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Dimension and Radio Planning of WiMAX Network for Advanced Real-Time Two-Way Communication Services: Case of Addis Ababa-to-Djibouti

BY
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Declaration

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

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Place: Addis Ababa

Date of Submission: ____________________

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

<u>Mr. Abi Abate</u> ____________________

Advisor's Name Signature

Abstract

Currently track circuit system is used for train controlling and signaling along Ethio-Djibouti railway line. However, track circuit system has a lot of limitations such as low data rate, narrow bandwidth, malfunction in bad weather and low reliability. Train control system is crucial issue that needs improvement in selected railway corridor. On other hand adopting entertainments for passengers will add a value for the company (Ethiopian Railway Corporation).

This thesis work analyze, design and dimension the WiMAX network for advanced real-time two-way communications services for the case of Addis-to-Djibouti. The main significance of WiMAX network for the selected route is attaining robust train control system and providing fast enough communication for passengers, real-time services for stations and on board controllers, and etc...

The study attempted in order to address the need to invest on more communication speed levels in Ethiopia and future available upgrade options from under construction system. In addition, levels of safety standards and train control technology are investigated by comparing with other communication systems. The research objectives endeavored by identifying series of steps towards achieving the best communication system along the selected route which can provide wide bandwidth. This will result safe, efficient and competitive transportation system.

The study mainly focus on WiMAX network coverage and capacity calculation in order to get appropriate position for transmitters (BTS) along the selected route. The numerical and simulation results offer a best mobile broadband network for different purposes on the specific transportation system such as train control, signaling, online ticketing, real time multimedia, online gaming and downloading.

The study methodologies selected are qualitative, quantitative and analytical data analysis methods and similarly data presentation methods of the study include, not exclusively; graphs, charts, tabular formation and in words. Finally computer aided simulation have done by using Atoll software and matlab. The scope of the research outlined is discussion concerning only the components of railroad infrastructure which are both technical and non-technical in their nature.

The final outputs of the study are documented series of technical measures that will enable Ethiopian rail service to boost its communication system speed.

Key-words

Mobile Broadband communication Architecture, Railway, WiMAX, IEEE802.6.

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Abbreviations/Acronyms

ADC	Analog-to-digital convertor
ASN	Access service network
BER	Bit error rate
BRAN	Broadband Radio Access Network
BS	Base station
CBTC	Communications-Based Train Control
CCTV	Closed-Circuit Television
CDMA	Code division multiple access
CSN	Connectivity Service Network
DSL	Digital Subscriber Line
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FEC	Forward error correction
HiperMAN	High-Performance MAN
IEEE	International Electrical and Electronics Engineers Association
ISI	Inter symbol interference
LDPC	low-density parity check
MAN	Metropolitan area network
MIMO	Multiple input multiple out put
MS	Mobile Station
NLOS	Non-line of-sight
NRM	Network reference model
OFDM	Orthogonal Frequency Division Multiple Access
PIS	Passenger Information system
RF	Radio frequency
SDH	Synchronous Digital Hierarchy
SNR	Signal-to-noise ratio
SS	Subscriber Station

TDD Time Division Duplex

TDMA Time division multiple access

Wi-Fi Wireless Fidelity

WiMAX **W**orldwide **I**nteroperability for **M**icrowave **Acc**ess

UIC Union International des Chemins de Fer; French version for **‘**International Union of Railways’

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Chapter One

1 Introduction

1.1 General Background

Since the origins of the railway in the 19th century most of the innovation and deployment efforts have been focused on aspects related to traffic management, driving support and monitoring of the train state [1]. The aim has been to ensure the safety of people and trains and to meet schedules, in other words, to ensure the railway service under secure conditions. To achieve this it has been necessary to establish a communication channel between the mobile elements (trains, infrastructure reparation machinery, towing or emergency vehicle, etc.) and the earth fixed elements (command posts and stations, signals, tracks, etc.) [1].

Now a day our country is expending on railway transport system; thereby we have to use late comer's advantage of technology development by implementing large bandwidth communication network in order to provide fast communication system for passengers as well as for train control system. No need to start from the scratch i.e. we have to use the latest Broadband communication architecture in Addis Ababa to Djibouti railway line for better transportation.

Addis Ababa-Djibouti route is the fundamental gate of our country; 75% of the total import and export goods are conveyed through this route [10, 14]. 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. The overall view of Addis Ababa to Djibouti railway route is shown as following figure (Figure 1. 1).

The implementing project is a railway inter-connecting Addis Ababa and Djibouti, which is the main corridor for passenger and freight transport, and for rapid transport of imported goods from Doharre new port to interior areas. Addis Ababa ~ Djibouti railway will be an east-west main trunk railway for the East Africa railway network, which plays a role for building national railway network of Djibouti and Ethiopia and facilitating their railway network. It is shown that the construction scheme of the line is technically feasible, economic and reasonable, and it is advisable to implement the line as soon as possible.

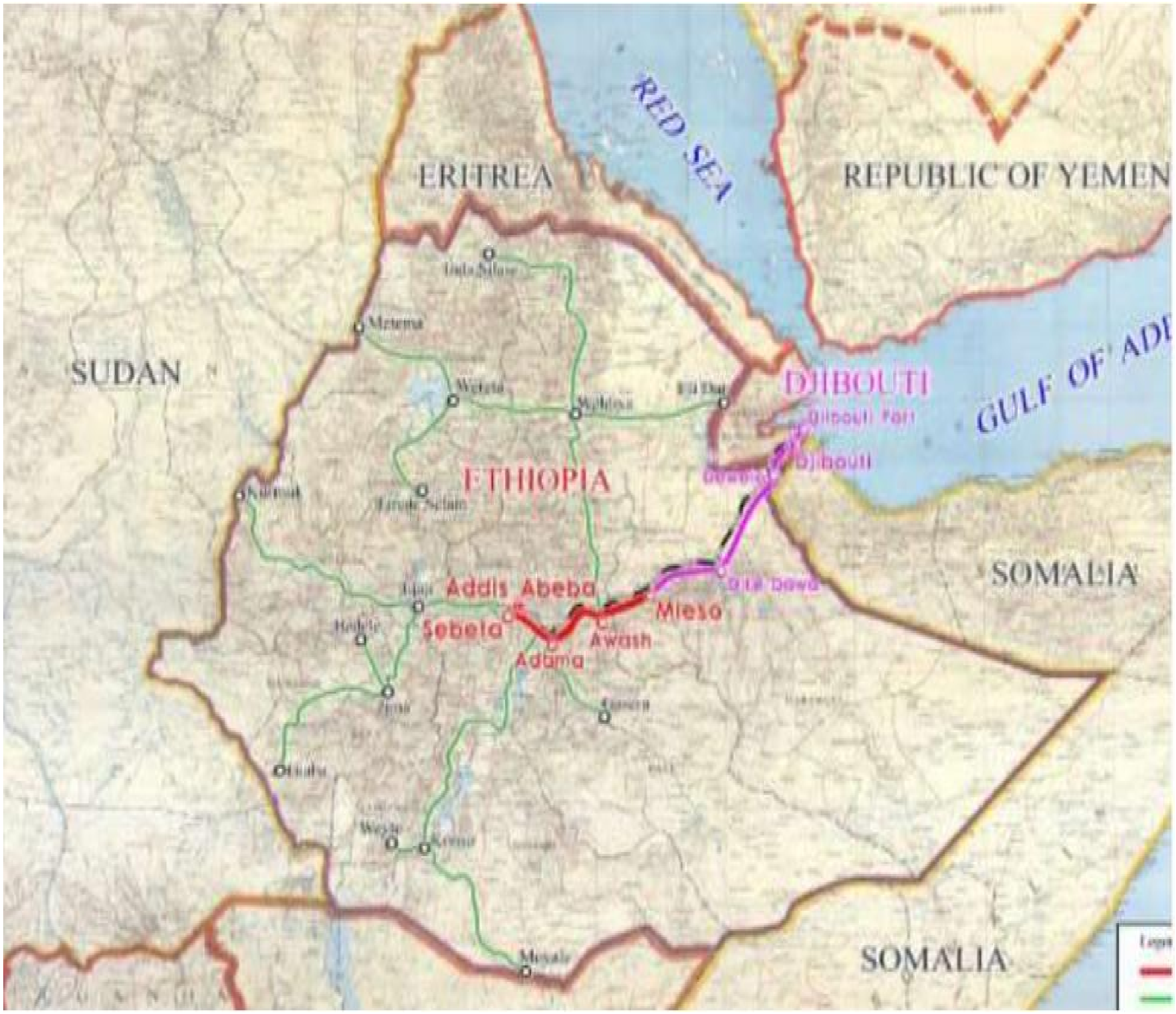


Figure 1. 1: Addis Ababa to Djibouti railway route [14]

1.2 Statement of the Problem

Increasing the speed of communication system in railway enhances the economic benefit for the company by adding values such as improving performance in terms of better control system and signaling, safety, reliability, increasing capacity & availability, reducing cost, delivering a sustainable future for the railway and as well as the accessibility of fast internet connection for passengers.

Track circuit system which used for train control and signaling along Addis Ababa to Djibouti can't address services discussed in above paragraph.

Now a day, widely implemented communication system on rail way line in most of the world is GSM-R. However, GSM-R has a lot of limitation. The main are:-

- Too frequent handover which causes a high call drop rate and quick battery drain; and
- Poor link quality due to high Doppler spread.

Mass transit operators are facing massive challenges while overcoming increasing traffic, ensuring passenger safety and security, improving travel comfort, and providing real-time multimedia information and access to social networks. Some of key challenges are:

1. **Heterogeneity of wireless and fixed broadband telecommunication networks[1]**
   Operators need to put these networks in place to meet requirements based on existing technologies such as Wi-Fi, satellite, 3G, and 4G — with unclear characteristics, limitations, and evolution strategies.
2. **Significant limitations on enhancement of operational efficiency, passenger security and, ultimately, quality of transport[1]**
   Railway transport authorities have deployed wireless system with limited data capabilities, signaling and control systems in unlicensed bands, and operational voice systems.

Telecommunications is a key component in operators' strategies, since it provides significant cost savings and better operational efficiencies in four areas [1]:

- ✓ Operation of the transportation system
- ✓ Safety and security
- ✓ Passenger experience
- ✓ Improvement of brand image and additional revenues

In order to achieve the benefits in these four areas, a telecommunications network has to completely fulfill requirements not only of vital applications such as *Communications-Based Train Control (*CBTC), but also non-vital applications such as *Passenger Information system (*PIS), Closed-Circuit Television (CCTV), remote maintenance, and the value-added services outlined below [1]:

- ✓ High degree of availability (at least 99.99 percent)
- ✓ Robustness and liability (packet error rate of 10^{-3} for a 200-byte packet)
- ✓ Higher bandwidth (10s of Mbits/s bi-directional train-to-ground and ground-to-train)
- ✓ Fewer constraints on robustness (a packet error rate of 10^{-2} for 1 MB packets)

Due to less capacity of Track circuit system and GSM-R, WiMAX network is selected in order improve of performance and respond the requirements of extra services discussed previously.

Generally this work mainly focused on capacity, coverage and hand-over enhancement of the route (i.e. Addis Ababa - Djibouti) by dimensioning WiMAX network in order to increase the reliability, safety, level of robustness and real time communication between passengers, dispatchers, controllers and drivers.

1.3 Objectives

1.3.1 General Objectives

In general, the objective of this thesis is to design and study safe, efficient, competitive and sustainable railway communication architectures to cater to the stringent performance requirements.

This thesis work has two main objectives. The first one is to dimension the access network parameters of mobile broadband communication architecture in order to come up with a viable solution for deployment in the railway route of Addis Ababa to Djibouti, given the demographic and geographic data of the route. Secondly, it strives to choose a suitable propagation model.

1.3.2 Specific Objectives

Specifically; the aim of this thesis is to:

- Perform an in-depth analysis on the strength and weakness of the current communication architecture.
- Perform an in-depth investigation on GSM-R Limitations.
- Investigate on future applications capacity demand
- Investigate the various communication system for supporting enhanced IT communication services in the railway context
- To investigate on handover enhancement techniques
- Perform survey on radio access technologies and architectures in the railway context
- Propose communication system for train to ground communication
- Performance evaluation of the proposed communication system

1.4 Related Works

Because of WiMAX or wireless mobile broadband is a new technology in communication system, it has got research attentions in the last few years. However this particular area of research is not an intensely explored one in the context of a thesis work or an academic research as this area is mostly dealt with by telecom companies earlier time to deployment.

There are only two other thesis related to this research had found and used as references. The first one is referred as [3], which is a case Study conducted for the basic dimensioning steps for the access and core networks and performs on the cities of Helsinki, Espoo and Kirkkonummi. And the second one is, referred as [22] which had mainly focused on Dimensioning and Radio Network Planning of Mobile WiMAX network for the case of Addis Ababa was conducted at Addis Ababa University.

The difference of previous works and this thesis work will briefly reviewed as follows. Both researches referred as [3] and [22] are mainly focused in metropolitan area which have huge number of subscribers and for the purpose of commercial telecom services. The first research work referred as [3] discus only in terms of theory (i.e. simulation haven't conducted). And the second thesis work referred as [22] had concluded that the coverage range of WiMAX radio network is around 1km. But this work mainly deal with WiMAX radio network for the case of railway scenario throughout the selected route which have a limited number of users. The simulation have done for each point of the Addis Ababa to Djibouti railway line on this thesis work. The author of this work didn't find other researches which studies WiMAX in detail for the purpose of Railway services.

1.5 Methodology

In order to achieve the main aim of this study there are different procedures followed. The first method is collecting materials dealing with Communication Architectures for case of Addis Ababa-to-Djibouti. Browse internet and read standard organizations reports to obtain basic information concerning the following points for Railway communication architecture Upgrading in general:-

- ✓ up to date UIC, IEEE, etc. standards;
- ✓ the philosophy, application principles and procedures;
- ✓ history and trends worldwide;
- ✓ current available technologies and future expected advances in the architecture, etc.

Beside literature reviewing, collection and verification of data for analysis is done. This is followed by studying the characteristics and modeling of Broadband communication Architecture constituent or elements. Once the model is developed by ATOL/Simulink, the analysis of the system was performed. Then based on the result of analysis Broadband communication Architecture designed for the specific corridor. Finally, the performance of Broadband communication architecture and comparison is made. The following flow chart shows the main procedures of this thesis work.

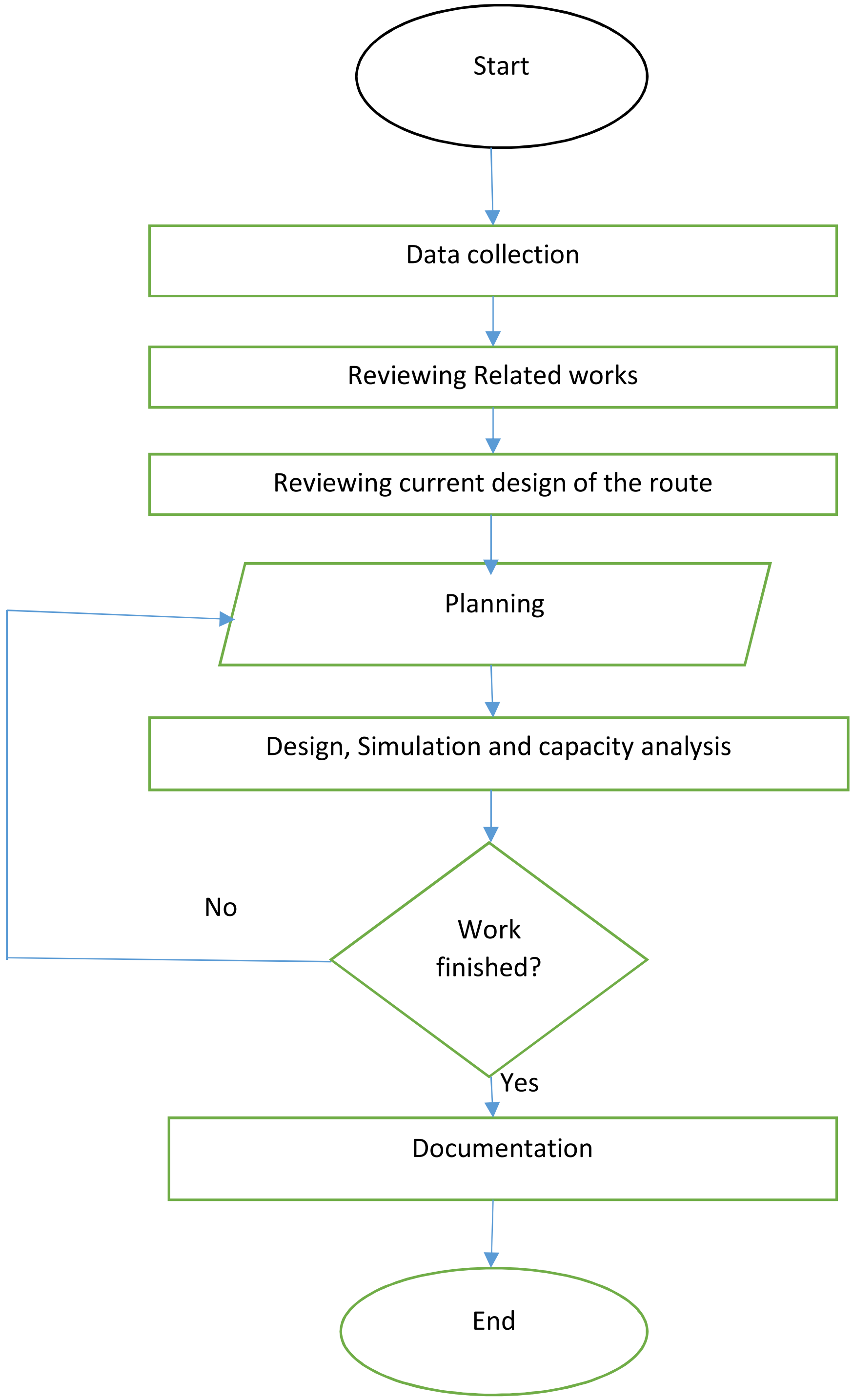


Figure 1. 2: Work flow chart

1.6 Scope of the Thesis

The performance analyses in this thesis work will be based on simulation of the proposed solutions using MATLAB and ATOLL. Thus, implementation details of the resulting systems will not be considered. The demographic and terrain data used on this thesis is entirely that of the Addis Ababa to Djibouti. Therefore, the scope of this research is limited to capacity, coverage and radio network planning for the route of Addis Ababa to Djibouti using computer aided simulations.

1.7 Contributions

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

As mentioned in anterior sections, this thesis work conducts all the capacity, coverage and radio network planning steps needed for deployment of WiMAX network in the route of Addis Ababa to Djibouti in order to get safe transportation by providing high data rate for the purpose of video surveillance, Personal information system (PIS), remote maintenance, controlling of train speed and position, train allocation, security, and online gaming, real-time multimedia for passengers. This research will serve as a good resource if/when WiMAX network is deployed in selected corridor and as well as for the other routes will be construct in Ethiopia.

1.8 Thesis Outline

Chapter Two presents the overview of the WiMAX networks and the route information. **Chapter Three** describing the Comparisons between Available Wireless Communication Systems and Wimax Network, architecture, technical capabilities, and technical differences, provides key factors to take into account prior to deploying a WiMAX network. **Chapter Four** describes the dimensioning of the mobile WiMAX network in the radio interface corridor of deployment; Addis Ababa to Djibouti corridor. **Chapter Five** takes into account the demographics, geographical factors, and data density requirements of the selected corridor so as to analyze how the network can be dimensioned using simulator software. Finally **Chapter Six** presents the conclusions and future work.

Chapter Two

2. Overview of WiMAX Network and the Route

In the previous chapter the introduction of this thesis work was briefly discussed. In this chapter the WiMAX network, wireless channels, OFDM, modulation techniques, antenna systems, quality of service and demographic nature of the route will be discussed.

2.1 Overview of Wireless Mobile Broadband Communication System

In telecommunication, broadband is a wide bandwidth data transmission with an ability to simultaneously transport multiple signals and traffic types. The medium can be coaxial cable, optical fiber, radio or twisted pair [21]. IEEE802.16d, IEEE802.16e and IEEE802.16m are some of broadband mobile communication systems. Among these, this thesis work mainly focus on wireless Mobile broadband radio network specifically on IEEE802.16e or WiMAX (**W**orldwide **I**nteroperability for **M**icrowave **Acc**ess) network.

Broadband Wireless Digital Access particularly WiMAX Support, high mobility support, high data rate support, low latency, end-to-end, advance security scheme, scalability, extensibility, coverage, operate at unlicensed and licensed exempt frequencies [15].

One of the major driving forces for the wide acceptance of WiMAX is the interoperability of different solutions for broadband wireless network provided by a WiMAX Forum. The WiMAX Forum is an industry led, non-profit organization formed to certify and promote the compatibility and interoperability of broadband wireless products based upon the harmonized IEEE 802.16 standard. It brings together vendors and equipment manufacturers of communications networks enabling equipment to interwork and thus driving down cost to operators. WiMAX offers an alternative access to the Internet with a ubiquitous access to high quality voice, data, video and streaming video services. It is an affordable and easy to access means compared to already existing broadband access technologies such as cable, DSL, and T1 lines [2].

2.2 WiMAX Network

Air interface standards for such broadband wireless metropolitan area network (MAN) systems in licensed and unlicensed bands below 11 GHz are being developed by the IEEE 802.16 working group and also by the European Telecommunications Standards Institute (ETSI) Broadband Radio Access Network (BRAN) High-Performance MAN (HiperMAN) group. Such systems, installed with minimal labor costs, may operate over non-line of-sight (NLOS) links.

Mobile broadband communications have been extensively developed for terrestrial transportation to respond to the increasing traffic of online multimedia, gaming, mobile application downloading. However, without changes, those mobile communication technologies may not be suitable for the needs of data intensive communications for high speed train passengers, since the relevant moving speeds are much higher and more challenging for communication designs.

Wireless communication systems have been developing and evolving in a furious pace in these recent years. The number of mobile subscribers is growing tremendously in the past decades. The early wireless systems consisted of a base station with a high-power transmitter which serves a large geographic area. Each base station could serve only a small number of users and was costly as well. Today, due to the advancement in technology, the cellular system consists of a cluster of base stations with low-power radio transmitters. Now the total number of users served is increased because of channel reuse and larger frequency bandwidth.

Although traditionally narrowband technologies have supported signaling and control systems but broadband communication system have extra feature. Some of them are listed below [15]

- Real-time access from the control center to on-board telemetry information
- Optimal train operation (golden run), optimize energy consumption (green concern)
- On-route information about the proximity of other trains, their route, speeds, etc...
- Support for remote train approaches
- Visualization from the control center of the route ahead the train, any emergency situation and yard congestion status
- Video surveillance, including identification and detection in real time of misleading behaviors that may affect passenger safety

IEEE 802.16e or "mobile WiMAX" is a standard targeted for portable, mobile application as well as fixed and nomadic applications in NLOS environments. Mobile WIMAX extends the fixed WiMAX standard by giving users the ability to keep ongoing connections active while moving at vehicular speeds greater than 120km/hr [21].

It uses Orthogonal frequency division multiplexing (OFDM) physical layer technology and smart antenna techniques which make it strong and robust against the effects of multipath, i.e., frequency selective fading. The OFDM technique splits a radio signal into multiple small signals which are then transmitted simultaneously at different frequencies to the receiver. This combats frequency selective fading.

Also, in the context of multiple access techniques, the use of OFDM allows large amount of data to be transmitted over the spectrum with greater efficiency than existing techniques such as time division multiple access (TDMA) and code division multiple access (CDMA) which are commonly in 2G network.

2.2.1 Wireless Channel Overview

All wireless digital communication systems must possess a few key building blocks, as shown in Figure 2. 1. The transmitter receives packets of bits from a higher protocol layer and sends those bits as electromagnetic waves toward the receiver. The key steps in the digital domain are encoding and modulation. The encoder generally adds redundancy that will allow error correction at the receiver. The modulator prepares the digital signal for the wireless channel and may comprise a number of operations. The modulated digital signal is converted into a representative analog waveform by a digital-to-analog convertor (DAC) and then up converted to one of the desired WiMAX radio frequency (RF) bands. This RF signal is then radiated as electromagnetic waves by a suitable antenna.

The receiver performs essentially the reverse of these operations. After down converting the received RF signal and filtering out signals at other frequencies, the resulting baseband signal is converted to a digital signal by an analog-to-digital convertor (ADC). This digital signal can then be demodulated and decoded with energy and space-efficient integrated circuits to, ideally, reproduce the original bit stream.

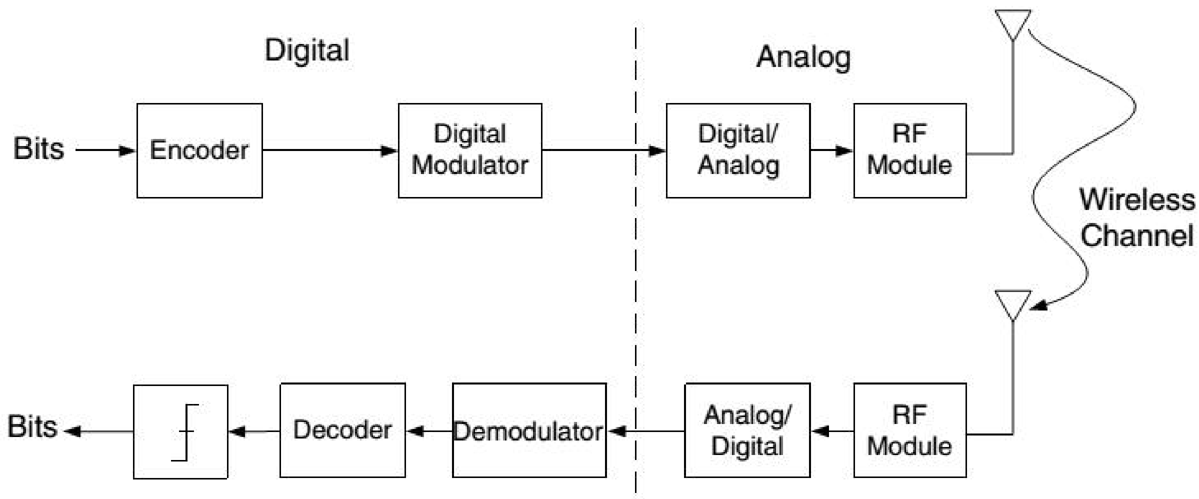


Figure 2. 1: Wireless digital communication system [22]

Wireless networks, as opposed to a wired network, can be grossly affected by pathloss, shadowing and fading. Pathloss refers to the reduction of the energy between transmitter and receiver that are located at a certain distance away from each other. Pathloss is dependent on the propagation environment. There are different formulas (propagation models) suggested for pathloss calculation in different urban, suburban and rural environments (see **Chapter Four** for detailed). Pathloss calculations are essential in determining the coverage area of a given wireless network.

Shadowing can be caused by obstacles that are located between transmitter and receiver that can affect the received power. In other words, any changes in the amount of received power in both decreasing or increasing way, for example absorption or diffraction caused by a building or a temporary LOS transmission path, is referred to as shadowing [23].

Multipath fading is caused by the reception of multiple versions of the same signal at the receiver. These multiple versions are referred to as multipath and may arrive out of phase with one another. Moreover, the multipath components may arrive at different time instants at the receiver. If the delay is comparable to the symbol duration of the signal, it leads to inter symbol interference (ISI) among the different versions of the same signal. In such a case, the multipath channel becomes frequency selective.

In frequency selective fading channels the OFDM comes in handy, to mitigate the effects of multipath fading (frequency selective fading). OFDM uses several lower rate subcarriers instead of a single carrier that occupies the entire band. This technique allows the increase in symbol duration by splitting the available data rate among several subcarriers. Therefore the relative delay will no longer be comparable to the symbol duration of our signal and ISI is consequently mitigated [22].

2.2.2 Orthogonal Frequency Division Multiplexing (OFDM)

Orthogonal Frequency Division Multiple Access [OFDMA] is a multiple access scheme that provides multiplexing operation of data streams from multiple users onto the downlink sub-9 channels and uplink multiple access by means of uplink sub-channels. OFDMA is an updated version of OFDM [31]. Previous OFDM systems, such as DSL, 802.11a/g, and the earlier versions of 802.16/WiMAX, use single-user OFDM: All the subcarriers are used by a single user at a time. WiMAX (802.16e-2005) takes a different approach, known as orthogonal frequency division multiple access (OFDMA), whereby users share subcarriers *and* time slots [19].

Essentially OFDMA is a combination of two multiple access strategies: TDMA and frequency division multiple access (FDMA). TDMA refers to the mechanism where each user is allocated a unique time slot to transmit. FDMA refers to the access policy when each user receives a unique carrier frequency and bandwidth [3].

Multiuser diversity and adaptive modulation and coding (AMC) are the two most important techniques in OFDMA to achieve higher performance. The objective of multiuser diversity is to select subcarriers with the highest signal-to-noise ratio (SNR). The objective of AMC is to select the appropriate modulation scheme under a specific environment [3].

OFDM also serves the added purpose of saving bandwidth as there is no need for guard intervals and the subcarriers are allowed to overlap as long as they remain mathematically orthogonal to one another. The synergetic nature of OFDM also allows us to use it in conjunction with other technologies such as multiple antenna system, CDMA and the like [24].

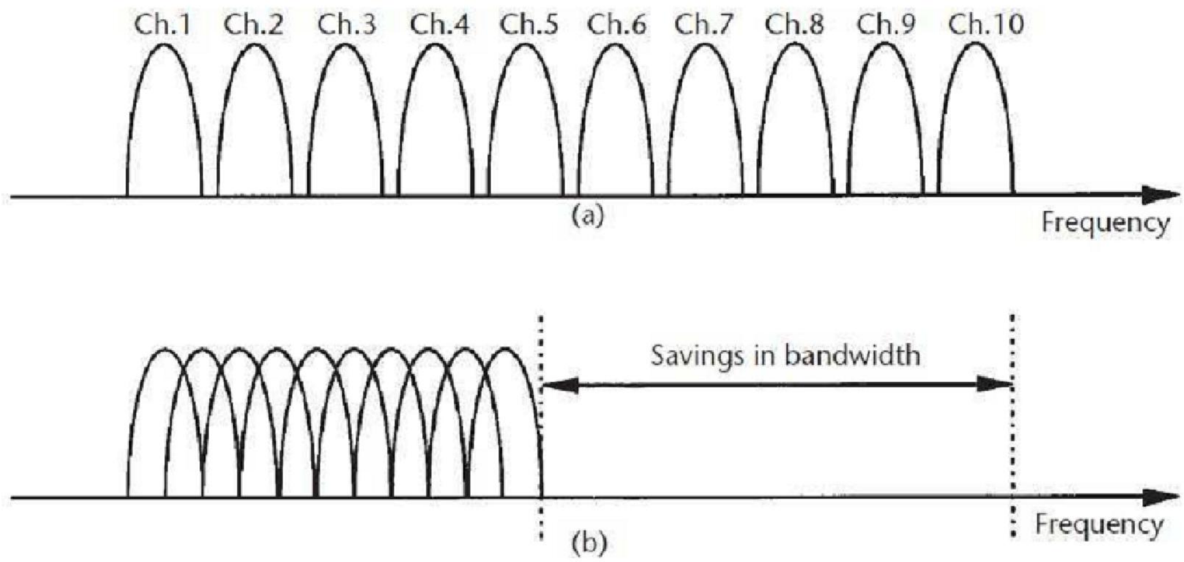


Figure 2. 2: a) Classical FDM carrier spacing b) OFDM subcarrier spacing [24]

2.2.3 Adaptive Modulation and Coding

WiMAX supports a variety of modulation and coding schemes and allows for the schemes to change on a burst-by-burst basis per link, depending on channel conditions. Using the channel quality feedback indicator, for the uplink case, the mobile can provide the base station with feedback on the downlink channel quality. The base station accordingly assigns the highest modulation order that can be supported in the aforementioned channel quality.

The base station can estimate the channel quality, based on the received signal quality. The base station scheduler can take into account the channel quality of each user's uplink and downlink and assign a modulation and coding scheme that maximizes the throughput for the available signal-to-noise ratio (SNR) that indicates the channel quality. For a specific coding or modulation scheme, the SNR determines the corresponding bit error rate (BER), AMC allows for the selection of the highest order modulation and coding without exceeding the maximum allowable BER needed to maintain a pre-defined quality of service.

Adaptive modulation and coding significantly increases the overall system capacity, as it allows real-time trade-off between throughput and robustness on each link. As we increase our throughput via a higher order modulation, the robustness of the signal decreases due to increased bit error rate (BER). AMC strives to achieve the highest supportable coding and modulation order while maintaining the minimum acceptable link quality in terms of BER. In the downlink, QPSK, 16-QAM, and 64-QAM are mandatory for both fixed and mobile WiMAX. 64-QAM is optional in the uplink [25].

Forward error correction (FEC) coding using convolutional codes is mandatory. The standard optionally supports turbo codes and low-density parity check (LDPC) codes at a variety of code rates as well. A total of 52 combinations of modulation and coding schemes are defined in WiMAX as profiles [19].

2.2.4 Multiple Antenna Systems

WiMAX technology offers a range of smart antenna technologies that improve the system performance and enhance both coverage and channel throughput. Mobile WiMAX also supports MIMO antenna solutions that offer advantages such as increasing the system reliability, increasing the achievable data rates, increasing the coverage area and decreasing the transmit power.

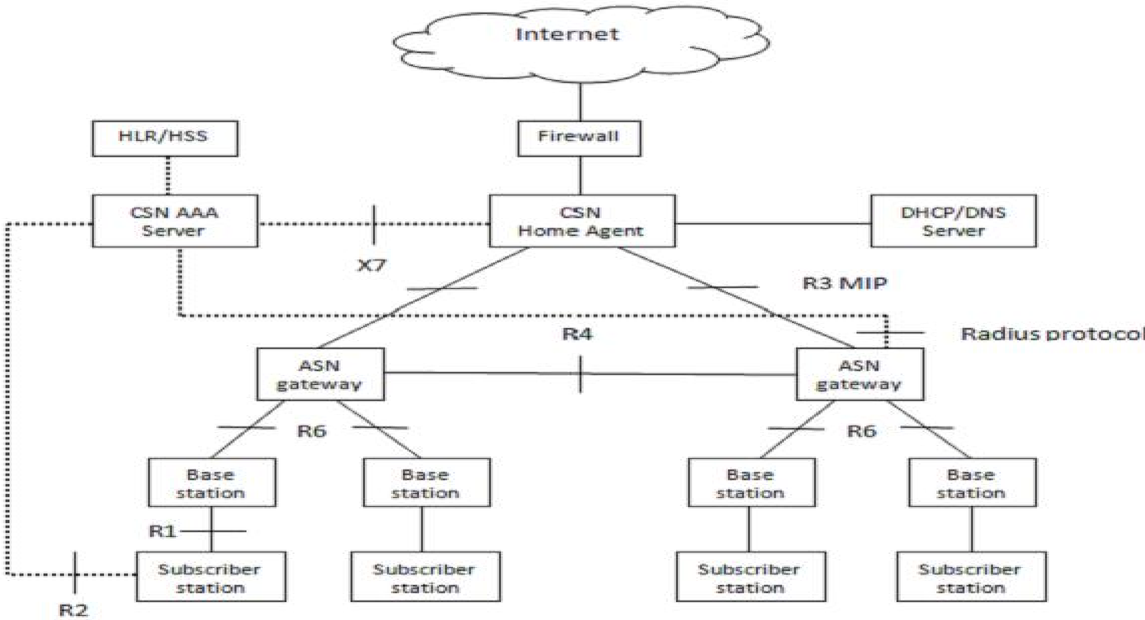
Multiple input multiple output (MIMO) techniques that are supported by WiMAX include 1×2 SIMO and 2 × 2 MIMO. 1 × 2 SIMO scheme uses one transmit antenna and two receive antennas, while 2 × 2 MIMO scheme uses two transmit antennas and two receive antennas at the base station [2].

With spatial multiplexing each of the base station transmit antennas send a different downlink data stream. This technique, theoretically, has the potential to double the downlink capacity.

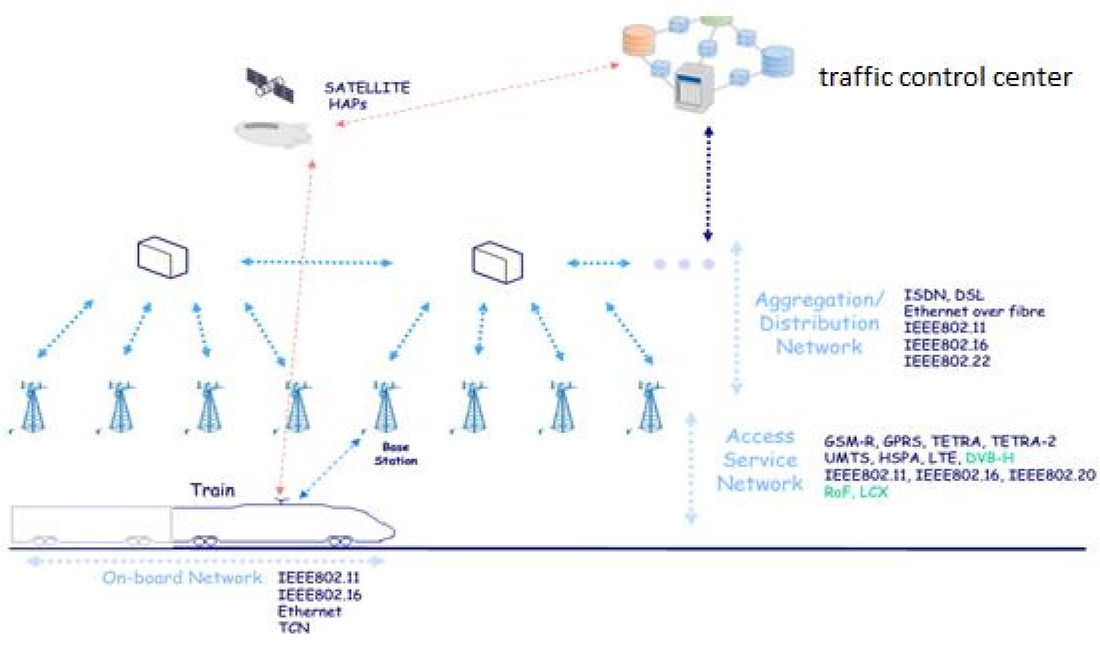
2.3 WiMAX Network Architecture

WiMAX Forum has developed a standard network reference model (NRM) which is shown in Figure 2. 3 (a). The NRM consists of the entities Mobile Station (MS)/Subscriber Station (SS), Base station (BS), Access service network (ASN) and Connectivity Service Network (CSN).

The ASN defines the logical boundary for functional interoperability with WiMAX clients, connectivity service functions and aggregation of functions embodied by different vendors. ASN deals with the message flows associated with the access services. ASN also provides an IP packet delivery service between WiMAX subscribers and the CSN. The ASN connects base stations to the WiMAX ASN gateway using transport networks such as microwave, copper or fiber links. The WiMAX ASN gateway also provides connectivity to the Internet through Home agent (HA) or a routing device [2].



(a)



(b)

Figure 2. 3: WiMAX network architecture (Network Reference Model) [2] & [15]: a & b

The CSN provides a set of networking functions that enable IP connectivity services to the WiMAX subscribers. The CSN is also responsible for the switching and routing of calls and data connections to external networks. It comprises of network elements such as routers, Authentication, Authorization and Accounting (AAA) servers, user databases and Interworking gateway devices [2].

The reference points R1-R6 connect the aforementioned entities. R1 is the interface between the MS and ASN. It implements air interface (IEEE 802.16e) specifications. Whereas R2 is the interface between the MS and CSN. It is a logical interface that is used for the authentication, authorization, IP host configuration management, and mobility management. R3 is the interface between the ASN and CSN. It is responsible for methods to transfer IP data between ASN and CSN. R4 is a set of control and bearer plane protocols originating or terminating in various entities within the ASN that coordinates MS mobility between the ASNs. R5 is also a set of control and bearer plane protocols for interworking between the home and visited network [2].

2.3.1 Quality of Service (QoS)

The IEEE 802.16 standard supports up to five QoS classes which are described as follow [2]

- **Unsolicited Grant Service (UGS):** This is designed to support real-time data streams that consist of fixed sized packets issued at periodic intervals, such as backhaul and voice over IP (VoIP) without silence suppression.
- **Extended Real-Time Polling Service (Ert-PS):** This is designed for the extended real-time services of variable rates such as VoIP with silence suppression, interactive gaming and video telephony.
- **Real-Time Polling Service (Rt-PS):** This is designed to support real-time data streams of variable rates that are issued at periodic intervals, such as MPEG video, audio and video streaming, and interactive gaming.
- **Non Real-Time Polling Service (Nrt-PS):** This is designed to support delay-tolerant data streams consisting of variable-sized data packets such as file transfer protocol (FTP), browsing, video download, and video on demand.
- **Best Effort (BE):** This is designed to support data streams for which there is no minimum service requirements, and no guarantee of timely delivery of packets such as E-mail and Internet browsing.

2.4 Description of Route

2.1.1 Addis Ababa to Djibouti Railway Rout

Sebeta to Djibouti Located in the mountain areas between the central plateaus of Ethiopia and Djibouti plateau, the line originates westward from SEBETA at southwest of Addis Ababa, runs eastward through LABU, INDODE, GELAN, DUKEM, BISHOFTU, MOJO, ADAMA, WELENCHITI, METEHARA, AWASH, ASEBOT, MIESO, MULU, AFDEM, BIKE, GOTA, DIRE DAWA to DEWELE, reaches

DJIBOUTI, then passes GUELILE and HOLHOL, and finally ends at NAGAD. The total length is 743.245km.

The line is an electrified railway designed for both passenger and freight trains. The design speed for passenger trains equals or is less than 120km/h and that of freight trains equals or is less than 80km/h. The section from SEBETTA (ADDIS) ~ ADAMA is double track railway, and the section from ADAMA ~ NAGAD is single track railway.

Ethiopia sets up a railway company in Addis Ababa (LABU) to manage the operation of SEBETA ~ DEWELE (included) section and coordination with Djibouti railway. Djibouti sets up a railway company to manage the operation of DEWELE (excluded) ~ NAGAD section and railway inside the port area [9].

2.2.2 Geological Description of the Route Nature

2.2.2.1 Sebeta~Mieso Section

The area that the line goes through belongs to the landform of the Ethiopian plateau platform, Low Mountain and shallow hill. The ground is wide, the topographical relief is not great, and part of the zone has low Mountain and river valley landform. The elevation of road surface is about 850~2300m, the relative elevation difference is scores of meters, and the traffic condition is relatively poor. Due to perennial scouring and undercutting of seasonal flood, the surface-incised dry gullies can be seen, which has a width of 2~5m, depth of 3~12m and length of hundreds kilometers. Both sides of the trench wall are almost vertical sidewalls and the bottom of the trench is mainly sandy soil.

2.2.2.2 Mieso ~Dewele Section

This section of the line belongs to the Ethiopian plateau platform and shallow hill landform. Part of the zone has low mountain and river valley landform, the ground is wide and the topographical relief is not great, The elevation of road surface is about 700~1200m, and the relative elevation difference is scores of meters. The climate is hot and the surface tropical plants is scarce with coverage of approximately 10% to 30%. There is dry riverbed. Bulk Gobi phenomenon can be seen with few roads and poor traffic conditions

2.2.3 Main Technical Standards

Scope	SEBETA~ADAMA (included)	ADAMA~MIESO	MIESO~DJIBOUTI PORT
Track Gauge	1435mm	1435mm	1435mm
Speed Target Value	Passenger Transport 120km/h; Freight Transport 70km/h	Passenger Transport 120km/h; Freight Transport 70km/h	Passenger Transport 120km/h; Freight Transport 70km/h
Minimum Radius of Curve	800m	800m	800m
Type of Traction	Electric Traction	Electric Traction	Electric Traction
Tractive Tonnage	Preliminary 3500T、Long-term 4000T	Preliminary 3500T、Long-term 4000T	Preliminary 3500T Long-term 4000T
Length of Arrival-departure Track	850m(Dual-locomotive 880m)	850m(Dual-locomotive 880m)	850m(Dual-locomotive 880m)
Distance between Centers of Tracks	4.0m	/	/
Block Type	Semi-automatic Block	Semi-automatic Block	Semi-automatic Block

Table 2. 1: Main technical standard of Ethio-Djibouti railway route

2.2.4 Overview of Station Distribution

The length of the whole international railway line from SEBETTA～NAGAD is 743.245km. The section from SEBETTA～ADAMA (included) is double track railway, with a length of 113.836km, 7 stations, and an average distance between two stations 16.26km. The section from ADAMA （excluded）～MIESO included） is single track railway, with a length of 213.418km, 12 stations, and an average distance between two stations 17.78km. The section from MIESO（excluded）～DEWELE（included） is single track railway, with a length of 334.014km, 21 stations, and an average distance between two stations 15.91km. The section from DEWELE（excluded）～NAGAD（included）in single track railway, with a length of 81.977km, 5 stations, an average distance between two stations 16.4km.

In the study, LABU Station is set as passenger station to meet the passenger transportation demand in the capital. INDODE Station is set as the technical station for freight trains, taking charge of the arrival-departure operation of cargoes in the capital and de-marshaling of freight trains to facilitate the technical operation of freight transportation. In initial stage, the following stations will have passenger transport operations: SEBETA, LABU, BISHOFTU, MOJO, ADAMA, AWASH, MIESO, DIRE DAWA, DEWELE, ALISABIEH, HOLHOL, NAGAD. (The other stations can choose to start freight transportation as appropriate based on the increase of transportation demand after the railway is put into operation.) In initial stage, the following stations will not have freight operation tentatively: FETO, METEHARA, AWASH, SIRBA KUNKUR, BIKE. (The five stations can choose to start freight transportation as appropriate based on the increase of transportation demand after the railway is put into operation.)

2.2.5 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 forecast of Ethiopian railway corporation freight and passenger trains are shown in the following table for each term stages.

Terms/stages	sections	Pair of trains per day (train/day)				Required passing capacity
		Passenger trains	Freight trains	Pickup & drop trains	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. 2: Number of pair trains per day on Addis Ababa to Djibouti railway line [12]

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 [9]. 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 [13].The total number of personnel will be hired in the whole line is accounted in Table 2. 3. 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
3	Personnel of all stations in total	403
4	Dispatching center staff (in Labu)	63
Total		536

Table 2. 3: Total personnel of the whole line

Chapter Three

3. Comparisons between Available Wireless Communication Systems and Wimax Network

In general this chapter will presents the comparison of WiMAX with the other broadband wireless technologies and GSM-R which used widely in railway lines all over the world, and it will be shows that WiMAX offers significant advantages when it comes to deployment. Also Since the target for a broadband wireless technology is to offer high data rates, the comparison deal with WiMAX is a better choice for that purpose than 3G and Wi-Fi, as well as GSM-R which is deployed in many countries of world.

3.1 Overview and Weakness of the Current Communication Architecture of the Route

Track circuit system is deployed for train control and signaling purpose along the selected railway corridor. SDH (Synchronous Digital Hierarchy) 2.5Gb/s (1+1) MSP main line layer transmission system and SDH 622Mb/s (1+1) MSP access layer transmission system are newly set throughout the line [8]. The access network shall have access to voice, data, images and etc. from stations along the line, transmission channel bandwidth of which varies from each other. Communication interfaces include audio, low-speed data, 2Mb/s and etc.

The Project adopts ITU-T G.652.B1 single mode fiber. Working wave length of the main line layer transmission system is 1550nm, using STM-16 L-16.2U optical interface. Optical regenerative repeater range of main line layer transmission system is as shown in Table 3. 1, all exceeding 88.9m. Repeater range can be increased in the way of adding dispersion compensation and the alike.

1	LABU～ADAMA	98
2	ADAMA～METEHARA	103
3	METEHARA～MIESO	106

Table 3. 1: The table of repeater section and range of optical regeneration [8]

The Project adopts ITU-T G.652.B1 single mode fiber with 1310nm working wave length and STM-4 L-1.1 optical interface. Optical regenerative repeater range of access layer transmission system is as shown in Table 3. 2. Ultra-long repeater section can use tabula rasa of maximum average transmission power or L-4.2 optical interface to increase its range.

S/N	Optical regenerative repeater section	Optical regenerative repeater range (km)
1	SEBETA～LABU	13.521
2	LABU～INDODE	18.9
3	INDODE～BISHOFTU	33.5
4	BISHOFTU～MOJO	23.45
5	MOJO～ADAMA	22.221
6	ADAMA～153 traction substation	40.03
7	153 traction substation ～ METEHARA	63.738
8	METEHARA～AWASH	29.128
9	AWASH～MIESO	31.9

Table 3. 2: The table of repeater section and range of optical regeneration

SDH (Synchronous Digital Hierarchy) is the most mature mainstream technology in the field of transmission network at present. The communication bearer network built based on the SDH technology-oriented multi-service transmission platform (MSTP) can provide various real-time and transparent TDM private line service, and achieve the full compatibility with various TDM-based basic communication service systems of the line. In addition, the IP transmission function of MSTP can also be used as the bearing platform of IP data network of this line in future.

SDH technology distinguishes itself by quite mature and perfect support for TDM services and the provision of connection-based private line service, and is regarded to be flawed for the low transmission efficiency of IP data service and the failure to allocate the bandwidth according to needs. However, the multi-service transmission platform (MSTP) of SDH can be used as the reliable basic transmission platform for ATM/IP data service. 97 types of 25Hz phase detecting track circuits will be used in the stations and nearby sections [8].

The nature of the current communication system discussed in detail in previous paragraphs. The expected limitation of the communication and GSM-R system will be discussed in detail as follow.

As discussed previously in main technical standard of Addis Ababa to Djibouti railway line, the speed of passenger and freight trains are 120km/h and 70km/h respectively. Such high mobility needs precise control system in order to monitor the speed and position of the train from control center or remote. If not, the accident of train will be fatal. So it needs a communication system which have a good handover scheme. However too frequent handover failure is the main problem in GSM-R.

For a being of a time, for freight and passengers 38 and 22 trains are assigned respectively. This figures clearly shows that there is a huge number of people are moving along this line. The selected railway route covers 661.245km. Such a long journey become very boring without acquiring different types of entertainments. Attaining wide band width is also another problem of GSM-R. Till GSM-R cannot address passengers demands such as social network, online gaming and video download while travelling.

Semi-automatic block system is proposed for the purpose of train control system in Addis Ababa to Djibouti railway line. In order to increase train availability, robustness, reliability and decrease human labor and operation cost automatic block system is the best choice. By using narrow band communication system such as GSM-R and track circuit deploying automatic block system is very difficult due to its small capacity.

Track circuit system which is deployed in Addis Ababa to Djibouti railway line has a lot of limitation. The main are:-

- Malfunctioning in bad whether
- Not easy for remote maintenance
- Less reliability and availability of train

Mass transit operators are facing massive challenges while overcoming increasing traffic, ensuring passenger safety and security, improving travel comfort, and providing real-time multimedia information and access to social networks. All those problems are widely visible in current communication system of Addis Ababa to Djibouti railway line.

In General GSM-R has the following limitation:-

GSM-R is derived from GSM (2G+) technology and part of the new European Rail Traffic Management System (ERTMS) standard. GSM-R is widely deployed communication system all over world. However it have a lot of limitations some are listed as follow;

- GSM-R is a 2G communication system [15]
    - Transmission data rate just 9.6 kbps Even considering immediate GSM-R evolution (HSCSD, GPRS, EDGE..) difficult to reach emerging and future railway communication services
- Limited frequency availability

    - Current deployments present limitations for offering available traffic channels for high priority connections (ETCS services) at borders and congested crossing or busy junctions
- GSM-R deployments unaffordable or unsustainable for emerging countries, secondary or low density lines.
- Unwanted emission coming from the public base stations (GSM, UMTS900, LTE900) which may leak into the GSM-R band and therefore raise the noise floor.
- Cumulated interferences signal level, due to high transmitting levels from public transmitters. All of the above, in combination with future systems installations close to railway lines without coordination, will cause severe interference to the GSM-R communications on railways lines [30].

3.2 WiMAX vs Wi-Fi

The major notable difference between Wi-Fi and WiMAX networks is the coverage area. While Wi-Fi covers a region of up to 300 meters, WiMAX can cover the region of up to 48 kms under NLOS and LOS conditions. Therefore, when it turns to covering large metropolitan area, Wi-Fi network requires an operator to deploy more number of base stations than WiMAX network. This means that it is more costly using Wi-Fi network to provide broadband wireless services that spans over a large area [2].

Wi-Fi supports fewer users per base station, typically one to ten users with a fixed channel size of 20MHz per base station. WiMAX on the other hand supports one to five hundred users per base station with variable channel size of 1.5MHz to 20MHz [3].

WiMAX uses both licensed and unlicensed spectrum whereas Wi-Fi uses only unlicensed spectrum. Operating in the licensed band means WiMAX has the ability to cover long distances and support more number of users by using sub-channelization [2].

3.3 WiMAX vs 3G and HSPA

Both technologies will converge to provide almost the same set of capabilities and services. WiMAX provides high data rates (up to 72Mbps) but provides less mobility. On the other hand, 3G provides smaller data rates (from 384kbps to 3Mbps) than WiMAX but provides users with seamless mobility using existing and evolved cellular mobility protocols and handover mechanisms [2].

Another notable key difference between WiMAX and 3G is the fact that 3G technologies such as HSPA have been the evolution of the existing GSM technology that only require software upgrade, while for the case of WiMAX the whole network has to be built from scratch. The fact that WiMAX requires green field implementation has a consequence on time and cost when deploying the network as compared to the 3G network [2]. 3G systems have fixed channel bandwidth while WiMAX has scalable channel bandwidth from 1.25MHz to 20MHz that allows for a very flexible deployment and high throughput capabilities. Table 3. 3 compares the WiMAX and 3G based upon the indicated performance metrics [2].

	WiMAX	HSPA
Initial downlink data rate (max)	23Mbps	14.4Mbps
Initial uplink data rate (max)	4Mbps	384kbps
Evolved downlink data rate (max)	46Mbps	28Mbps
Evolved uplink data rate (max)	4Mbps	11Mbps
Latency	50ms	100ms
Spectrum	2.5, 3.5GHz (licensed bands); 2.4, 5.8GHz (unlicensed band)	850MHz to 2,600 MHz
QoS	Supports five QoS classes	Supports four QoS classes
Mobility	support Limited mobility; based on mobile IP protocol for mobility management	Seamless mobility
Security	Based on certificates or EAP	SIM-based security
Service set-up time	50ms	2sec reducing to 0.6sec
Link adaptation	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM 64 QAM
Duplex scheme	FDD, TDD	FDD

Table 3. 3: Technical comparison of HSPA and WiMAX [2]

The other major difference between WiMAX and 3G mobile systems is that a user in WiMAX transmits in a sub channel and therefore does not occupy an entire channel. This is due to the fact that WiMAX is based on the OFDM and OFDMA technologies that divides a single channel into sub-channels. The sub channels allow users to transmit using only a fraction of the bandwidth allocated by the base station [2]. Due to this reason WiMAX is more flexible and have better capacity than 3G and HSPA.

3.4 Key Advantages of Mobile Broadband Network (IEEE802.16e)

Mobile WiMAX systems offer scalability in both radio access technology and network architecture, thus providing a great deal of flexibility in network deployment options and service offerings. Some of the salient features supported by Mobile WiMAX are [4]:

- **High Data Rates:** The inclusion of MIMO antenna techniques along with flexible sub-channelization schemes, Advanced Coding and Modulation all enable the Mobile WiMAX technology to support peak DL data rates up to 63 Mbps per sector and peak UL data rates up to 28 Mbps per sector in a 10 MHz channel.
- **Quality of Service (QoS):** The fundamental premise of the IEEE 802.16 MAC architecture is QoS. It defines Service Flows which can map to DiffServ code points or MPLS flow labels that enable end-to-end IP based QoS. Additionally, sub channelization and MAP-based signaling schemes provide a flexible mechanism for optimal scheduling of space, frequency and time resources over the air interface on a frame-by-frame basis.
- **Scalability**: Despite an increasingly globalized economy, spectrum resources for wireless broadband worldwide are still quite disparate in its allocations. Mobile WiMAX technology therefore, is designed to be able to scale to work in different channelization from 1.25 to 20 MHz to comply with varied worldwide requirements as efforts proceed to achieve spectrum harmonization in the longer term. This also allows diverse economies to realize the multi-faceted benefits of the Mobile WiMAX technology for their specific geographic needs such as providing affordable internet access in rural settings versus enhancing the capacity of mobile broadband access in metro and suburban areas.
- **Security:** The features provided for Mobile WiMAX security aspects are best in class with EAP-based authentication, AES-CCM-based authenticated encryption, and CMAC and HMAC based control message protection schemes. Support for a diverse set of user credentials exists including; SIM/USIM cards, Smart Cards, Digital Certificates, and Username/Password schemes based on the relevant EAP methods for the credential type.
- **Mobility:** Mobile WiMAX supports optimized handover schemes with latencies less than 50 milliseconds to ensure real-time applications such as VoIP perform without service degradation. Flexible key management schemes assure that security is maintained during handover [4].
- **IP-based architecture:** The WiMAX Forum has defined a reference network architecture that is based on an all-IP platform. All end-to-end services are delivered over an IP architecture relying on IP-based protocols for end-to-end transport, QoS, session management, security, and mobility.

Reliance on IP allows WiMAX the declining cost of IP processing, facilitate easy convergence with other networks, and use the application development that exists for IP [15].

- **Support for advanced antenna techniques:** The WiMAX solution allows for the use of multiple-antenna techniques, such as beamforming, space-time coding, and spatial multiplexing. These schemes can be used to improve the overall system capacity and spectral efficiency by deploying multiple antennas at the transmitter and/or the receiver.
- **Adaptive modulation and coding (AMC):** WiMAX supports a number of modulation and forward error correction (FEC) coding schemes and allows the schemes to be changed on a per user and per frame basis, based on channel conditions [15]. AMC is an effective mechanism to maximize throughput in a time-varying channel. The adaptation algorithm typically calls for the use of the highest modulation and coding scheme that can be supported by the signal-to-noise and interference ratio (SNIR) at the receiver such that each user is provided with the highest possible data rate that can be supported in their respective links.
- **Link-layer retransmissions:** For connections that require enhanced reliability, WiMAX supports automatic retransmission requests (ARQ) at the link layer [15]. ARQ enabled connections require each transmitted packet to be acknowledged by the receiver. Unacknowledged packets are assumed to be lost and are retransmitted. WiMAX also optionally supports hybrid-ARQ, which is an effective hybrid between FEC and ARQ.
- **Support for TDD and FDD:** IEEE 802.16-2004 and IEEE 802.16e-2005 support both time division duplexing (TDD) and frequency division duplexing (FDD), as well as a half-duplex FDD, which allows for a low-cost system implementation [15]. TDD is favored by a majority of implementations because of its advantages that include; (i) flexibility in choosing uplink-to-downlink data rate ratios, (ii) ability to exploit channel reciprocity, (iii) ability to implement in non-paired spectrum, and (IV) less complex transceiver design (see Section 4.5 for details).
- **Flexible and dynamic per user resource allocation:** Both uplink and downlink resource/capacity allocation are controlled by a scheduler in the base station. Capacity is shared among multiple users on a demand basis, using a burst TDM scheme. Multiplexing is additionally done in the frequency domain, by allocating different subsets of OFDM subcarriers to different users. Resources may be allocated in the spatial domain as well when using the optional advanced antenna systems (AAS). The standard allows for bandwidth resources to be allocated in time, frequency, and space [15].

In General, WiMAX offers significant advantages when it comes to deployment. For a given route selected for the deployment, WiMAX allows an operator to select a channel bandwidth from 1.25MHz to 20MHz. This gives the operator some flexibility during the deployment where he can select the appropriate channel bandwidth to serve the targeted services segment. Since the target for a broadband wireless technology is to offer high data rates, WiMAX is a better choice for that purpose than 3G and Wi-Fi, as it relies on OFDM and OFDMA technologies [2]. Although Wi-Fi also uses OFDM technology, it is faced with limited mobility.

WiMAX technology incorporated MIMO techniques during its initial design phase, providing it with higher spectral efficiency than 3G systems. 3G systems are implementing MIMO techniques in phases leading into low spectral efficiency. For a multicellular deployment, OFDM physical layer technology used by WiMAX gives it an advantage to exploit frequency and multiuser diversity to improve capacity [2].

3.5 Future applications capacity demand

Broadband communication system can increases the revenue and brand image of the company (ERC) and add extra features. Some of those are [15]:-

- ✓ Train position and speed
- ✓ Time table/Delay /connection
- ✓ Train allocation
- ✓ Arrival time

Travel info
- Route planers
- Traffic problems
- Telemedicine
- Booking (Hotel/car/Taxi)

Now a days
- Ticketing

Future
- Seat reservation
- National/International Ticketing
- Crew message
- Security
- External control messages
- Telemedicine
- others………..

In order to attain those services, the deployment of WiMAX technology is the best choice for selected route in order to gain all those services listed above. So, in next chapter the dimensioning of WiMAX will discussed in detail.

Chapter Four

4 WiMAX Network Deployment: The case of Addis Ababa to Djibouti Railway line

4.1 Dimensioning Mobile WiMAX

Planning of a wireless network usually involves a number of steps that are essential for a successful deployment. The first step is to define the geographic area along the route where the service is expected to be offered. Key metrics used to specify the geographic area are number of vehicles, number of customers, and the terrain type of the route which is studied in detail in chapter two.

The next step is to determine the spectrum and bandwidth to be used. From the available frequency bands specified by the standard (such as 2.5GHz and 3.5GHz), the selection of either of the frequency band determines the total bandwidth achievable. Depending upon the frequency band chosen, we can decide whether to use channel bandwidth of 1.25MHz, 1.75MHz, 3.5MHz, 5MHz, 8.75MHz, 10MHz, 14MHz or 20MHz.

The steps that will follow involve determining the parameters to calculate range and capacity. These Parameters include link budget, spectral efficiency, antenna configurations (SIMO, MIMO), frequency reuse factor which altogether control the coverage area per cell site and the total number of cell sites or base stations needed to cover the desired geographic area.

WiMAX network planning follows the flow of activities as presented in Figure 4. 1.

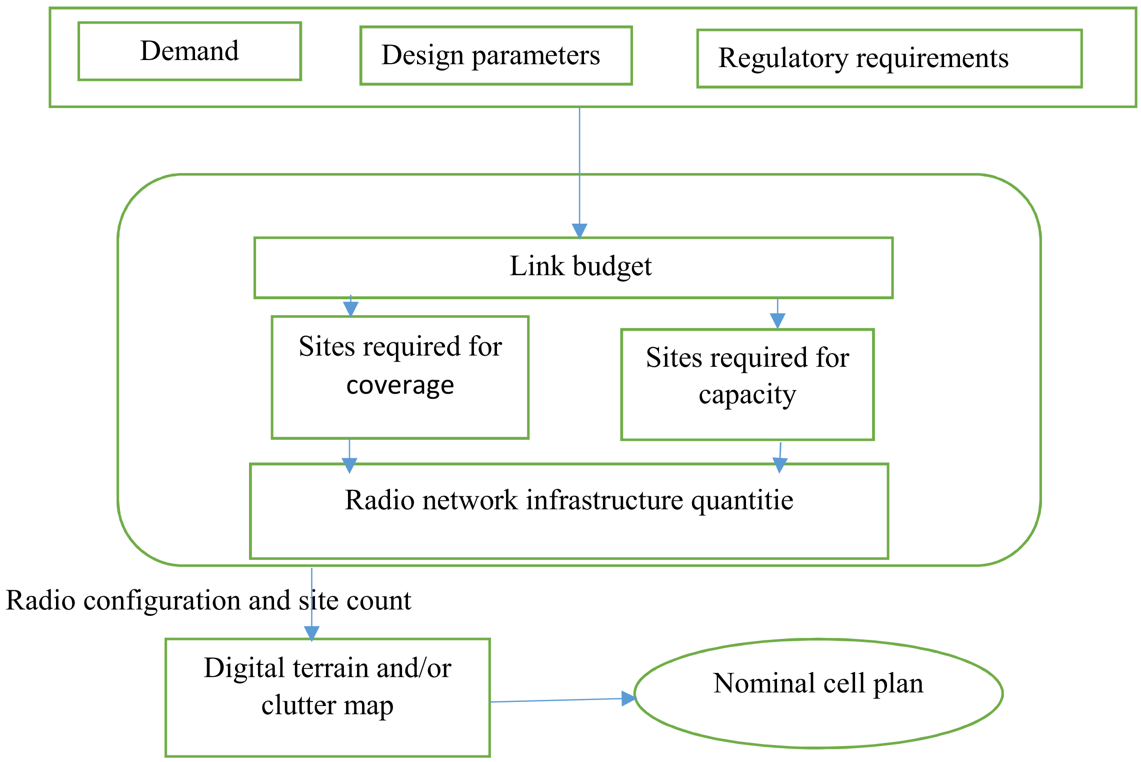


Figure 4. 1: Network dimensioning and planning process [11]

1.1 Coverage Planning

The target for the coverage planning is to find optimal locations for the base stations to build a continuous coverage according to the planning requirements. Coverage planning is performed with a planning tool that includes a digital map with topography information of a particular region. Propagation models that aid in determining the coverage area are then selected based on the planning parameters (frequency, base station antenna height and so on). The overall coverage prediction is then determined based upon the combination of the digital map information and the selected propagation model.

During this phase, the link budget analysis is performed that defines the maximum allowed path loss with certain configurations. Different parameters that constitute the link budget leads to the determination of the theoretical maximum cell size. The cell size or range leads to the determination of the coverage area with a certain location probability. Location probability is the probability of the receiver being able to capture the signal, that is, the signal level is higher than the receiver sensitivity.

The first step in coverage planning is to create a preliminary plan based upon the calculated number of base stations [3]. In this step, the theoretical locations of the BTSs are determined and the decision on whether to use Omni cells or sectored cells is made.

The next step is to find the actual location of the base stations. This task involves site acquisition team whose task is to determine proper locations where the sites can be located and the transmission requirements be fulfilled.

During coverage planning, ways for future enhancement of coverage are taken into consideration. To ensure sufficient coverage, base station power and antenna heights need to be considered and mechanical and electrical down tilts used when needed.

In achieving coverage in a selected corridor, several factors have to be taken into consideration such as buildings heights, terrain, building densities and so on. Mobile WiMAX can be deployed for coverage without regard to capacity requirements. This means at first, the minimum number of base stations are deployed to provide enough coverage in a particular area. Capacity is only increased whenever the need arises, and this can be done by adding more channels to the existing base stations assuming there is available spectrum or by decreasing cell size for better frequency re-use. This kind of technique is useful in situations where there are uncertainties [2].

4.2 Capacity Planning

Capacity planning is based on the coverage maps and traffic estimates obtained from the coverage planning. For a broadband service such as WiMAX, capacity planning involves anticipating how users will use the system and the demand they place on the system.

The metric that is used in determining the capacity planning is the data density expressed as Mbps per km^2. Given a certain demographics region, determining the required data density is a multi-step process involving classifying users of the systems on different categories. User categories depend on the load they place on the system in terms of usage. Various demands that are placed by the users on the system include browsing the web, e-mailing, VoIP, download or upload of video content (real time services), train controlling and signaling which altogether pose different requirements on the system.

Data density is used for matching the base station capacity to the selected railway line communication service requirements. Projected railway line services requirements determine the base station capacity requirements.

4.2.1 Estimation of Capacity Density

Data density estimation task starts by categorizing the expected customers within the target market segments as follows:

- **Professional users**: These are the business type of users who are most demanding in terms of broadband data usage. This type of users are assumed to be using the services in stationary, nomadic and mobile environments. The type of services that are perceived to be mostly used are file download, streaming media, video conferencing, and email [2]. In railway context professional users can be the one whose work is mainly concerned on safety issues. Some of those are Dispatchers, drivers, supervisors ……etc.
- **High end users**: These are type of users who use the services mostly for their personal use. They use the services on regular basis, and the dominant applications that they use the most are web browsing, gaming, music downloads, and so on. Passengers' on trains can be categorized in this group [2].
- **Casual users**: These are type of users who need access to use broadband services (web browsing, data oriented services) but are only connected few hours in a day. Passengers waiting trains in stations are assumed as casual users [2].

Assumptions made in our capacity density estimation are outlined in the following table. These assumptions were arbitrarily chosen in this case, and can be altered for the case of an actual deployment as the operator sees fit.

Description	**Assumption**
Customer mix	• 50% professional user
	• 30% high end user
	• 20% casual user

Table 4. 1: Assumptions made for capacity density estimation

The demographic data for the railway line from Addis Ababa to Djibouti previously discussed in detail in chapter two and also summarized as the following table. The data is taken from Ethiopian Railway Corporation (ERC) document which entitled as "feasibility study" document allows us to make sensible estimate of what the current demography of the Addis Ababa to Djibouti might looks like.

Demographics of the City of Addis Ababa	
Maximum expected number of personnel (passengers, employers of Ethiopian railway corp.) in 2016	725
Growth rate of personnel in the year of 2021	50%
Expected number of personnel of 2031	2441
Total numbers of yards, blocks, interlocking and station signaling systems	340
Total number of station	7
Number of train	60
Growth rate of number of train in the year of 2021	50%
Expected number of personnel of 2031	203
Distance between Addis Ababa to Djibouti	661.245km

Table 4. 2: Demographic data of Addis Ababa

There are (real-time) and non-vital (on-demand) communication systems in Railway communication network. Motor control, brake control, track signals, power electronics, GPS signals and related train commands and controls are with vital and hard real-time requirements. Audio and video passenger information, vehicle diagnostics that usually have soft or no real-time requirements and Class description Application type Bandwidth they are called non-vital 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 WIMAX radio network is listed in the following table.

Class description	Application type	Bandwidth	Transfer frequency
GPS	GPS	500bps	Every second
Train control and signaling	Signaling	250kbps	Every second
Interactive gaming	Interactive gaming	50 - 85 kbps	Event driven
VoIP, Video conferencing	VoIP	4 - 64 kbps	Event driven
	Video phone	32 - 384 kbps	Event driven
Streaming media	Music/Speech	5 - 128 kbps	Event driven
	Video clips	20-384kbps	Event driven
	Movies streaming	>2Mbps	Event driven
Information technology	Instant messaging, signaling and train control	<250 bps	Event driven
	Web browsing	>500 kbps	Event driven
	Email(with attachment)	>500 kbps	Event driven
Media content download (store and forward)	Bulk data, movie download	>1Mbps	Event driven
	peer-to-peer >	500 bps	Event driven

Table 4. 3: Information transfer of WiMAX network [2]

In above table the values of GPS and train signaling are assumed by author of this thesis work but the rest are taken from WiMAX standard.

800 kbps assigned to the professional user at the busiest hour of the day will allow him/her to download a 1Mb document within 10 seconds. The user will also be able to demand most of the services (apart from movie streaming, bulky data download, video surveillance and speed and position of trains) at a needed quality of service. It's also considering that these figures come into play only during the peak/busy hours of a day (i.e when the number of travelers is maximum and the number of train is more than two at a station)

and the data rate for the remainder of the time is much higher. The operator may choose to change these figures as per the need but that would also mean a change in data density requirement.

Type of customer	**Customer mix**	**Assigned PBH Data rate (minimum)**
Professional User	50%	800Kbps
High end user	20%	320Kbps
custom user	30%	200Kbps
Assumed Traffic Load		15%
Aggregate (Per User)		550kbps
Aggregate (for all expected of users)		1,454.200Mbps
Data density requirement		**2.1998Mbps/km**

Table 4. 4: Data density requirement

4.3 Carrier Frequency Band Selection

Unlike 2G/3G technologies, where the operating frequency is fairly defined, the WIMAX air interface is designed to operate over arrange of frequencies, both in the licensed band (2.5 to 2.69GHz) and in the unlicensed band (3.6 to 5.725GHz). The WIMAX Forum has identified several frequency bands for the initial 802.16 products. IEEE802.16 supports a variable channel bandwidth. The channel band width can be an integer multiple of 1.25MHz, 1.5MHz and 1.75MHz with maximum of 20 MHz. WIMAX support two mode of operation: FDD and TDD. In TDD the uplink and downlink can be asymmetrical, which means that the percentage of downlink sub frame to uplink sub frame of one frame can be decided according to the network's uplink/downlink capacity requirement [27].

Frequency band has a major consequence on the dimensioning and planning of the wireless network. The operator has to consider between the available frequency band and deploying area. 2.5 GHz band choose in this studies because it is widely used band all and it's low cost. 2.5GHz band operates in the frequency range 2.3 – 2.690GHz resulting into 390MHz of spectrum [2]. Bands of 300MHz or 390MHz are the total available spectrum that the regulator can allocate to all existing operators in a particular country. In this research work, it is assumed that the 300MHz spectrum is allocated to the operator in the region of Addis Ababa-Djibouti with a channel bandwidth 10MHz and a TDD duplexing scheme.

4.4 Modulation Technique

Modulation is the process by which a carrier wave is able to carry the message or digital signal (series of ones and zeroes). There are three basic methods to this: amplitude, frequency and phase shift keying. Higher orders of modulation allow us to encode more bits per symbol or period (time). Those methods are the concepts of digital modulation used in many communication systems today. Techniques described include quadrature phase shift keying (QPSK) and quadrature amplitude modulation (QAM) and how these techniques can be used to increase the capacity and speed of a wireless network. These modulation techniques are the basis of communications for systems like cable modems, DSL modems, CDMA, 3G, Wi-Fi* (IEEE 802.11) and WiMAX* (IEEE 802.16) [27].

Orthogonal Frequency Division Multiplexing (OFDM) is an alternative wireless modulation technology to CDMA [26].

4.2.1 Adaptive Modulation

Different order modulations allow you to send more bits per symbol and thus achieve higher throughputs or better spectral efficiencies. However, it must also be noted that when using a modulation technique such as 64-QAM, better signal-to-noise ratios (SNRs) are needed to overcome any interference and maintain a certain bit error ratio (BER). The use of adaptive modulation allows a wireless system to choose the highest order modulation depending on the channel conditions.

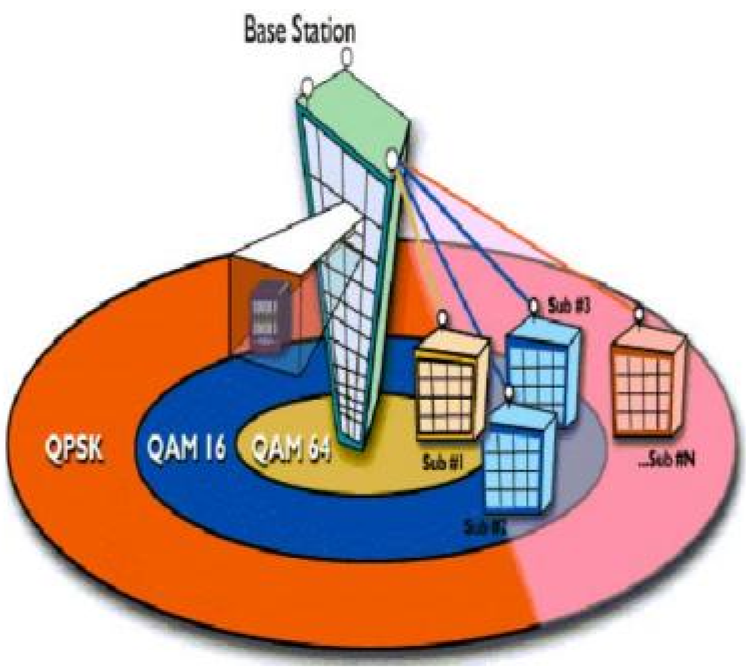


Figure 4. 2: Adaptive Modulation and Coding [28]

In Figure 4. 2, you can see a general estimate of the channel conditions needed for different modulation techniques. As you increase your range, you step down to lower modulations (in other words, QPSK), but as you are closer you can utilize higher order modulations like QAM for increased throughput. In addition, adaptive modulation allows the system to overcome fading and other interference [28].

4.5 Duplexing Scheme

Time Division Duplex (TDD) is called for in all of the current performance profiles for Mobile WiMAX [19]. TDD has several advantages over Frequency Division Duplex (FDD) and generally will be the preferred duplexing approach. One key advantage of TDD is that it assures channel reciprocity between the uplink and downlink. With FDD there would be some performance degradation due to the varied link conditions between the DL and UL channels because they may be separated by 100 MHz or more. Another important advantage is the ability of TDD to adapt to asymmetric traffic conditions. In TDD mode, mobile WiMAX supports downlink to uplink ratios 1:1 and 3:1. This provides a significant throughput advantage for data-centric traffic that is expected to be more dominant in the downlink direction. This is shown in Figure 4. 3, which shows the downlink channel capacity for both a 1:1 and 3:1 downlink to uplink ratio and for different antenna configurations.

We can see in Figure 4. 3 that this represents a 50% increase in the downlink data throughput for a 3:1 downlink to uplink traffic ratio as compared to 1:1 for the same channel bandwidth for all the antenna configurations. If this was an FDD system, the downlink channel capacity would be limited to the 1:1 values regardless of the traffic asymmetry and the uplink channel would be underutilized.

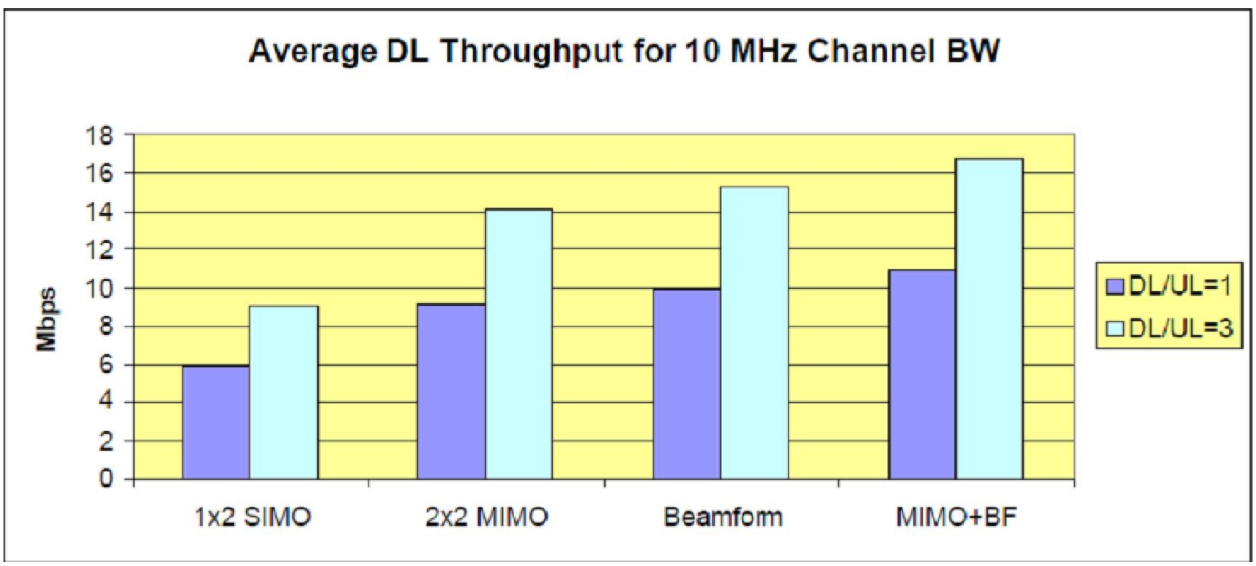


Figure 4. 3: Relative DL data rates for 1:1 and 3:1 TDD schemes for different antenna configurations [29]

4.6 Principal of Propagation Models

In wireless communication systems, transfer of information between the transmitting antenna and the receiving antenna is achieved by means of electromagnetic waves. The interaction between the electromagnetic waves and the environment reduces the signal strength send from transmitter to receiver that causes path loss. Different models are used to calculate the path loss. Some empirical and semi deterministic models will be described in this chapter to introduce the readers to before analyzing the path loss data in this Chapter below:

4.6.1 Types of Propagation Models

Models for path loss can be categorized into three types as follow:

- Empirical Models
- Deterministic Models
- Stochastic Models

4.6.2 Empirical Path Loss Models

Sometimes it is impossible to explain a situation by a mathematical model. In that case, we use some data to predict the behavior approximately. By definition, an empirical model is based on data used to predict, not explain a system and are based on observations and measurements alone. It can be split into two subcategories, time dispersive and non-time dispersive. The time dispersive model provides us with information about time dispersive characteristics of the channel like delay spread of the channel during multipath. The Stanford University Interim (SUI) model is the perfect example of this type. COST 231 Hata model, Hata and ITU-R model are example of non-time dispersive empirical model [4].

4.6.2.1 Free Space Path Loss

Path loss in free space *PLFSPL* defines how much strength of the signal is lost during propagation from transmitter to receiver. FSPL is diverse on frequency and distance. The calculation is done by using the following equation

$$PL_{FSPL}=32.45+20Log_{10}(d)+20Log_{10}(f) \quad \text{(4.1)}$$

Where

- f: Frequency in (MHz)
- d: Distance between transmitter and receiver in (m)

4.6.2.2 Okumura Model

The Okumura model [7-8] is a well-known classical empirical model to measure the radio signal strength in buildup areas. The model was built by the collected data in Tokyo city in Japan. This 26 model is perfect for using in the cities having dense and tall structure, like Tokyo. While dealing with areas, the urban area is sub-grouped as big cities and the medium city or normal built cities. But the area like Tokyo is really big area with high buildings. In Europe, the urban areas are medium built compared to Tokyo. Moreover, Okumura gives an illustration of correction factors for suburban and rural or open areas. By using Okumura model we can predict path loss in urban, suburban and rural area up to 3 GHz. However this thesis is using 2.5 GHz. So this model is not going to be selected for this work.

P_l=Median L_f+AMmn(f,d)-G(h_{te})-G(h_{rs})-G_{AREA}……………………………..…………….(4.2)

Where

- *PL*: Median path loss [dB]
- L_f: Free space path loss [dB]
- *A mn* (*f,d*): Median attenuation relative to free space [dB]
- *G* (h_{te}): Base station antenna height gain factor [dB]
- *G* (h_{re}): Mobile station antenna height gain factor [dB]
- G_{AREA}: Gain due to the type of environment

And parameters

- *f*: Frequency [MHz]
- *hte*: Transmitter antenna height [m]
- *hre*: Receiver antenna height [m]
- *d*: Distance between transmitter and receiver antenna [km]

G(h_{te}) can be calculated by using the following equation.

$$\mathbf{G(h_{te})} = \begin{cases} \mathbf{20\log\left(\frac{h_{te}}{200}\right)} & \mathbf{for\ 1000m > h_{re0} > 10m} \\ \mathbf{10\log_{10}\left(\frac{h_{re}}{3}\right)} & \mathbf{for\ h_{re} \leq 3m} \\ \mathbf{20\log_{10}\left(\frac{h_{re}}{3}\right)} & \mathbf{for\ 10m > h_{re} > 3m} \end{cases} \quad \text{……………………………………} \mathbf{(4.2.1)}$$

Although this model is ideally suited for urban areas with high building density, it can also be used for sub-urban and rural areas. The gain due the type of environment (GAREA) and the median attenuation relative to free space (Amn (f, d)), are different for the various types of metropolitan areas and can be extracted from Figure 4. 4. This model was the basis for the Okumura-Hata propagation model. The Okumura-Hata model was derived as a numerical fit to the propagation curves published by Okumura. As such, the model is somewhat specific to Japan's propagation environment. But a more generic and widely used model was further developed from the Okumura-Hata model which will be discussed in the next section.

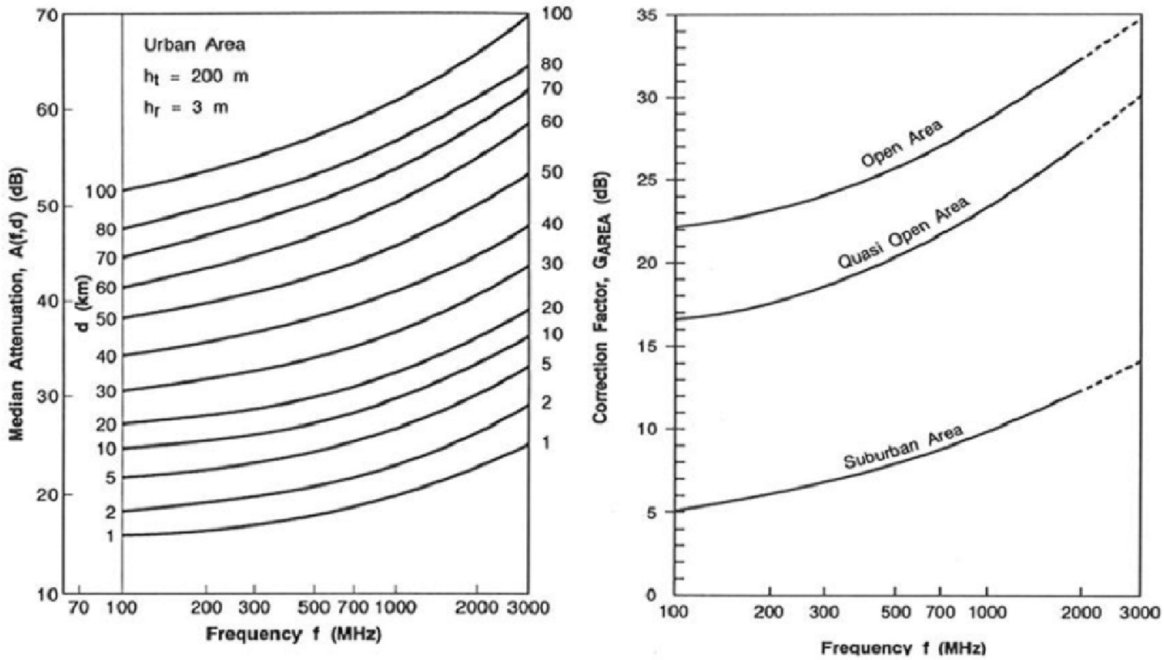


Figure 4. 4: Curves for extracting Amn (f, d) and GAREA [20]

4.6.2.3 COST 231 Hata Model

COST 231 Hata model is an extension of the Okumura-Hata model. It is used to calculate pathloss in three different environments like urban, suburban and rural (flat). This model provides simple and easy ways to calculate the path loss. Although the chosen frequency for this work case, which is, 2.5 GHz is outside of its measurement range, its simplicity and correction factors still allowed to predict the pathloss in this higher frequency range. In fact, this model is recommended by the WiMAX forum to calculate pathloss in urban and sub-urban areas at operating frequencies of 2.5 GHz and 3.5 GHz [2,19], Due to those reasons this propagation model is applied for this thesis work.

$$PL=46.3+33.9\log_{10}(f)-13.82\log_{10}(h_b)-ah_m+(44.9-6.55\log_{10}(h_b))\log10d+C_m \quad (4.3)$$

Where

- d: Distance between transmitter and receiver antenna in [km]
- f: Frequency in [MHz]
- hb: Transmitter antenna height in [m]
- ahm: Mobile station antenna height correction factor in [dB]
- Cm: Metropolitan area correction factor in [dB]

The parameter Cmhas different values for different environments like 0 dB for suburban and 3 dB for urban areas. ahmis defined in urban areas as,

$$\mathbf{ah_m = 3.20(\log_{10}(11.75h_r))^2 - 4.79} \qquad (4.3.1)$$

The value for ahmin suburban and rural (flat) areas is given as,

$$\mathbf{ah_m = (1.11\log_{10}f - 0.7)h_r - (1.5\log_{10}f - 0.8)} \qquad (4.3.2)$$

Where the hr is the receiver antenna height in meter.

4.6.2.4 Stanford University Interim (SUI) Model

The IEEE 802.16 Broadband Wireless Access working group proposed the standard for the frequency band below 11 GHz. This model developed by Stanford University and is named the SUI model [20].

The base station antenna height of SUI model can range from 10 m to 80 m. Receiver antenna height is from 2 m to 10 m. The cell radiuses from 0.1 km to 8 km. The SUI model describes three types of terrain, they are terrain a, terrain B and terrain C.

Terrain A can be used for hilly areas with moderator very dense vegetation. This terrain presents the highest pathloss. Terrain A can be taken as a dense populated urban area. Terrain B is characterized for the hilly terrains with rare vegetation, or flat terrains with moderate or heavy tree densities. This is the intermediate pathloss scheme. We consider this model for suburban environment. Terrain C is suitable for flat terrains or rural with light vegetation, here path loss is minimum [20]. The basic pathloss expression of the SUI model is given as;

$$PL(dB) = A + 10\gamma log_{10}\left(\frac{dy}{do}\right) + X_f + X_h + S \; for \; d > d_o \qquad (4.4)$$

Where

- d: Distance between BS and receiving antenna in [m]
- do: 100 in [m]
- λ: Wavelength in [m]
- X f: Correction for frequency above 2 GHz [MHz]
- Xh: Correction for receiving antenna height [m]
- S: Correction for shadowing [dB]
- γ: Path loss exponent

The log normally distributed factor S, is for shadow fading because of trees and other clutter on a propagations path and its value is between 8.2 dB and 10.6 dB [20]. The parameter A is defined as,

$$A = 20log_{10}\left(\frac{4\pi d_o}{\lambda}\right) \qquad (4.4.1)$$

And the path loss exponent γ is given by,

$$\lambda = a - bh_b + (\frac{c}{h_b}) \ldots\ldots (4.4.2)$$

Where, the parameter hb is the base station antenna height in meters. This is between 10 m and 80m. The constants a, b, and c depend upon the types of terrain, that are given in the table below. The value of parameter $\gamma = 2$ for free space propagation in an urban area, $3 < \gamma < 5$ for urban NLOS environment, and $\gamma > 5$ for indoor propagation [6].

Model Parameter	Terrain A	Terrain B	Terrain C
a	4.6	4.0	3.6
b (m^{-1})	0.0075	0.0065	0.005
C (m)	12.6	17.1	20

Table 4. 5: Values of model parameters for all three terrain models [20]

The frequency correction factor Xf and the correction for receiver antenna height Xh for the model are expressed by,

$$X_f = 6.0\log_{10}(\frac{f}{2000}) \ldots\ldots (4.4.3)$$

$$X_h = \begin{cases} -10.8\log_{10}\left(\frac{h_r}{2000}\right) & \text{for terrain type A and B} \\ -20\log_{10}\left(\frac{h_r}{2000}\right) & \text{for terrain type C} \end{cases} \ldots\ldots (4.4.4)$$

Where, f is the operating frequency in MHz, and hr is the receiver antenna height in meter.

4.6.2.5 Hata-Okumura Extended Model or ECC-33 Model

This model was developed based on the Okumura model. The original Okumura model doesn't provide any data greater than 3 GHz. This method is applied to predict the model for higher frequency greater than 3 GHz. In this model path loss is given by the following equation.

$$PL(dB) = A_{fs} + B_{bm} - G_b - G_r \ldots\ldots (4.5)$$

Where

- Afs: Free space attenuation in [dB] given in equation (4.12 a)
- Abm: Basic median path loss in [dB] given in equation (4.12 b)

- Gb: Transmitter antenna height gain factor given in equation (4.12 c)
- Gr: Receiver antenna height gain factor given in equation (4.12 d)

The gain and loss parameters can be calculated as,

$$\mathbf{A_{fs} = 92.4 + 20\log_{10}(d) + 20\log_{10}(f)} \text{.........} \mathbf{(4.5.1)}$$

$$\mathbf{A_{bm} = 20.41 + 9.83\log_{10}(d) + 7.894\log_{10}(f) + 9.56(\log_{10}(f))^2} \text{.........} \mathbf{(4.5.2)}$$

$$\mathbf{G_b = \log_{10}(\frac{h_b}{200})\{13.958 + 5.8[\log_{10}d]^2\}} \text{.........} \mathbf{(4.5.3)}$$

$$\mathbf{G_{r=}[42.57 + 13.7\log_{10}(f)][\log_{10}(h_r) - 0.585]} \text{.........} \mathbf{(4.5.4)}$$

Where

- d: Distance between transmitter and receiver antenna in [km]
- f: Frequency in [GHz]
- hb: Transmitter antenna height in [m]
- hr: Receiver antenna height in [m]

4.6.2.6 COST 231 Walfish-Ikegami (W-I) model

This model is a combination of the J. Walfish and F. Ikegami models [6]. The COST 231 project further developed this model. Now it isknown as a COST 231 Walfish-Ikegami (W-I) model. The equations are expressed as,

For LOS condition,

$$\mathbf{PL_{LOS} = 42.6 + 26\log_{10}(d) + 20\log_{10}(f)} \text{.........} \mathbf{(4.6)}$$

And for NLOS condition,

$$\mathbf{PL_{NLOS} = \begin{cases} L_{FSL} + L_{rts} + L_{msd} & \text{for urban and suburban} \\ L_{FS} & \text{if } L_{rts} + L_{msd} > 0 \end{cases}} \text{.........} \mathbf{(4.7)}$$

Where

- LFSL= Free space loss
- Lrts= Roof top to street diffraction
- Lmsd= Multi-screen diffraction loss

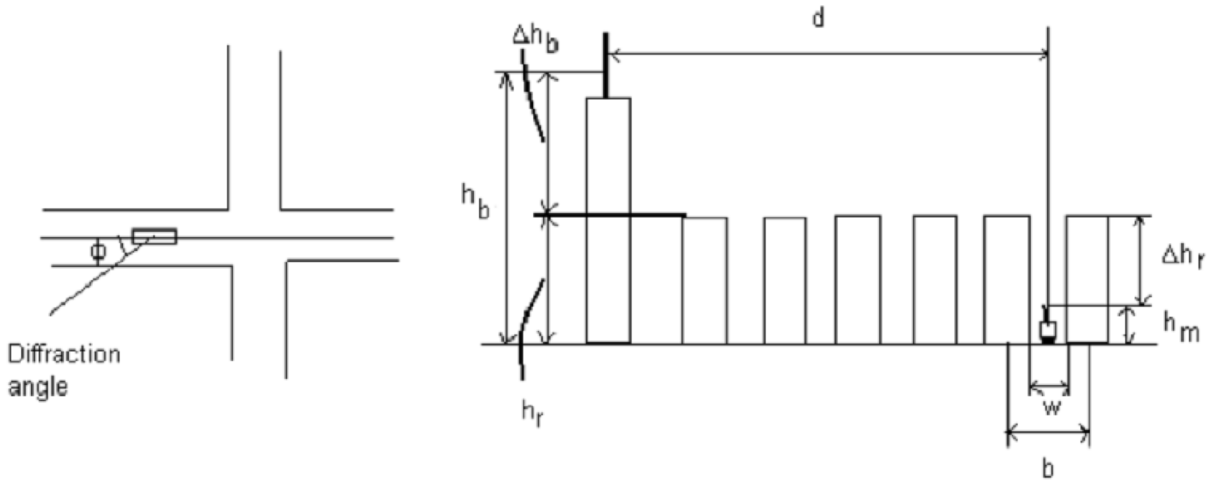


Figure 4. 5: Illustration of terrain parameters for COST 231 Walfish-Ikegami model [3]

Where,

Δhmobile= hroof– hmobile

Δhbase= hbase– hroof

The expression for L

FSL is given on Equation (4.1)

The expression for roof top to street diffraction is,

$$\mathbf{L_{rts}} = \begin{cases} -16.9 - 10\log_{10}(w) + 10\log_{10}(f) + 20\log_{10}h_m + L_{ori} & \text{if } h_{roof} > h_m \\ 0 & \text{otherwise} \end{cases} \quad \ldots\ldots\ldots\ldots (4.7.1)$$

$$\mathbf{L_{ori}} = \begin{cases} -10 + 0.354\varphi & \text{for } 0 \le \varphi \le 35 \\ 2.5 + 0.075(\varphi - 35) & \text{for } 35 \le \varphi \le 55 \\ 4 - 0.114(\varphi - 55) & \text{for } 55 \le \varphi \le 90 \end{cases} \quad \ldots\ldots\ldots\ldots (4.7.2)$$

The multi-screen diffraction loss is,

$$\mathbf{L_{msd}} = \begin{cases} L_{bsh} + k_a + k_d\log_{10}(d) + (K_f - 9)\log_{10}(f) - 9\log_{10}(B) & \text{if } L_{msd} > 0 \\ 0 & \text{otherwise} \end{cases} \quad \ldots\ldots\ldots\ldots (4.7.3)$$

Where

$$\mathbf{L_{bsh}} = \begin{cases} -18\log_{10}(1 + \Delta h_{base}) & \text{for } h_b > h_{roof} \\ 0 & \text{otherwise} \end{cases} \quad \ldots\ldots\ldots\ldots (4.7.4)$$

$$K_a = \begin{cases} 54 & for h_b > h_{roof} \\ 54 - 08\Delta h_{base} & for\ d \ge 0.5km\ and\ h_b < h_{roof} \\ 54 - 08\Delta h_{base}\left(\frac{d}{0.5}\right) & for d < 0.5km\ and\ h_b > h_{roof} \end{cases} \quad \ldots\ldots\ldots\ldots (4.7.5)$$

$$K_d = \begin{cases} 18 & for\ h_b > h_{roof} \\ 18 - 15\left(\frac{\Delta h_{base}}{h_{roof}}\right) & for\ h_b \le h_{roof} \end{cases} \quad \ldots\ldots\ldots\ldots (4.7.6)$$

$$\mathbf{K_f} = \begin{cases} -4 + 0.7\left(\frac{f}{925} - 1\right) & \textbf{for suburban} \\ -4 + 1.5\left(\frac{f}{925} - 1\right) & \textbf{for urban} \end{cases} \quad \text{...} \textit{(4.7.7)}$$

Where

- d: Distance between transmitter and receiver antenna [m]
- f: Frequency [GHz]
- B: Building to building distance [m]
- w: Street width [m]
- ϕ: Street orientation angel with respect to direct radio path [degree]

4.7 Determining Number of BTS and Cell Radius Calculation

The WiMAX base station is the key network element in connecting the core network to the end user, it determines the coverage of the network and defines the end-user experience. The link budget analysis as presented in section 4.11 results into determining the cell radius, R, of the base station. Based on the cell radius, we determine the coverage area of a single base station. The coverage area of a single base station leads into determining the total number of base stations required to cover a particular region in a given metropolitan area [2].

The base station coverage area is determined depending upon the number of sectors that the base station has. There are three sectoring techniques that are employed in cellular systems. These include either the use of Omni-directional sector (one cell with one antenna covering all directions), bi-sector (two cells per one base station) and tri-sector (three cells per one base station). For this thesis work, bi-sector cells in a single base station are preferred to others in order to provide precise coverage for the selected regions pertaining to the deployment.

4.8 Frequency Reuse Scheme

Cellular network suffering from inter cell interference ICI caused by using the same frequency band in the neighbor cells. One of the key aspects used by network designers are frequency planning and Fractional Frequency Reuse (FFR), the available bandwidth distribute through the neighbor cells to reduce the ICI. The ICI leads to decrease the cell coverage area, number of users per cell, and network throughput especially at the cell edge. Therefore, the aim at the proposed algorithm is to reallocate network resources according to the network users' type such as fixed or mobile users, also this algorithm maximize the usage of the available network resources.

The main aim of Fractional Frequency Reuse are:

1- To improve the cell coverage area by reducing the inter-cell interference (ICI), this leads to increase the coverage area and cell capacity as well as network throughput.
2- To maximize the utilization of the available recourse at the base station.
3- To maximize the system throughput by utilizing channel fluctuation.

Inter-cell interference mainly affects the performance of users at the cell edge, with high level of interference the packet loss will be increased, which requires retransmission technique. The redundancy of retransmission of the lost packets causes reduction in network performance.

The nomenclature for naming the frequency reuse patterns is (c,n,s) where c stands for the number of base stations, n the number of channels and s the number of sectors per base station site [2]. Two common frequency reuse configurations for a multi-cellular deployment with 3-sector base stations are a sector reuse of 3 (c, 3, 3) and a sector reuse of 1 (c, 1, 3) also referred to as universal frequency reuse. With a frequency reuse of 1 the same channel is deployed in each of the three base station sectors. This approach has the advantage of using the least amount of spectrum. With Reuse 1, a pseudorandom subcarrier permutation scheme is employed where with a segmentation mechanism users are given sub channels that are only a small part of the whole bandwidth. With this fractional frequency reuse, the mobile station uses part of the sub channel set, partially used subcarriers (PUSC), when approaching the borders of the cell. When it is close to the middle of the cell, it uses all the sub channels, fully used sub-carrier (FUSC) to mitigate co-channel interference at the sector boundaries and at the cell-edge. As a result some downlink channel capacity is sacrificed since some subcarriers will not be fully utilized throughout the entire cell. Nevertheless, the downlink spectral efficiency for WiMAX with universal reuse is still quite high and generally preferred over reuse3 [2].

For our case, (c, 1, 2) is the best choice tacking into account Reuse 1 advantages and it’s simplesity.

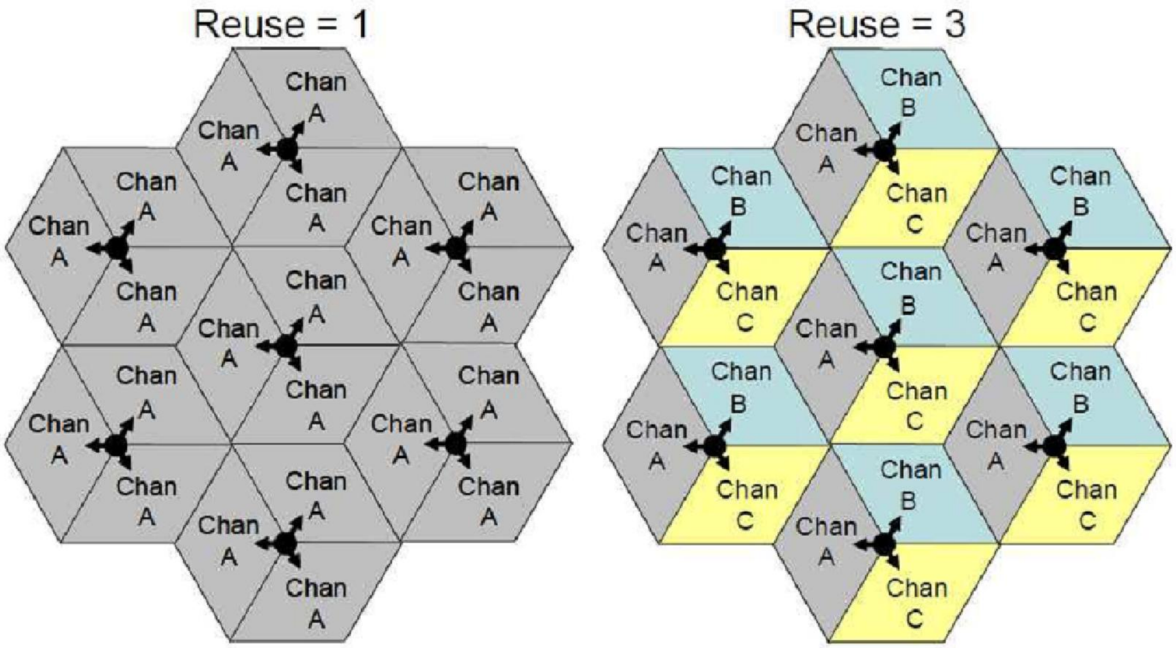


Figure 4. 6: Frequency reuse schemes [3]

Clustering and sectorization: To avoid interference cells are combined into clusters in which there is uniquely channel slot for each cell. Applying a cluster order K, the distance to co-channel cells D. R is radius of cell [6]:

D=R√3K……………………………………………………………………………………………. (4.8)

Where

- K Є {1, 3, 4, 7, 9, 12…}

For this work, suppose k=1, then D=3.88

4.9 Tunnel Radio Network

The selected route includes 380m distance tunnel at Awashisht. The running train inside the tunnel must be communicated with the BTS deployed around the infrastructure. In order to get affordable signal in the tunnel, Off-air repeater antenna and radiating cable is deployed inside and at the entrance of the tunnel. It provides coverage for other technologies and WiMAX in band intervals ranging from 380 MHz to 2700MHz.

Off-air 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 a best signal level.

4.10 Bts Antenna Selection

4.10.1 Smart Antenna Technologies

Smart antenna technologies typically involve complex vector or matrix operations on signals due to multiple antennas. OFDMA allows smart antenna operations to be performed on vector-flat sub-carriers. Complex equalizers are not required to compensate for frequency selective fading. OFDMA therefore, is very well-suited to support smart antenna technologies. In fact, MIMO-OFDM/OFDMA is envisioned as the corner-stone for next generation broadband communication systems [22]. Mobile WiMAX supports a full range of smart antenna technologies to enhance system performance. The smart antenna technologies supported include:

- **Beamforming:** With beamforming [22], the system uses multiple-antennas to transmit weighted signals to improve coverage and capacity of the system and reduce outage probability.
- **Space-Time Code (STC):** Transmit diversity such as Alamouti code [22] is supported to provide spatial diversity and reduce fade margin.
- **Spatial Multiplexing (SM):** Spatial multiplexing [22] is supported to take advantage of higher peak rates and increased throughput. With spatial multiplexing, multiple streams are transmitted over multiple antennas. If the receiver also has multiple antennas, it can separate the different streams to achieve higher throughput compared to single antenna systems. With 2x2 MIMO, SM increases the peak data rate two-fold by transmitting two data streams. In UL, each user has only one transmit antenna, two users can transmit collaboratively in the same slot as if two streams are spatially multiplexed from two antennas of the same user. This is called UL collaborative SM [22].

In addition to SIMO and MIMO antenna configurations, mobile WiMAX technology supports smart antenna technologies to enhance both coverage and throughput.

4.10.1.11x2 SIMO

A typical WiMAX base station antenna configuration is (1x2) SIMO. Even with only a single transmit antenna at each end of the link this configuration takes advantage of multipath to improve both the downlink and uplink received signal strength as compared to a single input single output (SISO) configuration. With dual receive antennas at both the base station and the mobile station the received signal is enhanced through the use of spatial diversity and the use of maximal ratio combining techniques [22].

4.10.1.2 2x2 MIMO

Adding a second transmitting antenna for both uplink and downlink provides a (2x2) MIMO configuration. This offers the possibility for Space-Time Coding (STC). Downlink data streams are sent from each transmit antenna providing space and time diversity. In an environment with rapid fading and multipath, STC enhances the signal-to-noise ratio of the received signal at the mobile station to enable support of higher modulation efficiency bursts and thus enhance DL range. With Spatial Multiplexing (SM), each of the base station transmit antennas send a different downlink data stream. This technique uses multipath to distinguish between the different data streams and theoretically has the potential to double the DL capacity. To take best advantage of STC and SM, Mobile WiMAX also supports adaptive MIMO Switching. This enables dynamic switching between STC and SM depending on existing channel conditions at any given time [22].

Dual polarization diversity can also be supported with MIMO 2x2 to provide improved performance when there is not sufficient multipath.

4.10.1.3 Adaptive Beamforming

Beamforming is another advanced antenna option supported by WiMAX technology. This antenna technology, also commonly referred to as smart or Adaptive antenna system, can be implemented in a variety of ways.

The simplest approach, known as switched beam, provides the ability to switch between several narrow beam antennas or between different beams in an antenna array. Switched beam systems have several available fixed beam patterns. A decision is made as to which beam to access, at any given point in time, based upon the requirements of the system. Adaptive arrays allow the antenna to steer the beam to any direction of interest while simultaneously nulling interfering signals. Beam direction can be estimated using the direction-of-arrival (DOA) estimation methods.

A second approach, known as dynamically phased array, dynamically phased array antennas form a beam to a device digitally. The array forms a beam by activating certain Omni-directional elements in the array which have a multiplying effect to form a beam. This beam can then be steered or pointed in the direction of a device by phasing the transmission of the signal in the elements and adjusting the gain on each antenna element. A dynamically phased array steers the created beam at the desired device. As the beams are formed digitally the same array of elements can target beams at multiple devices on multiple frequencies. Both of the above approaches enhance the received signal strength and therefore can provide range and/or channel capacity improvement but are also subject to angle spread due to scattering and multipath.

A third approach to beamforming is known as adaptive array or adaptive beamforming. With this approach the beamforming parameters are adaptively determined based on both channel and interference conditions. This can also enable the array to not only maximize signal strength to the desired user but also provides a mechanism to null out interference.

The 2x2 MIMO and beamforming techniques are quite essential in increasing the channel throughput as well as improving the SNR of the link. But they also require a relatively higher capital expenditure for deployment [22]. The 1x2 SIMO is most commonly used Dimensioning and Radio Network Planning of Mobile WiMAX: The Case of Addis Ababa to Djibouti railway line for current traffic using 1x2 SIMO seems the outstanding choice for deployment in the selected railway corridor. There is always the possibility to upgrade the system to a MIMO (2x2), beamforming or even a combination of these two.

4.11 Link Budget Analysis and Calculation

A link budget is the sum of the loss and gain of the signal strength as it travels through different components down the path from the transmitter to the receiver. The link budget allows determining the required transmit power that is able to overcome losses in the transmission medium so that the receive power is adequate for the reception of the signal.

As a result of the link budget, the receive power is sufficiently greater than the noise power, and the targeted bit error rate can be achieved. The link budget determines the theoretical maximum cell radius of each base station and comprises of two types of components [17].

- System level components which include receiver sensitivity, power level and modulation efficiency. These components do not vary significantly across different frequency bands.
- Non-system related components that are expected to vary across different frequencies. These components include
    - -Path loss
    - -Physical environment:
    - -Cable loss:
    - -Shadow margin:

Basic link budget parameters are summarized as following table.

Parameter	Mobile handheld in outdoor scenario		Notes
	Downlink	Uplink	
Power amplifier output power	43.0 dB	27.0 dB	A1
Number of transmit antennas (assuming 2×2 MIMO Base stations)	2	2	A2
Transmit antenna gain	18 dBi	0 dBi	A3
Transmitter losses	3.0 dB	0 dB	A4
Effective isotropic radiated power	66 dBm	27 dBm	A5 = A1 + 10log10(A2) + A3 - A4
Channel bandwidth	10MHz	10MHz	A6
Number of sub channels	30	35	A7
Receiver noise level	-104 dBm	-104 dBm	A8 = -174 + 10log10(A6×1e6)
Receiver noise figure	8 dB	4 dB	A9
Required SNR	0.8 dB	1.8 dB	A10
Subchannelization gain	0 dB	12 dB	A11 = 10log10(A7)
Data rate per sub channel (kbps)	151.2	34.6	A12
Receiver sensitivity (dBm)	-95.2	-110.2	A13 = A8 + A9 + A10 -A11
Receiver antenna gain	0 dBi	18 dBi	A14
System gain	156.2 dB	155.2 dB	A15 = A5 – A13 + A14
Shadow-fade margin	10 dB	10 dB	A16
Building penetration Loss	0 dB	0 dB	A17
Link margin	160 dB	151.64 dB	A18 = A15 – A16 -A17

Table 4. 6: Link budget [2]

Link budget calculation is used to determine the maximum allowable pathloss (MAPL). MAPL is the link margin we get when we subtract all the loss parameters from the sum of our gain parameters. The pathloss at any given point in our intended coverage area needs to be less than or equal to this link margin. With the data discussed in the previous sections, it is possible to calculate the link budget.

For the downlink communication MAPL is defined as,

$$MAPL = EIRP + CPE\ DL\ RX\ antenna\ gain + other\ CPE\ DL\ RX\ antenna\ gain - Head\ or\ Body\ loss - RX\ sensetivity - lognormal\ fadining\ margin - fast\ fading\ margin - interference\ margin - building\ penetration\ loss \quad (4.9)$$

For the uplink communication MAPL is defined as,

$$MAPL = EIRP + CPE\ UL\ RX\ antenna\ gain + other\ CPE\ UL\ RX\ antenna\ gain - RX\ sensetivity - lognormal\ fading\ margin - fast\ fading\ margin - nterferance\ margin - buildng\ penetration\ loss + UL\ Subchaneling\ gain \quad (4.10)$$

Where,

- EIRP is Effective isotropic radiated power
- CPE is customer premises equipment (assumed 6db for worst case of Mobile and portable CPE)
- Lognormal fading margin is the slow fading margin expressed as a lognormal ratio.
- Interference margin is the loss margin attributed to various sources of interference.
- Fast fading margin is fading margin due to fast fading (Coherence time of the channel is small relative to the delay constraint of the channel).
- Building penetration loss is the loss in signal power while penetrating walls for indoor reception.
- Other parameters have been discussed in previous discussions.

Using equations enlisted in Section 3.9, and taking into consideration choices made regarding operating frequency band (2.5 GHz), antenna configuration (SIMO) and channel bandwidth (10 MHz), we can now proceed with the calculation for MAPL. For the purposes of calculating MAPL, we will assume the lowest modulation order, QPSK ½ which requires only 0.8dB [1] SNR at the receiver.

The resulting MAPL for a mobile handheld device would equate to 148.4 dB in the uplink and 149.4 dB in the downlink. From the value of the MAPL for the UL cases (since range is limited by the uplink transmission rather than the downlink due to constraints on power and antenna gain of CPEs) it is possible to predict the coverage range using the COST-231 Hata propagation model (see Section 4.6.2.3). Assuming a base station antenna height of 50 meters and a mobile station height of 1.5 meters, our coverage range will equate to 2.2 km.

We can now predict the coverage per base station as follows, the total length of Addis Ababa to Djibouti railway route is 661.245 and the computed radius of coverage range is 2.2km. Hence, expected maximum number of BTS needed along the route will be (661.245/2*2.2)=150. While deploying on the ground the computed number may change due to the curvature nature of the line.

4.12 Handover Algorithm in WiMAX Network

To meet the second challenge of mobility, the system should provide a method for seamlessly handing over an ongoing session from one base station to another as the user moves across them. A handoff process typically involves detecting and deciding when to do a handoff, allocating radio resources for it, and executing it.

Compared to location management, handoff management has a much tighter real-time performance requirement. For many applications, such as VoIP, handoff should be performed seamlessly without perceptible delay or packet loss. To support these applications, WiMAX requires that for the full mobility—up to 120kmph scenario—handoff latency be less than 50ms with an associated packet loss that is less than 1 percent.

Handoff decisions may be made by either the MS or the network, based on link-quality metrics. In WiMAX, the MS typically makes the final decision, whereas the BS makes recommendations on candidate target base stations for handoff. The decision is based on signal-quality measurements collected and periodically reported by the MS. The MS typically listens to a beacon or a control signal from all surrounding base stations within range and measures the signal quality. In WiMAX, the base station may also assist in this process by providing the MS with a neighbor list and associated parameters required for scanning the neighboring base stations. The received signal strength (RSS) or signal-to-interference plus noise ratio (SINR) may be used as a measure of signal quality. SINR is a better measure for high-density cellular deployments but is more difficult to measure than is RSS.

Three handoff methods are supported in IEEE 802.16e-2005; one is mandatory and other two are optional. The mandatory handoff method is called the hard handover (HHO) and is the only type required to be implemented by mobile WiMAX initially. HHO implies an abrupt transfer of connection from one BS to another. The handoff decisions are made by the BS, MS, or another entity, based on measurement results reported by the MS. The MS periodically does a radio frequency (RF) scan and measures the signal quality of neighboring base stations. And also for this thesis work hard handover (HHO) is selected.

The two optional handoff methods supported in IEEE 802.16e-2005 are fast base station switching (FBSS) and macro diversity handover (MDHO). In these two methods, the MS maintains a valid connection simultaneously with more than one BS.

Chapter Five

5 Simulation Result and Analysis

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

5.1 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 and network designers to create and define radio-planning project in a single application using different file formats. Atoll includes advanced multi-technology network planning features, and a combined single-RAN, multi-RAT GSM/UMTS/LTE/WiMAX Monte Carlo simulator and traffic model. Operators can save the entire project as a single file, or it can link a 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 copying 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.

5.2 Simulation Results and Analysis of Empirical Models

For the purposes of this numerical simulation (and others that follow), the author assume Ethio-Djibouti railway route as sub-urban metropolitan area for reasons discussed in Section **4.6.1** and section **2.2.2**. Other assumptions include an average building-to-building distance is negligible and street width 1435mm (width of Addis to Djibouti railway line). Average building and trees height is assumed as 15 m, base station height 30 m. The operating frequency is set at 2500MHz. Note that the above assumed values are subject to change and were selected based on a reasonable estimate.

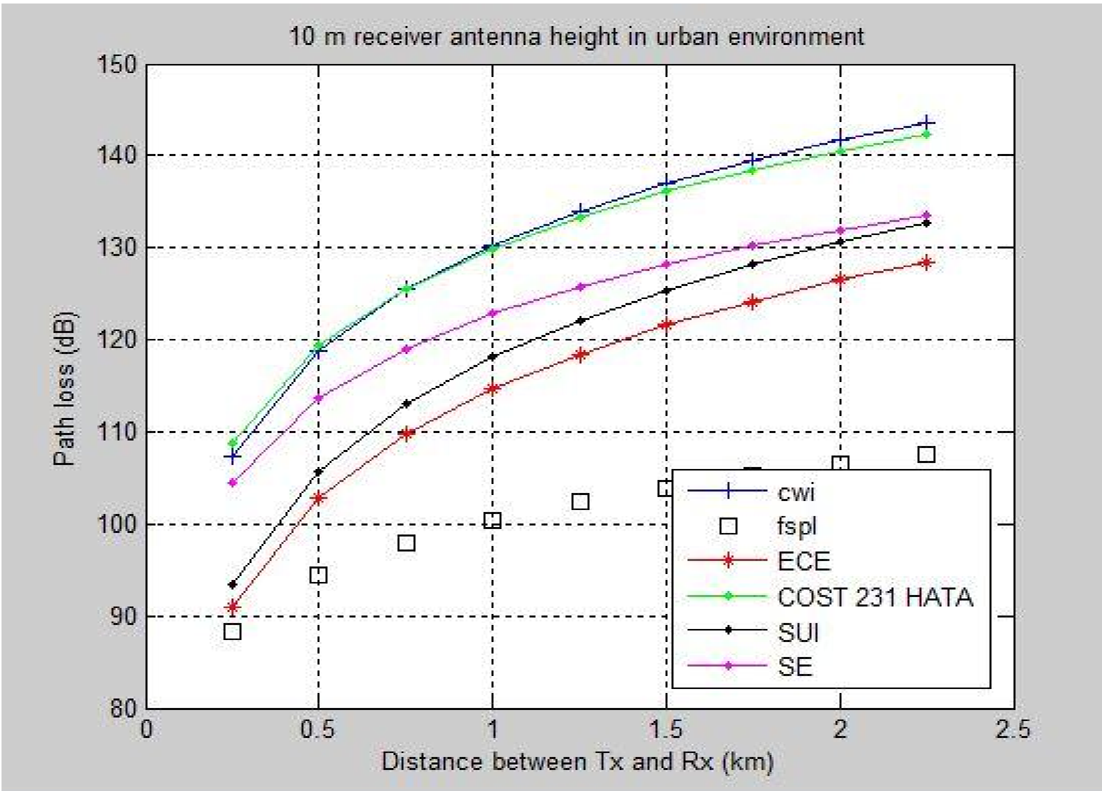


Figure 5. 1: Numerical result for the four propagation models

As mentioned in previous chapter (see section **4.6.2.3** for detail), the WiMAX forum recommends the COST-231 Hata model for pathloss/range calculations in urban and suburban areas. This model is expected to perform better (yield more accurate pathloss estimates) than the other propagation models in the Addis Ababa to Djibouti route according to the WiMAX forum. However, the COST-231 Hata model is an empirical model that can only be used to calculate the average range or more specifically, cell radius. It does not take into account the terrain data (such as particular building heights, street width etc.…) for each nominal direction as the average values for these parameters have already been incorporated into the formula.

Also we can see in Figure 5. 1 that the propagation model that yields the nearest result to the COST-231 Hata model given the particular scenario we assumed is the COST 231 Walfish-Ikegami (W-I) model. In fact, the pathloss versus range curves almost overlap for the two models. However, we will be able to see what our actual coverage area might correspond. Because we are calculating our range by considering different constraints such as cost, signal strength and wider coverage area. The COST-231 Hata model only yields the average cell radius for this study case.

From a planning perspective, it is better to assume worst case scenarios in order to avoid risking an inadequate coverage because if once accident happen in railway transportation, it will be fatal.

The simulation result shown above Figure 5. 1 is applied for both section of the Addis Ababa to Djibouti railway route and due to the advantages discussed in above paragraphs, COST-231 Hata model is selected for this thesis work.

5.3 WiMAX Network Design Using Atoll

This thesis had planned to simulate the signal strength and coverage of BTSs along the selected railway line with the digital map of the selected corridor but the author couldn'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, Global Mapper and Atoll software are the technologies used in the simulation process.

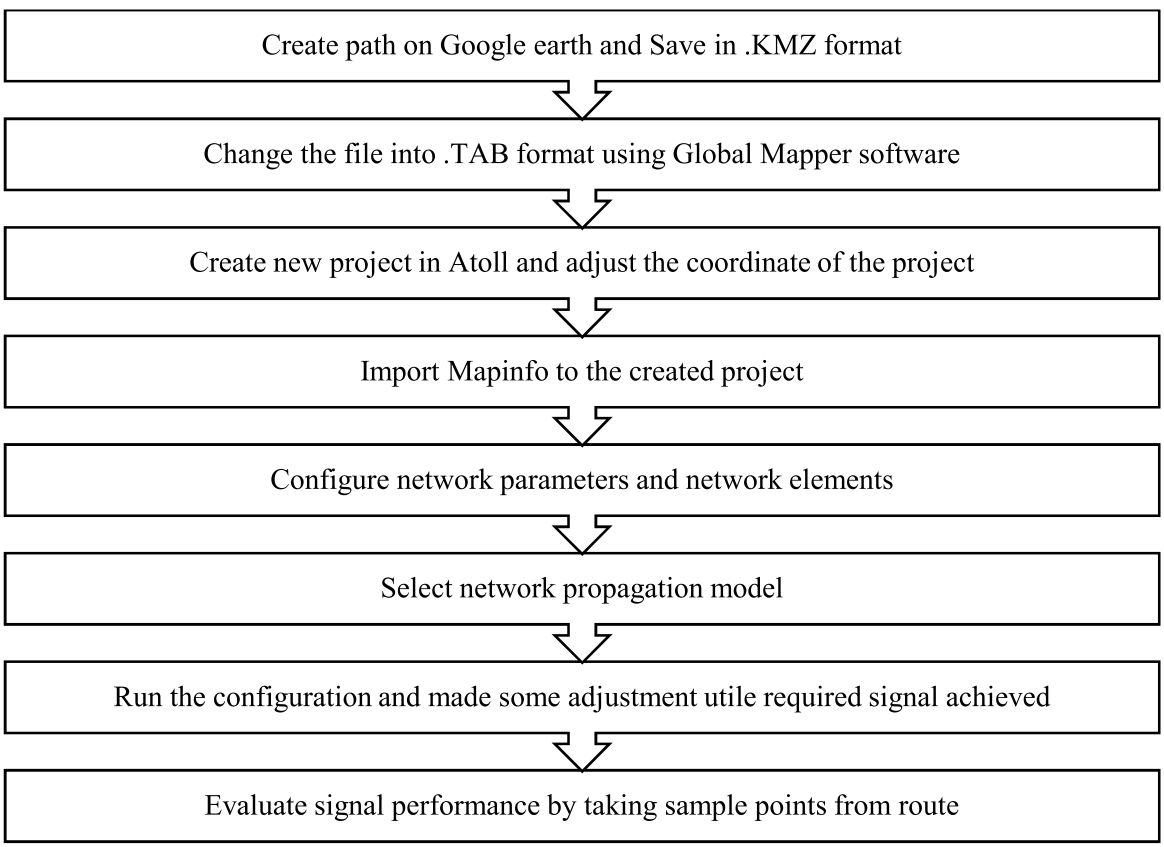


Figure 5. 2: Block diagram of simulation steps

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. Subsequently, adding the transmitters and settings of the parameters which are calculated in the previous chapter.

Google earth map is used 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 first section of the route include from Addis Ababa to Meiso and the second section covers from Meiso to Dewele.

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 5. 3: path from Addis Ababa to Meiso section

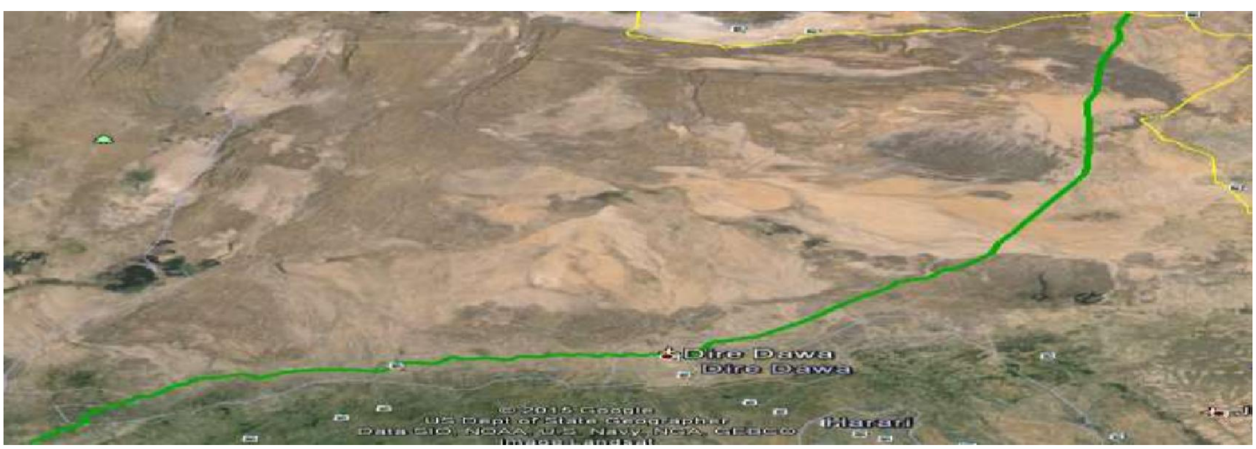


Figure 5. 4: Meiso-Dewele section

5.4 Simulation Results

The best signal level is shown in Figure 5. 5 with different colors. This legend shows the prediction property of each signal level.

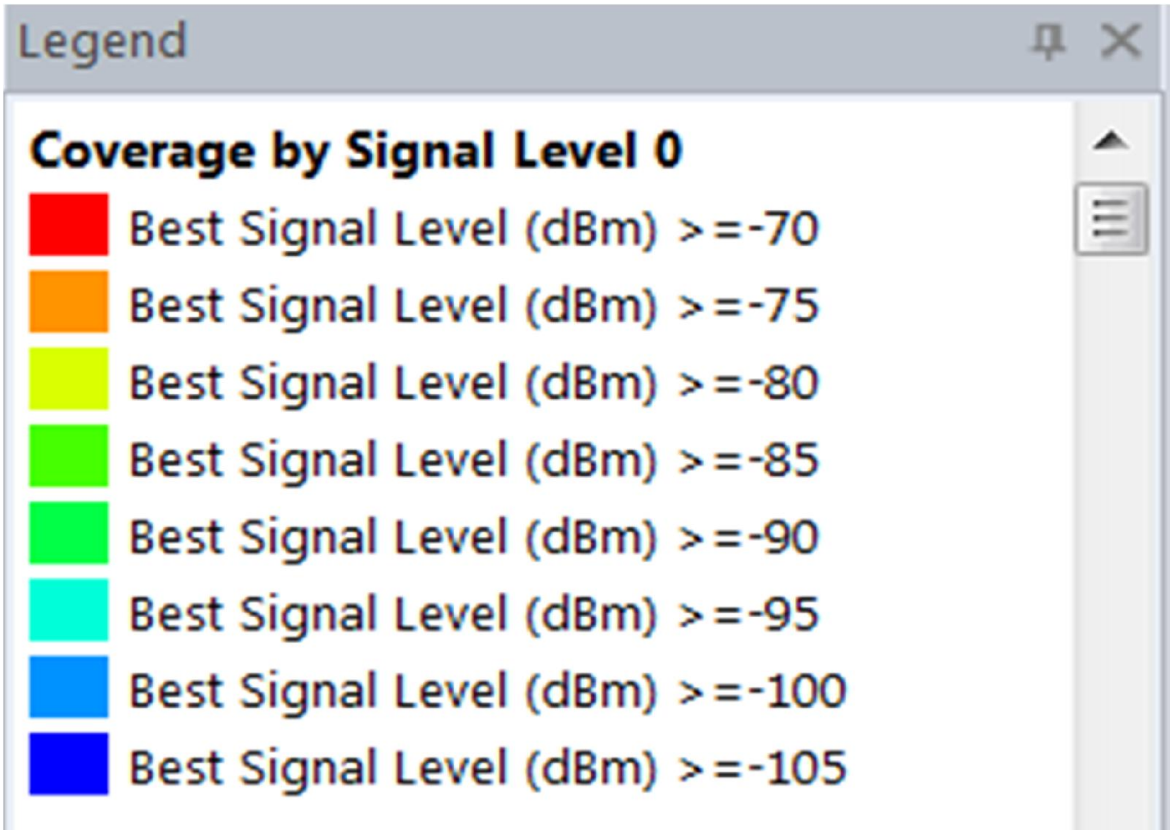
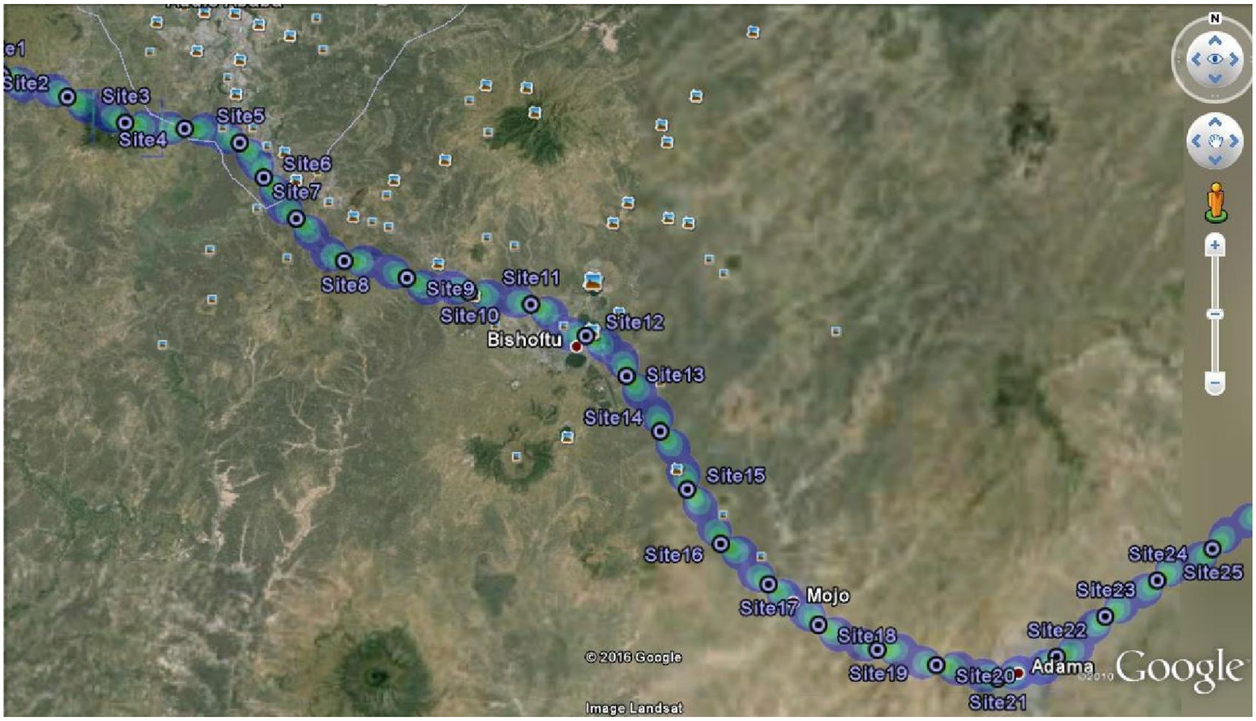


Figure 5. 5: Signal level coverage indication with different colors

The route divided into two sections (i.e. Sebeta-Meiso and Meiso-Dewele sections). Figure 5. 6 shows the simulation result of the signal coverage level for Sebeta - Meiso section and it covers 327.245km distance. As the simulation result, there are 63 BTS's which are required in this section and the signal strength is very good at every point of the route as we can see from Figure 5. 6-(a), (b) and (c).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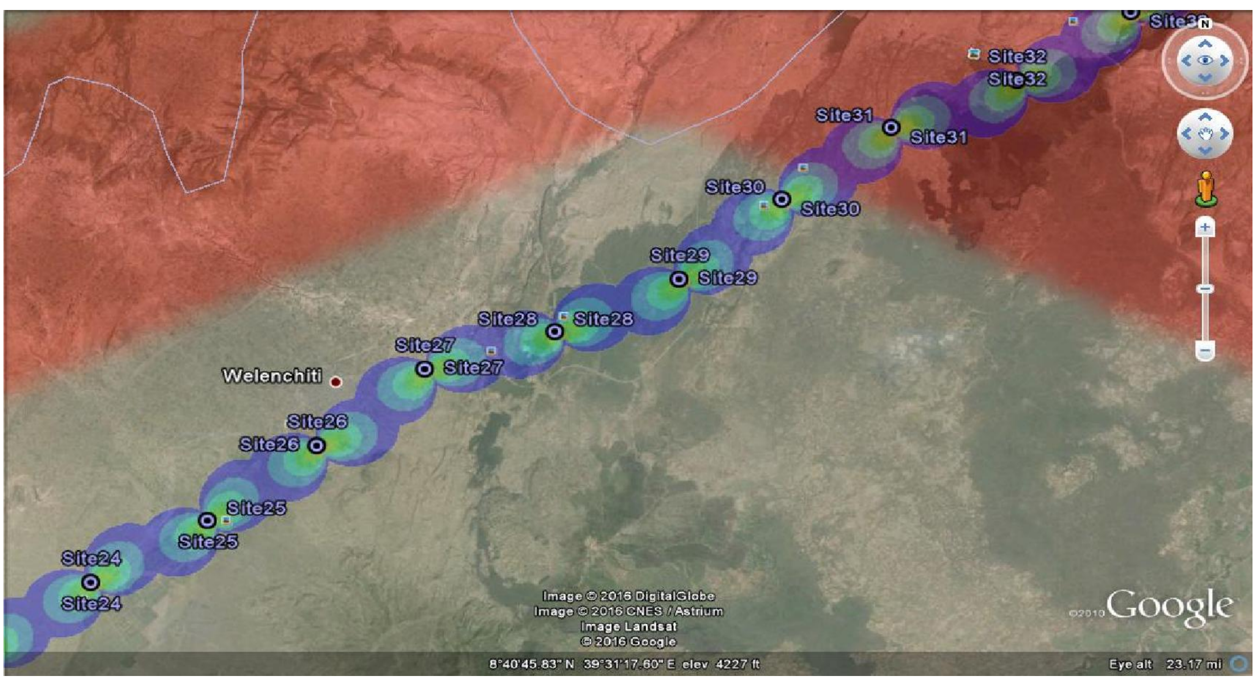
(a)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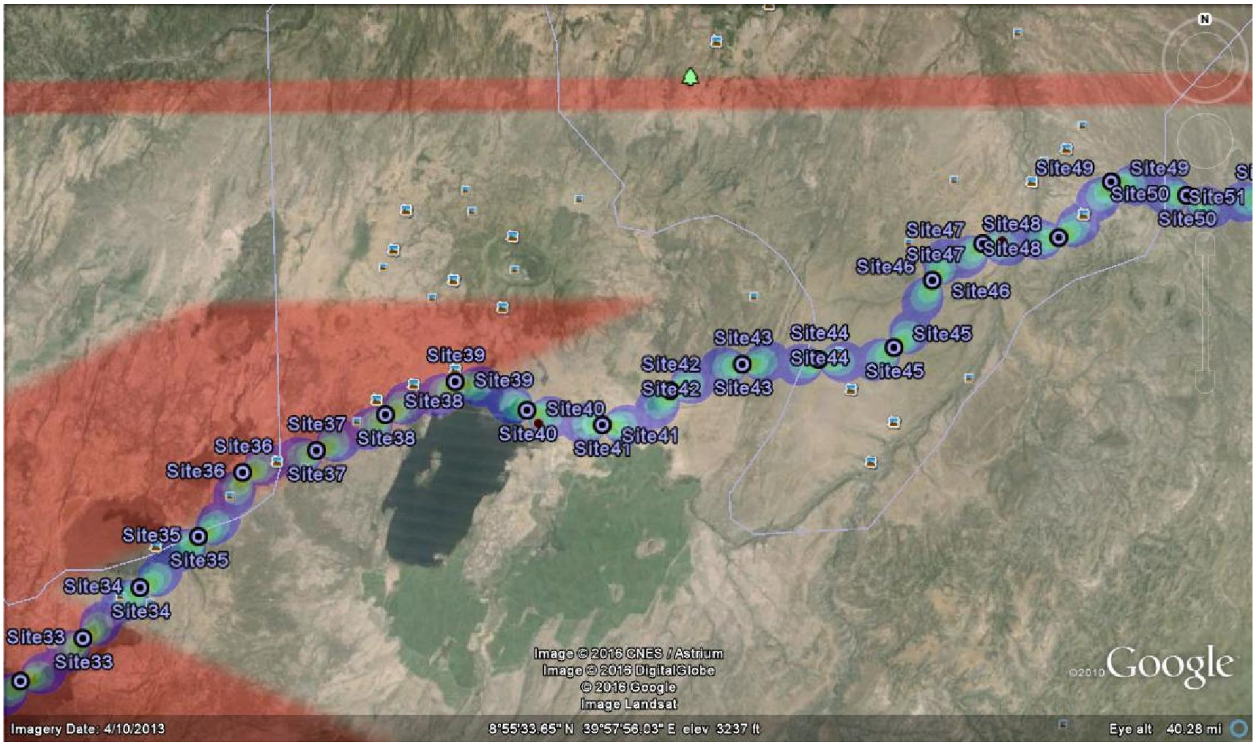
(b)



(c)

Figure 5. 6: Sebeta-Meiso BTS's signal level simulation-(a), (b) and (c)

As we can see from above Figure 5. 6-(a), (b) and (c) each Bts have covered 2.2km cell radius as expected from numerical calculation result which have done in chapter four. The appropriate locations of the Bts sites theoretically proposed by this thesis work are summarized as following table.

S/n	**Name**	**Longitude**	**Latitude**	**Pylon Height (m)**	**Comments**
1	Site0	38°34'46.57"E	8°56'17.72"N	50	
2	Site1	38°36'55.46"E	8°55'20.63"N	50	
3	Site2	38°39'27.51"E	8°54'30.19"N	50	
4	Site3	38°41'41.9"E	8°53'31.1"N	50	
5	Site4	38°43'56.49"E	8°53'19"N	50	
6	Site5	38°46'3.11"E	8°52'47.56"N	50	
7	Site6	38°46'59.61"E	8°51'27.62"N	50	
8	Site7	38°48'15.61"E	8°49'53.62"N	50	
9	Site8	38°50'6.97"E	8°48'16.89"N	50	

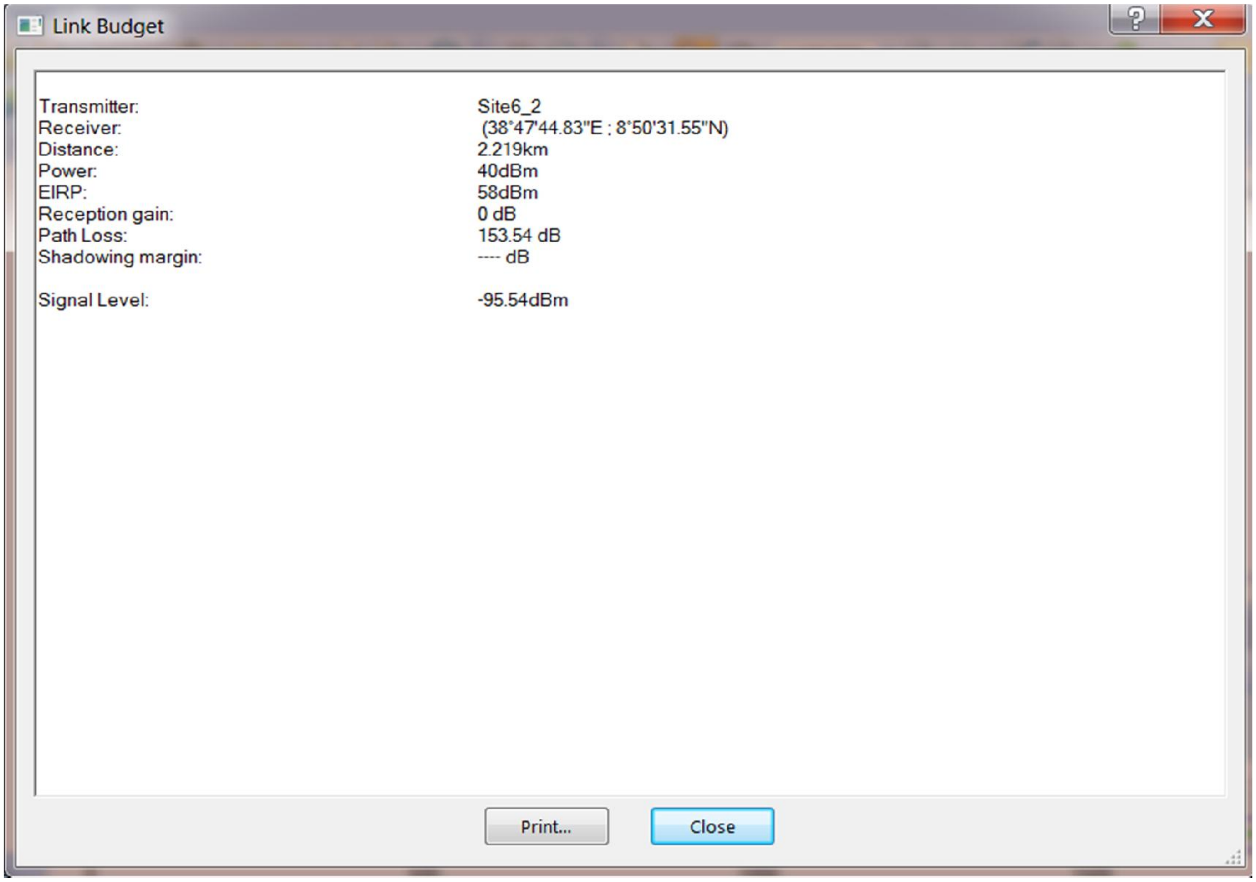
10	Site9	38°52'30.25"E	8°47'38.8"N	50	
11	Site10	38°54'52.71"E	8°47'7.53"N	50	
12	Site11	38°57'17.02"E	8°46'38.83"N	50	
13	Site12	38°59'24.67"E	8°45'26.83"N	50	
14	Site13	39°0'58.81"E	8°43'54.75"N	50	
15	Site14	39°2'16.97"E	8°41'48.45"N	50	
16	Site15	39°3'19.56"E	8°39'35.54"N	50	
17	Site16	39°4'37.31"E	8°37'30.6"N	50	
18	Site17	39°6'28.33"E	8°35'57"N	50	
19	Site18	39°8'24.12"E	8°34'24.14"N	50	
20	Site19	39°10'40.56"E	8°33'27.73"N	50	
21	Site20	39°12'58.22"E	8°32'51.72"N	50	
22	Site21	39°15'21.52"E	8°32'19.42"N	50	
23	Site22	39°17'39.26"E	8°33'9.45"N	50	
24	Site23	39°19'34.36"E	8°34'41.02"N	50	
25	Site24	39°21'36.51"E	8°36'3.78"N	50	
26	Site25	39°23'42.8"E	8°37'17.17"N	50	
27	Site26	39°25'41.09"E	8°38'46.03"N	50	
28	Site27	39°27'37.48"E	8°40'16.74"N	50	
29	Site28	39°29'58.22"E	8°41'1.31"N	50	
30	Site29	39°32'13.14"E	8°42'3.66"N	50	
31	Site30	39°34'4.9"E	8°43'38.6"N	50	
32	Site31	39°36'4.36"E	8°45'4.71"N	50	
33	Site32	39°38'21.52"E	8°46'0.89"N	50	
34	Site33	39°40'24.55"E	8°47'22.27"N	50	
35	Site34	39°42'15.65"E	8°48'57.89"N	50	
36	Site35	39°44'7.49"E	8°50'33.48"N	50	
37	Site36	39°45'32.05"E	8°52'34.12"N	50	
38	Site37	39°47'54.35"E	8°53'14.58"N	50	
39	Site38	39°50'7.33"E	8°54'21.66"N	50	
40	Site39	39°52'22.48"E	8°55'23.25"N	50	
41	Site40	39°54'40.49"E	8°54'27.64"N	50	
42	Site41	39°57'5.57"E	8°53'58.38"N	50	

43	Site42	39°59'17.76"E	8°55'2.85"N	50	
44	Site43	40°1'36.61"E	8°55'51.41"N	50	
45	Site44	40°4'4.31"E	8°55'59.58"N	50	
46	Site45	40°6'29.6"E	8°56'20.55"N	50	
47	Site46	40°7'45.44"E	8°58'28.11"N	50	
48	Site47	40°9'24"E	8°59'37.39"N	50	
49	Site48	40°11'51.01"E	8°59'47.56"N	50	
50	Site49	40°13'33.94"E	9°1'33.34"N	50	
51	Site50	40°15'59.42"E	9°1'5.69"N	50	
52	Site51	40°18'27.94"E	9°0'58.16"N	50	
53	Site52	40°20'54.34"E	9°0'40.41"N	50	
54	Site53	40°23'21.76"E	9°0'51.2"N	50	
55	Site54	40°25'47.38"E	9°1'20.68"N	50	
56	Site55	40°27'54.3"E	9°2'34.42"N	50	
57	Site56	40°29'46.36"E	9°4'6.26"N	50	
58	Site57	40°31'29.36"E	9°5'44.28"N	50	
59	Site58	40°33'10.54"E	9°7'31.85"N	50	
60	Site59	40°35'23.34"E	9°8'25.36"N	50	
61	Site60	40°37'52.1"E	9°9'3.43"N	50	
62	Site61	40°39'50.2"E	9°10'14.96"N	50	
63	Site62	40°42'1.5"E	9°11'23.2"N	50	
64	Site63	40°44'8.47"E	9°12'45.12"N	50	

Table 5. 1:- Proposed location of Bts along Sebeta-Meiso

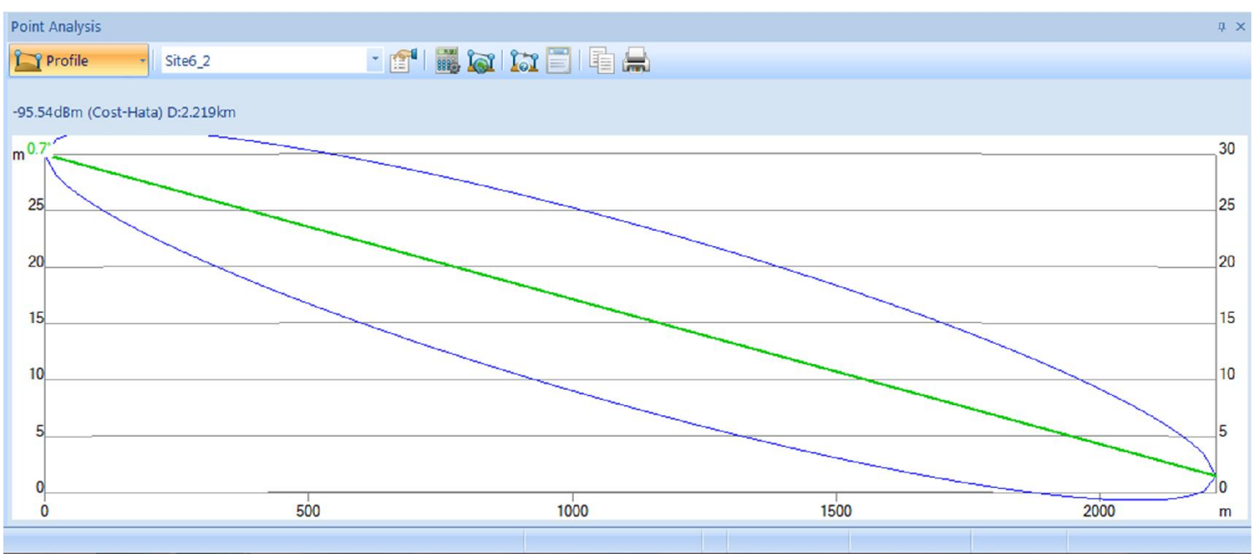
5.5 Performance Analysis of Sebeta-Meiso Section

Using point analysis tool of Atoll software, a random point is chosen between site6_2 and site7_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 5. 7(a), geographical profile and reception signal level of the selected point is shown in Figure 5. 7(b) and (c) respectively.



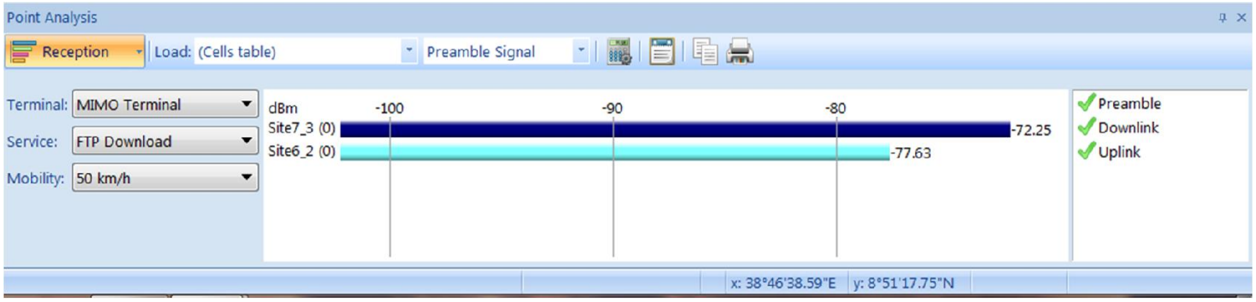
Link Budget
Transmitter: Site6_2
Receiver: (38°47'44.83"E ; 8°50'31.55"N)
Distance: 2.219km
Power: 40dBm
EIRP: 58dBm
Reception gain: 0 dB
Path Loss: 153.54 dB
Shadowing margin: ---- dB
Signal Level: -95.54dBm
Print...
Close

(a)



Point Analysis
Profile
Site6_2
-95.54dBm (Cost-Hata) D:2.219km
m
0
500
1000
1500
2000
m

(b)

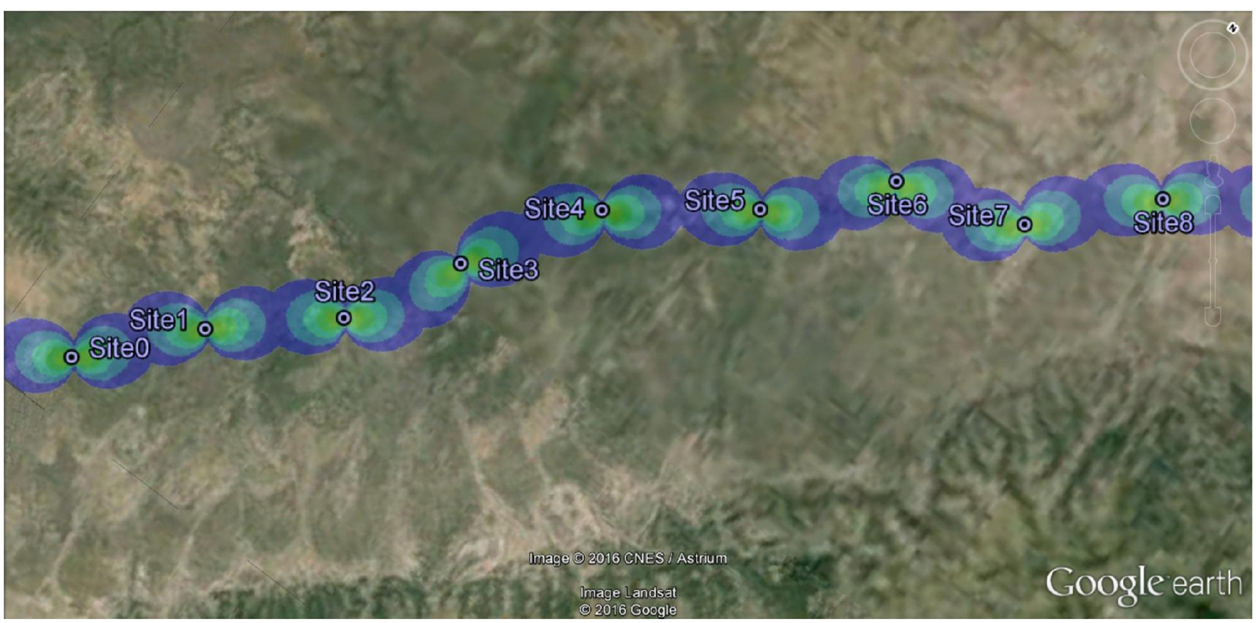


(c)

Figure 5. 7: Point analysis and performance result of chosen site - (a), (b) and(c)

As we can see from above figure (Figure 5. 7-(a) and (b)) a receiver is receiving a signal level -95.54 db from site6_2 at the distance 2.219 km far from a transmitter. However the pathloss is exceeded from the limit which we have calculated in previous section. So at this point as we can see from Figure 5. 7-(c) site7_3 have a better signal (-72.25dBm) level than site6_2 (-77.63dBm). Hence at this location handover will be held on.

The following figure (Figure 5. 8-(a), (b), (c), (d), (e) and (f)) is also the section from Meiso to Dewele route and it covers a distance of 334km. 73 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.



(a)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(b)


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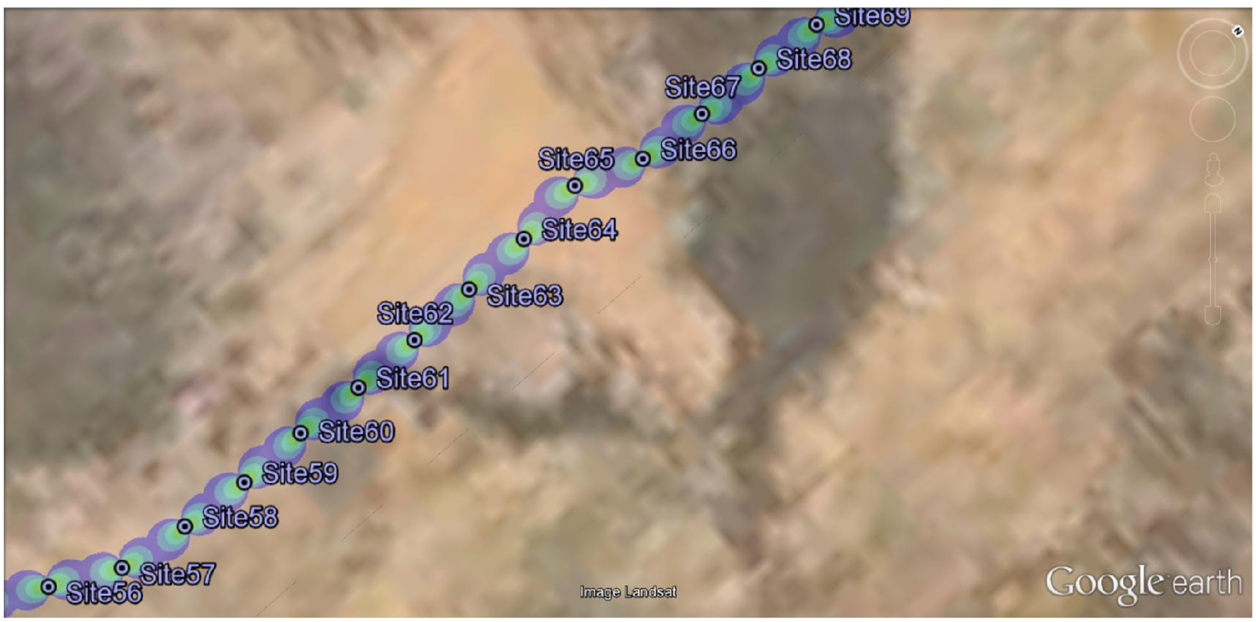
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(e)

(f)

Figure 5. 8: Meiso-Dewele BTS"s signal level simulation result-(a), (b), (c), (d), (e) and (f)

As discussed previously for the case of first section of the route (Sebeta-Meiso) we can see from above Figure 5. 8-(a), (b), (c), (d), (e) and (f) each Bts have covered 2.2km cell radius as expected from numerical calculation result which have done in chapter four. The appropriate locations of the Bts sites theoretically proposed by this thesis work are summarized as following table.

S/n	Name	Longitude	Latitude	Pylon Height (m)	Comments
1	Site0	40°46'32.33"E	9°14'9.44"N	50	
2	Site1	40°48'8.46"E	9°15'58.01"N	50	
3	Site2	40°50'0.1"E	9°17'35.55"N	50	
4	Site3	40°51'5.28"E	9°19'35.77"N	50	
5	Site4	40°52'31.95"E	9°21'50.83"N	50	
6	Site5	40°54'47.48"E	9°23'32.09"N	50	
7	Site6	40°56'26.56"E	9°25'23.26"N	50	
8	Site7	40°58'44.56"E	9°26'7.82"N	50	
9	Site8	41°0'27.17"E	9°27'57.3"N	50	
10	Site9	41°2'27.37"E	9°29'24.63"N	50	
11	Site10	41°4'34.48"E	9°30'55.44"N	50	

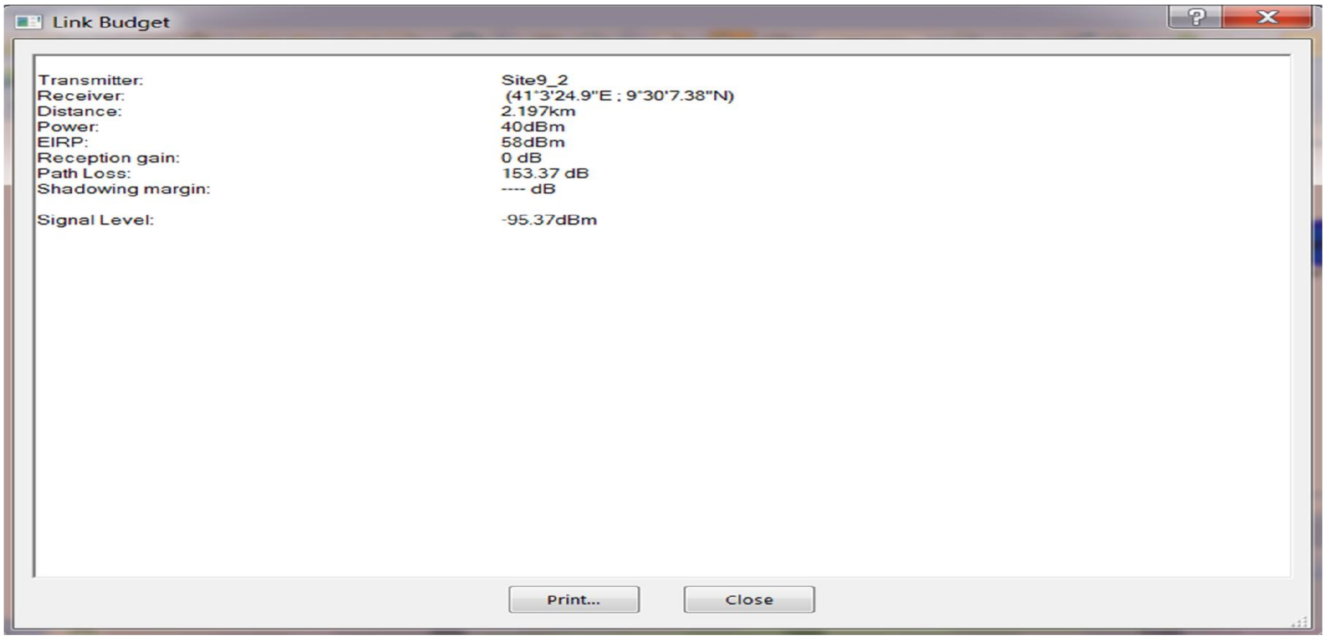
12	Site11	41°6'59.57"E	9°31'29.75"N	50	
13	Site12	41°9'12.09"E	9°30'8.69"N	50	
14	Site13	41°11'22.96"E	9°31'17.16"N	50	
15	Site14	41°13'42.79"E	9°31'59.95"N	50	
16	Site15	41°16'18.52"E	9°32'17.12"N	50	
17	Site16	41°18'44.04"E	9°32'16.95"N	50	
18	Site17	41°21'22.06"E	9°31'40.79"N	50	
19	Site18	41°22'26.49"E	9°33'53.86"N	50	
20	Site19	41°24'53.45"E	9°34'24.64"N	50	
21	Site20	41°27'15.87"E	9°33'51.69"N	50	
22	Site21	41°29'0.36"E	9°35'49.73"N	50	
23	Site22	41°31'21.24"E	9°34'59.54"N	50	
24	Site23	41°33'50.08"E	9°35'19.94"N	50	
25	Site24	41°36'18.4"E	9°35'41.2"N	50	
26	Site25	41°38'40.82"E	9°36'20.43"N	50	
27	Site26	41°41'9.68"E	9°36'26.16"N	50	
28	Site27	41°43'36.91"E	9°36'37.9"N	50	
29	Site28	41°46'2.48"E	9°36'42.71"N	50	
30	Site29	41°48'33.25"E	9°36'49.25"N	50	
31	Site30	41°51'2.37"E	9°36'43.76"N	50	
32	Site31	41°53'29.93"E	9°36'22.73"N	50	
33	Site32	41°55'16.52"E	9°38'6.92"N	50	
34	Site33	41°56'47.58"E	9°39'37.19"N	50	
35	Site34	41°59'11.13"E	9°40'19.75"N	50	
36	Site35	42°1'20.55"E	9°41'34.89"N	50	
37	Site36	42°3'21.19"E	9°43'1.98"N	50	
38	Site37	42°5'20.07"E	9°44'34.19"N	50	
39	Site38	42°7'8.49"E	9°46'16.64"N	50	
40	Site39	42°8'35.95"E	9°48'16.15"N	50	
41	Site40	42°10'15.64"E	9°50'7.11"N	50	
42	Site41	42°12'9.4"E	9°51'41.01"N	50	
43	Site42	42°14'3.16"E	9°53'13.15"N	50	
44	Site43	42°15'25.5"E	9°55'10.89"N	50	

45	Site44	42°17'49.21"E	9°55'55.08"N	50	
46	Site45	42°19'34.25"E	9°57'40.93"N	50	
47	Site46	42°21'41.58"E	9°58'59.55"N	50	
48	Site47	42°23'17.26"E	10°0'47.71"N	50	
49	Site48	42°24'48.02"E	10°2'44.1"N	50	
50	Site49	42°25'27.2"E	10°5'6.23"N	50	
51	Site50	42°26'40.52"E	10°7'16.27"N	50	
52	Site51	42°27'44.07"E	10°9'31.69"N	50	
53	Site52	42°28'46.96"E	10°11'47.15"N	50	
54	Site53	42°29'51.94"E	10°13'58.48"N	50	
55	Site54	42°30'58.34"E	10°16'14.65"N	50	
56	Site55	42°32'6.14"E	10°18'25.29"N	50	
57	Site56	42°33'13.27"E	10°20'35.24"N	50	
58	Site57	42°34'21.11"E	10°22'47.29"N	50	
59	Site58	42°34'40.86"E	10°25'12.72"N	50	
60	Site59	42°34'52.95"E	10°27'36.74"N	50	
61	Site60	42°34'52.51"E	10°30'2.74"N	50	
62	Site61	42°34'59.75"E	10°32'26"N	50	
63	Site62	42°35'2.11"E	10°34'49.26"N	50	
64	Site63	42°34'57.49"E	10°37'14.51"N	50	
65	Site64	42°34'53.58"E	10°39'39.77"N	50	
66	Site65	42°34'40.6"E	10°42'2.9"N	50	
67	Site66	42°35'28.98"E	10°44'17.54"N	50	
68	Site67	42°35'38.95"E	10°46'42.22"N	50	
69	Site68	42°35'44.8"E	10°49'4.14"N	50	
70	Site69	42°35'54.99"E	10°51'25.89"N	50	
71	Site70	42°36'30.56"E	10°53'50.94"N	50	
72	Site71	42°37'15.43"E	10°56'10.4"N	50	
73	Site72	42°37'53.61"E	10°58'19.98"N	50	
74	Site73	42°37'47.19"E	11°0'47.98"N	50	

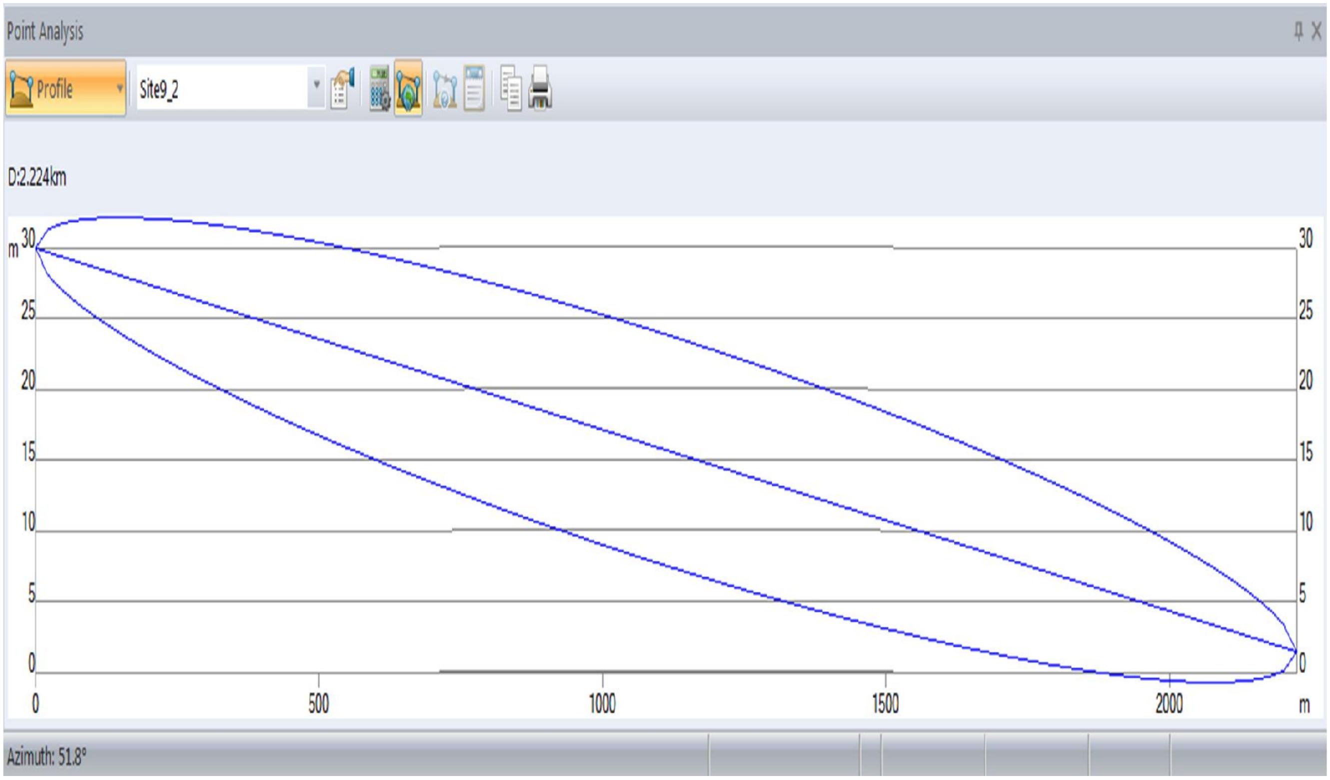
Table 5. 2: Proposed location of Bts along Meiso-Dewele

5.6 Performance Analysis of Meiso-Dewele Section

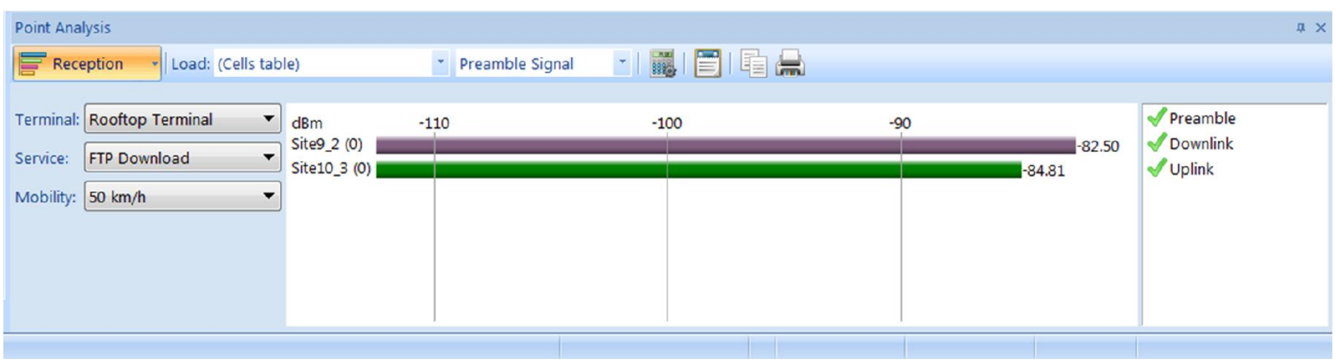
A random point is chosen between site9_2 and site 10_3 from the Meiso-Dewele section along with a receiver to analyze the cell edge throughput scenario. Link budget, Geographical profile and reception signal level of the selected point is shown in Figure 5. 9-(a), (b) and (c) respectively.



(a)



(b)



(c)

*Figure 5. 9: Point analysis and performance result of chosen sites for Meiso-Dewele section- (a), (b) & **(c)***

As we have discussed before for the case of Sebeta-Meiso, we can see from above figure (Figure 5. 9-(a) and (b)) a receiver is receiving a signal level -95.37 db from site9_2 at the distance 2.19 km far from a transmitter. However the pathloss is exceeded from the limit which we have calculated in previous section. So at this point as we can see from Figure 5. 9-(c) site10_3 have a better signal (-91.81dBm) level than site9_2 (-99.44dBm). Hence at this location handover will be held on.

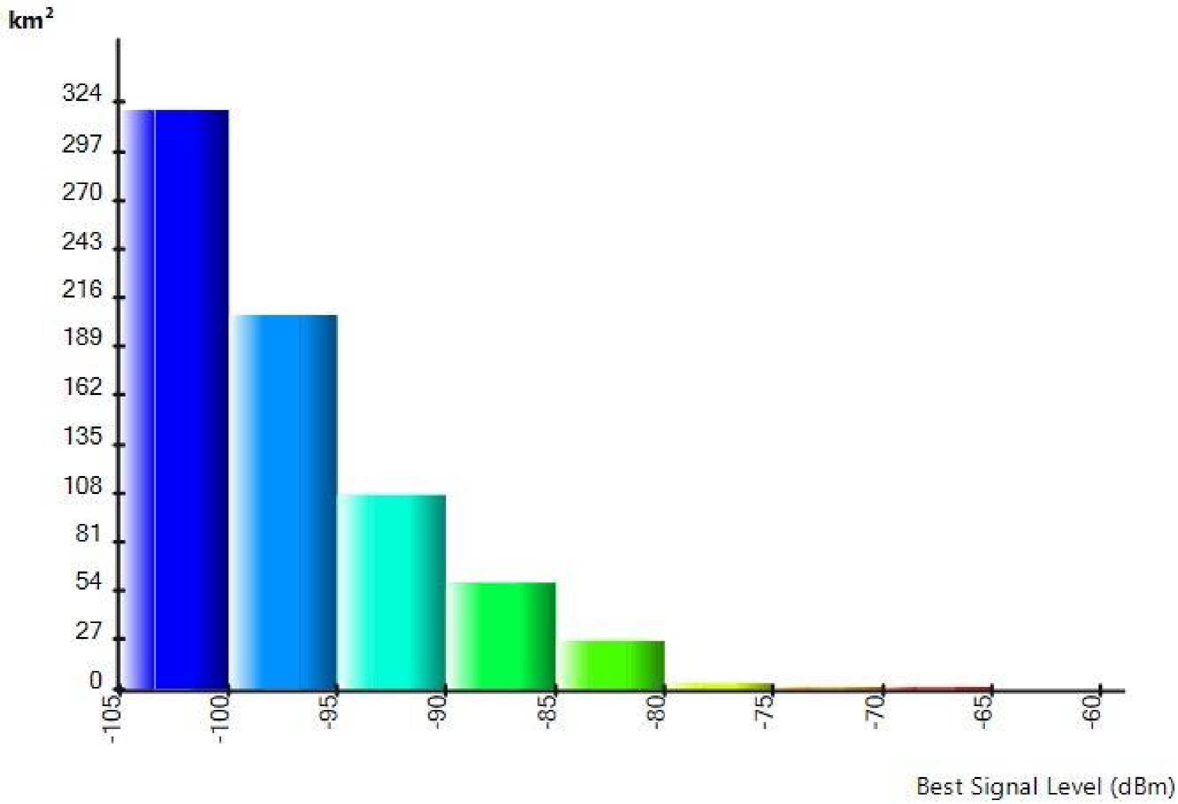


Figure 5. 10: Area coverage per each signal level

As we can see from the above figure (Figure 5. 10) that, the lowest signal level indicated by the blue color is covered an area of about 324km^2. Therefore we can conclude that the area covered with the low signal level which have indicated by blue color covers largest area than all other signal levels.

Chapter Six

6 Conclusion and Recommendations

6.1 Conclusion and Limitations

In the railway industry, communications were deployed mainly for the purpose of managing and regulating traffic flow. This sector of transportation system requires two modes of communication: those are communications occur between fixed elements of the rail infrastructure, which are based mainly in wired systems and those which take part in the fixed and mobile elements (communications known as “train-to-earth"). Those modes are capable to boost the efficiency and robustness.

In order to attain safe, efficient and competent transportation system in our country, radio network planning of WiMAX need serious assessment in coverage, capacity and quality requirements. The estimation of coverage and capacity should determine or provide the data about the nature of the route for the deployment and implementation process of the technology. In the process of doing this thesis, there have been different problems like lack of data of selected technology and related reference materials in our country.

As we seen in previous chapter (Chapter Four) 138 BTS transmitters with the maximum data rate of 2.1998Mbps/km are needed along the Addis Ababa to Djibouti railway route. The computed maximum number of BTS’s along Addis Ababa to Djibouti is 150 but the demographical factors of the route such as curves reduced the computed number to 138.

From the simulation result of Atoll software in Chapter Five, we can conclude that the theoretical performance figures, the coverage range of the cells per base station is 2.2km. And within this cell range WiMAX network can afford very good signal strength.

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. Since our aim is attaining safe transportation, using COST-231 Hata Model the same cell radius calculated along throughout route in order to reduce risks.

Currently implementing communication system on selected corridor is satisfactory for only train control purpose. But it is difficult to address extra services in order to satisfy the passenger’s demand of bandwidth, real-time control of station and train speed. For the future Addis Ababa to Djibouti railway route expected as the main gate way for tourists. This will forces the company (ERC) in order to enhance its system within every aspect. So the communication system is the base for all other systems improvement.

6.2 Recommendations

This work gives a seeable dimension and valuable estimation of the WiMAX radio network system for the purpose of train controlling, signaling, video surveillance in station and fast internet access for passengers though out the route. Though, this work also doesn't include core network dimensioning so this work needs greater investigation in order to make complete and practical in all aspects of fields. So this work can be extended farther. Also material cost and technology analysis is another way to enhance this thesis work. Considering more detail traffic of the route and doing survey on site brings this work forward to more practical.

In order to become more competent in transportation industry using better technology is the only choice in all aspect of services. Hence, on selected railway line WiMAX network deployment should take place soon.

Reference

[1] Itziar Salaberria,Roberto Carballedo and Asier Perallos; "Wireless Technologies in the Railway: Train-to-Earth Wireless Communications"; Deusto Institute of Technology (DeustoTech), University of Deusto Spain, 14, March, 2012

[2] Mwesiga W. Barongo, "Dimensioning Mobile WIMAX in the Access and Core Network: A case Study", Helsinki University of Technology, Finland, 2008.

[3] Yan Zhang Hsiao-Hwa Chen, "MOBILE WiMAX: Toward Broadband Wireless Metropolitan Area Networks", Auerbach Publications, 2008.

[4] WiMAX Forum, "Mobile WiMAX—Part I: A Technical Overview and Performance Evaluation", White Paper, 2006.

[5] WiMAX Forum, "Mobile WiMAX—Part II: A Comparative Analysis", White Paper, 2006.

[6] WiMAX Forum, " Deployment of Mobile WiMAX™ Networks by Operators with Existing 2G & 3G Networks", White paper, 2007.

[7] Ethiopian Railways Corporation, "Ethiopia/Sebeta-Djibouti/Nagad Railway Feasibility Study, Communication," Executive Edition, Volume II, September 2012, p. 10.

[8] Ethiopian Railways Corporation, "Ethiopia/Sebeta-Djibouti/Nagad Railway Feasibility Study, Signaling," Executive Edition, Part XVII, September 2012, pp.10-12.

[9] Ethiopian Railways Corporation, "Ethiopia/ Sebeka-Djibouti/Nagad Railway; Feasibility Study, Transportation Organization" Executive Edition, Part III, September 2012, pp.3-12.

[10] Ethiopian Railways Corporation, "Ethiopia/Sebeta-Djibouti/Nagad Railway Feasibility Study, Water supply and drainage" Executive Edition, Part XV, September 2012, p. 2.

[11] Ethiopian Railways Corporation, "Ethiopia /Sebeta-Djibouti/Nagad Railway, Feasibility Study, Economy and Traffic Volume," Executive Edition, Part II, September 2012, p. 25

[12] Ethiopian Railways Corporation, "Ethiopia/Sebeta-Djibouti/Nagad Railway, Feasibility Study, General Specification," Executive Edition, Part I, September 2012, p.73, p.174.

[13] Ethiopian Railways Corporation, "Ethiopia/Sebeta-Djibouti/Nagad Railway, Feasibility Study, Transportation Organization," Executive Edition, Part III, September 2012, pp.11-16.

[14] Ethiopian Railways Corporation, "Ethiopia/Sebeta~ Djibouti/Nagad Railway Feasibility Study, Informatization" Executive Edition, Chapter 18, Volume II, September 2012, pp.1-3

[15] Marina Aguado,"Broadband Communication Architectures for Train to Ground Communication:" Services The William W. Hay Railroad Engineering Seminar University of Illinois at Urbana-Champaign, Friday - 21 September 2012

[16] Y.Okumura, “Field Strength Variability in VHF and UHF Land Mobile Services” Rev. Elec. Comm. Lab, Japan, 1968.

[17] Fabricio Lira Figueiredo, Paulo Cardieri; “Coverage Prediction and Performance Evaluation of Wireless Metropolitan Area Networks based on IEEE 802.16”, WiMAX Forum, 2005.

[18] Kuo-Hui Li, “WiMAX Network Architecture”, WiMAX Solutions Division Intel Mobility Group, 2006.

[19] Jefferey G. Andrews, Arunabha Ghosh, Rias Muhamed;”Fundamentals of WiMAX: Understanding Broadband Wireless Networking”, prentice hall, 2008.

[20] Mohammad Shahajahan, ”Analysis of Propagation Models for WiMAX at 3.5 GHz”, Blekinge Institute of Technology, Sweden, 2009.

[21] http://enterprise.huawei.com/ilink/cnenterprise/download/HW_276910 visited 03/02/2016

[22] Benyam Getenet, ‘‘Dimensioning and Radio Network Planning of Mobile WiMAX: The Case of Addis Ababa’’, Addis Ababa, Ethiopia, February 2013

[23] Amir Masoud Ahmadzadeh, “Capacity and Cell-Range Estimation for Multitraffic Users in Mobile WiMAX”, University College of Borås, Sweden, 2008.

[24] Hara S. and R. Prasad, “Multicarrier Technique for 4G Mobile Communications”, Norwood Artech House, 2005.

[25] Frank Ohrtman, ”WiMAX Handbook Building 802-16Wireless Networks”, McGRAWHill Networking and Telecommunications, 2006.

[26] Umesh Sharma, ‘‘Comparative Study of Digital Modulation Techniques in WIMAX’’, International Journal of Engineering and Innovative Technology (IJEIT) Volume 2, Issue 2, August 2012

[27] Bharathui Upase, Mythri Hunukumbure, Sunil Vadgama ‘‘Radio Network dimensioning and planning for WiMAX Network”, Manuscript may 7/2007

[28] Lily Mishra, M.H.Patwardhan: ‘‘Review Of Various Adaptive Modulation And Coding Techniques In Wireless Network’’,

[29] Doug Gray, “A Comparative Analysis of Mobile WiMAX Deployment Alternatives in the Access Network”, WiMAX forum, 2007.

[30] https://www.scribd.com/doc/223277981/RSCom-Mtg-35-GSM-R-Interference-23-March-2011 visited 10/02/2016

[31] Muhammad Arshad Awan, “WiMAX Traffic Calculations in WRAP” Linköpings Institute of Technology, Sweden, 15/09/2009

Appendix-1:

```
%%%%%%%%%%%%%%% models for Ethio-Djibouti railway line in 10/6/3 m receiver antenna
height%%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=2.2;
d=0.0:0.25:N;
%frequency in MHz
f=2500;
%transmitter antenna heights 30 m
hb=30;
%receiver antenna heights 10/6/3 m
hr=15;
%%%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%%%

fsmodel=32.45+20.*log10(d)+20.*log10(f);

%%%%%%%%%%%%%%%% COST 231 W I model%%%%%%%%%%%%%%

%distance between buildings
B=200;
%street width B/2
w=2;
%Hmobile=h roof-h mobile(15-10)m we consider h roof is 15 m
Hmobile=5;
%street orientation angel 30 degree
theta=30;
Lori=-10+0.354*theta;
Lrts=-16.9-10.*log10(w)+10.*log10(f)+20.*log10(Hmobile)+Lori;
```

```
Lfs=32.45+20.*log10(d)+20.*log10(f);
%Hbase=h base-h roof(30-15)we cosider transmitter height is 30 m
Hbase=15;
Lmsd=-18.*log10(1+Hbase)+54+18.*log10(d)+(-4+1.5*((f/925)-1)).*log10(f)-9.*log10(B);
PLcwi=Lfs+Lrts+Lmsd;

%%%%%%%%%%%%ECC-33 Model %%%%%%%%%%%%

y=log10(hr)-0.585;
%frequency in GHz
f=2.5;
Afs=92.4+20.*log10(d)+20.*log10(f);
Abm=20.41+9.83.*log10(d)+7.894.*log10(f)+9.56*2.*log10(f);
%in urban environment the parameter a=3.6,b=0.005,c=20 in m
a=(5.8*2*(log10(d)));
b=13.958;
c=log10(hb/200);
Gb=c.*(b+a);
x=42.57+13.7.*log10(f);
Gr=x.*y;
PLecc=Afs+Abm-Gb-Gr;
%%%%%%%%%%%%%%%%%%Cost 231 hata Model%%%%%%%%%%%%%%%

%frequency in MHz%
f=2500;
%3dB in urban area%
cm=0;
ahm2=3.20.*(log10(11.75*hr))^2-4.97;
PLch=46.3+33.9.*log10(f)-13.82.*log10(hb)-ahm2+(44.9-6.55.*log10(hb))*log10(d)+cm;

%%%%%%%%%%%%%%%%%SUI model%%%%%%%%%%%

%100 m used as a reference
d1= 0.1;
```

```
%receiver hight
lambda=((3*10^8)/( 3500*10^6));
% frequency in MHz
f=2500;
%fading standard deviation s is 10.6 dB in urban
s=10.6;
a=3.6;
b=0.005;
c=20;
gamma=a-b*hb+c/hb;
PLsui=20.*log10((4*pi*d1)/lambda)+10*gamma.*log10(d/d1)+6.*log10(f/2000)-20.*log10(hr/2000)+s;

%%%%%%%%%%%%%%%%%%%% Ericsson Model 9999 %%%%%%%%%%%%%%%%%%%%%%%%%

g(f)=44.49.*log10(f)-9.56.*log10(f);
PL9999=36.2+30.2.*log10(d)-12.*log10(hb)+0.1.*log10(hb)*log10(d)-6.4.*log10(11.75*hr)+g(f);

%%%%%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%%%

plot(d,PLcwi, 'b+-',d,fsmodel,'ks',d,PLecc, 'r*-',d,PLch,'g.-',d,PLsui,'k.-',d,PL9999,'m.-');
grid on;
legend('cwi','fspl','ECE','COST 231 HATA', 'SUI','SE')
%%%%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%%%

xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('10 m receiver antenna height in urban environment')
```