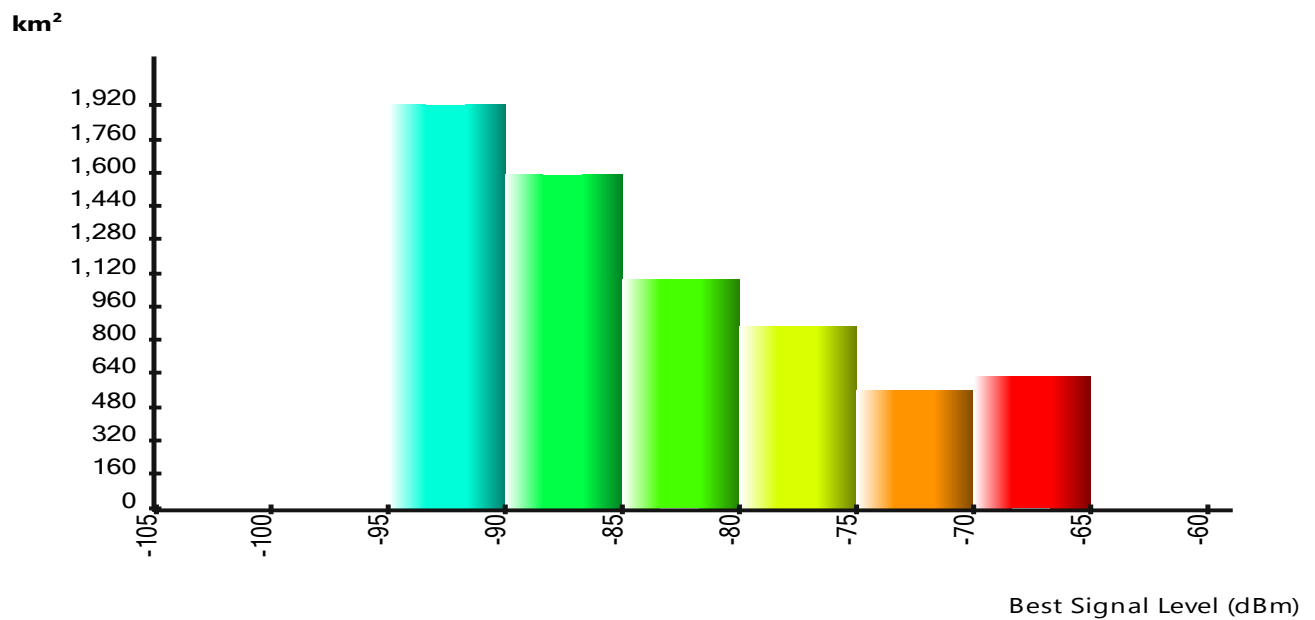


Figure 4.9: area coverage per each signal level

As we can see from the above figure that, the lowest signal level designated by the blue color is covered an area of 1,920km². The area covered with the low signal level is the largest of all signal levels.

Chapter five

5. Conclusion and recommendations

5.1. Conclusion and limitations

The radio network planning of GSM-R for the route needs extensive assessment in terms of capacity, coverage, quality requirements and standards. The estimations of capacity and coverage should contribute for the deployment and implementation process of the technology by providing significant data about the nature of the route. In the process of doing this thesis, there have been different problems like insufficiency of data and related reference materials in our country. Even though it had many difficulties, this thesis tried to design GSM-R radio coverage and capacity planning for the route. This work also attempts to propose a solution how to optimize the wired network proposed by the Chinese companies using GSM-R technology radio communication.

The route passes through three broad different topographic and geographic natures of terrains. Small cities having moderate and/or no coverage of forests with small hills, rural areas having moderate forest coverage with hilly and flat topographic type and rural with no forest and flat areas are incorporated in the route. Using Okumura –Hata model three different cell radius of the three terrain type are calculated correspondingly.

The route needs a total of 37 BTS transmitters with a total information data rate capacity of 7.29622Mbps and the maximum needed user information data rate is 6.43850Mbps which is less than the total capacity. The first three largest stations are demanding a BTS with double channels but the other BTSs need a single channel.

This work is simulated with Atoll software and the result is analyzed with different signal level colors and sample point discussions.

5.2. Recommendations

This work gives a macroscopic dimension and valuable estimation of the GSM-R radio network system. This work needs greater investigation in order to make complete and practical in all aspects of fields, because for every project done, there is always a room for improvements and further enhancements. There are number of ways in which this work can be extended forward. The work done in this thesis covers the access network and interface dimensioning of GSM-R network. This can be extended and compared with other technologies like GPRS, 3G and 4G (LTE) networks on the subject of their service quality and investment and/or maintenance cost analysis. Using a more detail traffic and site visiting investigation, this work will get better and more practical. The material cost aspect and effective technology analysis for practical implementation is also a possible extension of this work. Since the route's train control mechanism is not decided yet, this work can be a milestone to choose the train protection and control methodology. RF signal interference between domestic GSM and other networks with GSM-R network can also be an issue to be investigated and studied more.

References

- [1] C. Schmelzer, “*Standardization of CBTC Systems – Mixed Operation on Shared Lines In accordance with ERTMS/ETCS Standards*,” Siemens AG, Sector Industry, Division Mobility , Brunswick, Germany, 2006, pp. 2-3.
- [2] Alexandrescu and Nemțoi, “Considerations regarding a radio planning procedure for the GSM-R network covering the Bucuresti–Constanta Railway Corridor,” U.P.B. Sci. Bull., Series C, Vol. 73, Iss.3, 2011.
- [3] Jørgen Binningsbø, (2006, February). “*GSM-R Radio Planning Guidelines*,” Jernbaneverket, 3A-GSM-038, Revision 00, Norway.
- [4] Valentin I. Popov, Andrei J. Baranovskii, “Design Principles of Mobile Railway Networks” UDC 621.396.931, Riga Technical University, Riga, Latvia, Volume 1, Number 1, 2010.
- [5] Jan Magne Tjensvold, “*GSM network design for Stavanger and Sandnes*,” Norway, November 2007.
- [6] Ethiopian Railways Corporation, “*Ethiopia/Sebeta-Djibouti/Nagad Railway Feasibility Study, Communication*,” Executive Edition, Volume II, September 2012, p. 10.
- [7] Ethiopian Railways Corporation, “*Ethiopia/Sebeta-Djibouti/Nagad Railway Feasibility Study, Signaling*,” Executive Edition, Part XVII, September 2012, pp.10-12.
- [8] Ethiopian Railways Corporation, “*Ethiopia/ Sebeta-Djibouti/Nagad Railway; Feasibility Study, Transportation Organization*” Executive Edition, Part III, September 2012, pp.3-12.
- [9] Ethiopian Railways Corporation, “*Ethiopia/Sebeta-Djibouti/Nagad Railway Feasibility Study, Water supply and drainage*” Executive Edition, Part XV, September 2012, p. 2.
- [10] Ethiopian Railways Corporation, “*Ethiopia /Sebeta-Djibouti/Nagad Railway, Feasibility Study, Economy and Traffic Volume*,” Executive Edition, Part II, September 2012, p. 25
- [11] Ethiopian Railways Corporation, “*Ethiopia/Sebeta-Djibouti/Nagad Railway, Feasibility Study, General Specification*,” Executive Edition, Part I, September 2012, p.73, p.174.
- [12] Ethiopian Railways Corporation, “*Ethiopia/Sebeta-Djibouti/Nagad Railway, Feasibility Study, Transportation Organization*,” Executive Edition, Part III, September 2012, pp.11-16.
- [13] Ethiopian Railways Corporation, “*Ethiopia/Sebeta~ Djibouti/Nagad Railway Feasibility Study, Informatization*” Executive Edition, Chapter 18, Volume II, September 2012, pp.1-3
- [14] <http://gsmr-info.com/> (05-May-2015)
- [15] <http://en.wikipedia.org/wiki/GSM-R> (08-May-2015)
- [16] <file:///D:/railway-academic/thesis/gsm-r/new1/GSM-R.htm> (10-May-2015)
- [17] Prof. (Dr.) V Purnachandra Rao, “*Institute of Signal Engineering & Telecommunications (IRISET)-Secunderabad GSM - R*,” Indian Rail ways, India, 2012, P. 21.
- [18] <file:///C:/Users/Hitech/Desktop/GSMRadioNetworkPlanning.htm> (14-May-2015)
- [19] <http://www.techopedia.com/definition/24191/base-station-controller-bsc> (14-May-2015)
- [20] <http://www.in2eps.com/3g02/tk-gsm02-67.html> (16-May-2015)
- [21] <http://gsmr-info.com/gsmr-expert-interview.html> (14-May-2015)

- [22] <http://ieeexplore.ieee.org/> (12-May-2015)
- [23] Gary Portsmouth, "Procedures for using the Siemens GSM-R cab radio," GSM-R user procedures (cab radio), Version 2, RSSB, Issue 6.3, June 2012, p. 13.
- [24] Sophia Cedex, "Railway Telecommunications (RT), GSM-R in support of EC Mandate M/486 EN on Urban Rail," France, ETSI TR 103 134 V1.1.1 (2013-03), 2013, p. 9.
- [25] Montegrotto Terme, "Practical Mechanism to Improve the Compatibility between GSM-R and Public Mobile Networks and Guidance on Practical Coordination," ECC report 162, May 2012, p.31.
- [26] file:///H:/newdata/Receiver_Sensitivity-Learning-Center_Digi-International.htm (06-May-2015)
- [27] Monte grotto Terme, "Practical Mechanism to Improve the Compatibility between GSM-R and Public Mobile Networks and Guidance on Practical Coordination," ECC Report 162, May 2011, p. 9.
- [28] <file:///H:/newdata/noisefigure-Wikipedia,theencyclopedia.htm>(17-May-2015)
- [29] [En.wikipedia.org/wiki/noise-figure](http://en.wikipedia.org/wiki/noise-figure) (16-May-2015)
- [30] <http://www.teletopix.org/4g-lte/calculation-for-body-loss-and-feeder-loss-for-lte/> (14-May-2015)
- [31] http://wiki.yatebts.com/index.php/Radio_Performance_Concepts(14-May-2015)
- [32] [http://en.wikipedia.org/wiki/Noise_\(electronics\)](http://en.wikipedia.org/wiki/Noise_(electronics))(14-May-2015)
- [33] http://en.wikipedia.org/wiki/Antenna_gain(14-May-2015)
- [34] <http://www.l-com.com/content/Article.aspx?Type=N&ID=9475>(14-May-2015)
- [35] Alireza Shirvani, Bruce A.Wooley, (2003), "Design and control of RF power Amplifier,"online, Available: [Http://books.google.com.et](http://books.google.com.et).
- [36] Mr. Lars Forsberg, "Implementation of 3G Capabilities in Developing Countries a Straightforward Path to IMT-2000," R:\REFTXT00\ITU-D\SG-D\SG02\100\169E.DOC,Documente 2/169-E, July 2000, p. 2.
- [37] http://www.cellular.co.za/gsm_400.htm(15-May-2015)
- [38] Granada, "Spectrum Efficiency of CDMA-PAMR and other wideband systems for PMR/PAMR," ECC Report 42, February 2004, p. 41.
- [39] ECC Decision (04)06, "the availability of frequency bands for the introduction of Wide Band Digital Land Mobile PMR/PAMR in the 400 MHz and 800/900 MHz bands," Europe, December 2011, p. 5.
- [40] ETSI SMG Plenary No. 28, "GSM 450 Feasibility Study Extension," SMG2,Agenda Item 6.2, Milan, Italy, Rev 1.1, February 1999, p. 13.
- [41] Fahredd'n Sadikoglu, "Digital Modulation Techniques in Mobile Communications," presentation, p. 3.
- [42] IEEE, "Channel Models for Fixed Wireless Applications," IEEE 802.16.3c-01/29, 2001, P. 12.

- [43] Wu Hao, Wang Qiang & Zhong Zhangdui, “*The GSM-R Handover Algorithm Analysis and Research for High-speed Railway*, ” 2010, p.1-2.
- [44] [https://sikandarhyat.files.wordpress.com/.../gsm-channels-onair-interface\(14-May-2015\)](https://sikandarhyat.files.wordpress.com/.../gsm-channels-onair-interface(14-May-2015))
- [45] D.Russo et.al. (2005) “*Power Line Communication: a new approach for Train Passenger Information Systems*, ”Bologna, Italy, p.4.
- [46] <http://www.nuntius.com/solutions21.html>(16-May-2015)
- [47] Segun Isaiah Popoola, Olasun kanmi Fatai Oseni, “*Empirical Path Loss Models for GSM Network Deployment in Makurdi*, ” Nigeria, Volume 3, Issue 6, June 2014, pp. 85-86.
- [48] <https://trv.jbv.no/PDF/Tele/JD0560/Vedlegg/T6009b00.pdf>(10-May-2015)
- [49] <http://en.wikipedia.org/wiki/Fading>(14-May-2015)
- [50] “*Okumura and Hata Macroscopic Propagation Models*” <http://www.google.com.et/u> , pp. 1-2
- [51] N. Elfadhil, F. Touati “*Pathloss Determination Using Okumura-Hata Model And Spline Interpolation For Missing Data For Oman*, ” Proceedings of the World Congress on Engineering 2008 Vol I WCE 2008, London, U.K, July 2008, p. 8.
- [52] http://en.wikipedia.org/wiki/COST_231_model(05 May 2015)
- [53] http://en.wikipedia.org/wiki/Omnidirectional_antenna(06-May-2015)
- [54] Bekele Mulu, 2013. “*Institute of Technology School of Computing and Electrical Engineering, Dimensioning and Planning of LTE Radio Network for Future Deployment in Bahir Dar City*, ” Bahir Dar University, Ethiopia, pp. 25-26.
- [55] Nafaa M. Shebani et.al. “*Simulation and Analysis of Path Loss Models for WiMax Communication System*, ”Faculty of Engineering, Sabratah, Libya, 2013, p. 697.
- [56] LU Fengzheng, “*Ethiopian Railway project drawing Sebeta-Meiso DK120+000-DK342+100*” CCECC, Addis Ababa, Drawing Version A, 2013, p. 1.
- [57] LU Fengzheng, “*Ethiopian Railway project drawing Meiso-Dewele DK129+000-DK332+100 and DK129+300-DK332+100*, ” CCECC, Addis Ababa, Drawing Version A, 2013, p. 1.
- [58] Vijay Garg, “*Wireless communication and networking*, ” chapter 5, 2007, p. 143.
- [59] <http://exlanta.com/4.html>(16-May-2015)
- [60] <http://www.teletopix.org/gsm/antenna-types-and-antenna-characteristics/>(06-May-2015)
- [61] <http://en.wikipedia.org/wiki/Isotropy>(05-May-2015)
- [62] <http://encyclopedia2.thefreedictionary.com/Isotropic+antennas>(05-May-2015)
- [63] http://en.wikipedia.org/wiki/Directional_antenna(05-May-2015)
- [64] Jahangir khan, (2010, October). “*Handover management in GSM cellular system*, ” International Journal of Computer Applications (0975 – 8887), Volume 8– No.12, Pakistan, p. 17.
- [65] Dr. Jitendra Kumawat, (2013, JUNE), “*Soft and Softer Handover in Communication Networks*, ” ISSN 2321 – 8169, Volume: 1, Issue: 6, Amity University, Jaipur, p. 558.
- [66] Manish Srivastava, “*Handover*, ” URL: <http://www.slideshare.net>(14-May-2015)

Appendix-1:

```
clear
clc
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% PATH LOSS SIMMULATION OF DIFFERENT EMPERICAL MODELS %%%%%%%%%
d = 1:1:16;
fc = 450:1:465;
hb = 35;
hm = 4.5;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Akumoara model %%%%%%%%%
Htx = -18;
Hrx = -2.8;
Aul = 20;
Ffl = 32.5 + 20*log10(fc)+ 20*log10(d)-18-2;
Ploss1 = -Htx-Hrx+Aul+Ffl;
i=size(fc);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Okumura-Hata %%%%%%%%%
for i=1:16
a= (1.1*log10(fc(i)) -0.7)*hm - 1.56*log10(fc(i)) - 0.8;
%%for suburban and rural%%
Ploss2(i)= 69.55 + 26.16*log10(fc(i)) + (44.9-6.55*log10(hb))*log10(d(i))-
13.82*log10(hb)-a;%%urban%%
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%COST 231 - Hata Model %%%%%%%%%

a = (1.1*log10(fc)- 0.7)*hm - (1.56*log10(fc)-0.8);
C = 0; %%%for suburban and rural
areas %%%%%%%%%
Ploss5=46.3 + 33.9*log10 (fc) - 13.82*log10 (hb) - a + (44.9 -
6.55*log10(hb))*log10(d)+C;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Stanford University Interim (SUI) Model%%%%%%%%

d1=100:100:1600;
lam = (3*1.0e8)/(460*1.0e6);
do=100;
A = 20*log10 (4*3.1414*do/lam);
a=4.6;
b=0.0075;
c=12.6;
S =10.6;
gama = a-b*hb+(c/hb);
Xf=-1*(6*log10(fc/2000));
Xh = 1*(10*log10(fc/2000)); %%%for terain A and B%%%%%%%%
% Xh = -20*log10(fc/2000);%%for terain C %%%%%%%%%
Ploss6 = A + 10*gama + log10(d1/do) + Xf + Xh + S;

plot(Ploss1,'r','linewidth',2)
```

```

title('path loss of different models'),xlabel('distance(km)'), ylabel('path
loss(dB)');
hold on
hold all
plot(Ploos2,'b','linewidth',2)
hold on
hold all
plot(Ploss5,'y','linewidth',2)
hold on
hold all
plot(Ploss6,'g','linewidth',2)
legend('Ak','Ak-Hata','Cost 231-Hata','SUI', 'location','SE')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for i=1:16
    Ploss3(i) = Ploos2(i) - 2*(log10(fc(i)/28))^2 - 5.4;
%%suburban%%
    r2(i) =(130.2 - 69.55 - 26.16*log10(fc(i)) + 13.82*log10(hb) + a +
2*(log10(fc(i)/28))^2 + 5.4)/(44.9-6.55*log10(hb));
    Rsu =10^r2(i);
    Ploss4(i) = Ploos2(i) + (18.33*log10(fc(i)) -
4.78*log10(fc(i))*log10(fc(i)) - 40.94);%%for open rural areas %%
    r3(i)= (130.2- 69.55 - 26.16*log10(fc(i)) + 13.82*log10(hb) + a -
18.33*log10(fc(i)) + 4.78*log10(fc(i))*log10(fc(i)) + 40.94)/(44.9-
6.55*log10(hb));
    Ror =10^r3(i);
    Ploss4(i) = Ploos2(i) + (18.33*log10(fc(i)) -
4.78*log10(fc(i))*log10(fc(i)) - 35.94);%%for semi-open rural areas %%
    r4(i)= (130.2 - 69.55 - 26.16*log10(fc(i)) + 13.82*log10(hb) + a -
18.33*log10(fc(i)) + 4.78*log10(fc(i))*log10(fc(i)) + 35.94)/(44.9-
6.55*log10(hb));
    Rsor =10^r4(i);
end
Rsu
Ror
Rsor

```