



ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

**Multichannel Multipoint Distribution Service Coverage Planning for Addis
Ababa City**

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Multichannel Multipoint Distribution Service Coverage Planning for Addis Ababa City

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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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Abstract

Multichannel Multipoint Distribution Service (MMDS) is one of the currently used Fixed Wireless Broadband (FWB) systems that provide multichannel broadcasting, broadband internet and other interactive services. It works mostly at 2.5-2.7 GHz frequency band through terrestrial propagation. As its name implies, it provides multiple television channels because of its high frequency band. It is more cost efficient than cable and satellite broadcastings for relatively small coverage areas like cities and towns.

Addis Ababa is a city with a population size of more than 4 million that have complex linguistic, cultural, religious and ideological varieties. The city is the site for many diplomatic community and hosts many international organizations. Moreover, it accommodates many international conferences. Addis Ababa, which has now only few television channels, needs to benefit from broadcast communication systems like MMDS that can provide far more number of channels with relatively lower cost to foster its national and international values for maximum benefit.

In this thesis, coverage planning of MMDS, which is an integral part of the entire planning, is carried out for Addis Ababa. In coverage planning, propagation models are used to predict the path loss at a certain distance from the transmitter site considering terrain and other environmental effects. The planning involves two steps; firstly, system dimensioning is done using the Institute of Electrical and Electronic Engineering, *IEEE 802.16 (Stanford University Interim) model*. Secondly, detail planning is accomplished using the International Telecommunications Union Recommendation, *ITU-R P.1546-5 model*.

In coverage planning, the important parameters are the transmitter output power, number of transmitters needed, locations of transmitters for maximum coverage, and the positions and output powers of repeaters to cover small shadowed areas. Most of these parameters are determined based on the propagation models used.

This work took 10 high altitude locations in the city as candidate sites for maximum coverage. The result shows that one 70 meter transmitter with 57dBm output power located at a mountain around Lebu area (South-Western part of Addis Ababa) and a 25 meter repeater with 32 dBm

output power located around Country Club Developers Homes (North-Eastern tip of Addis Ababa) can cover 96.14% of the area of the city, which is satisfactory coverage.

Keywords

Multichannel Multipoint Distribution Service, Propagation models, Broadcasting, Coverage planning, System dimensioning, detailed planning, ITU-R P.1546-5 model.

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Abbreviations

AM	Amplitude Modulation
COFDM	Code Orthogonal Frequency Division Multiplexing
COST	Cooperate in Science and Technology
CPE	Customer Premise Equipment
DSB	Digital Sound broadcasting
DTM	Digital Terrain Map
DVB	Digital Video Broadcasting
ERP	Effective Radiated Power
FCC	Federal Communications Committee
FEC	Forward Error Correction
FM	Frequency Modulation
FSPL	Free Space Path Loss
FWB	Fixed Wireless Broadband
IEEE	Institute of Electrical and Electronic Engineering
ITFS	Instructional Television Fixed Service
ITU-R	International Telecommunications Union Radio Sector
LTE	Long Term Evolution
MMDS	Multichannel Multipoint Distribution Service
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shifting Keying
SUI	Stanford University Interim
UHF	Ultra High Frequency

VHF

Very High Frequency

WiMAX

Worldwide Interoperability for Microwave Access

Chapter One: Introduction

Chapter One: Introduction

1.1. Introduction to Television Broadcasting

Since the mid-nineteenth century numerous exciting discoveries and researches has been carried out on electromagnetic (EM) propagation and its effective use for communication. Many EM communication technologies have evolved in the past century of which television broadcasting is one of the earliest applications of these efforts [1].

As all wireless services, television broadcasting involves transfer of information through electromagnetic signals which can be radiated into space with the help of an antenna. The information signal modulates a radio frequency (RF) carrier which could be either in the VHF, UHF, or in the microwave frequency ranges.

Television broadcasting commonly works at these higher frequency ranges as it requires large bandwidth and as the lower frequency bands are needed for other services [2]. As we go up to the microwave and higher frequency bands, the path loss increases and, as a result, the signal travels shorter distance with at least near line-of-sight requirement [3]. The frequencies just at the lower edge of the microwave band, however, can be used for terrestrial television broadcasting with additional advanced error correction and modulation techniques needed to increase the coverage and overcome multipath and other propagation phenomena.

Based on the modulation schemes and error correction methods used, the development of television (TV) broadcasting involves two phases: analog and digital TV broadcasting. In analog TV broadcasting, which is the earlier one, the information signals are analog EM waves that have continuous amplitude or frequency variations depending on the modulation techniques used. In this case, in addition to the picture, another RF carrier is required for transmitting the sound [2]. In analog TV broadcasting, Amplitude Modulation (AM) is used for the video signal as it provides better bandwidth and Frequency Modulation (FM) is used for the sound signal as it is effective in noise reduction [2].

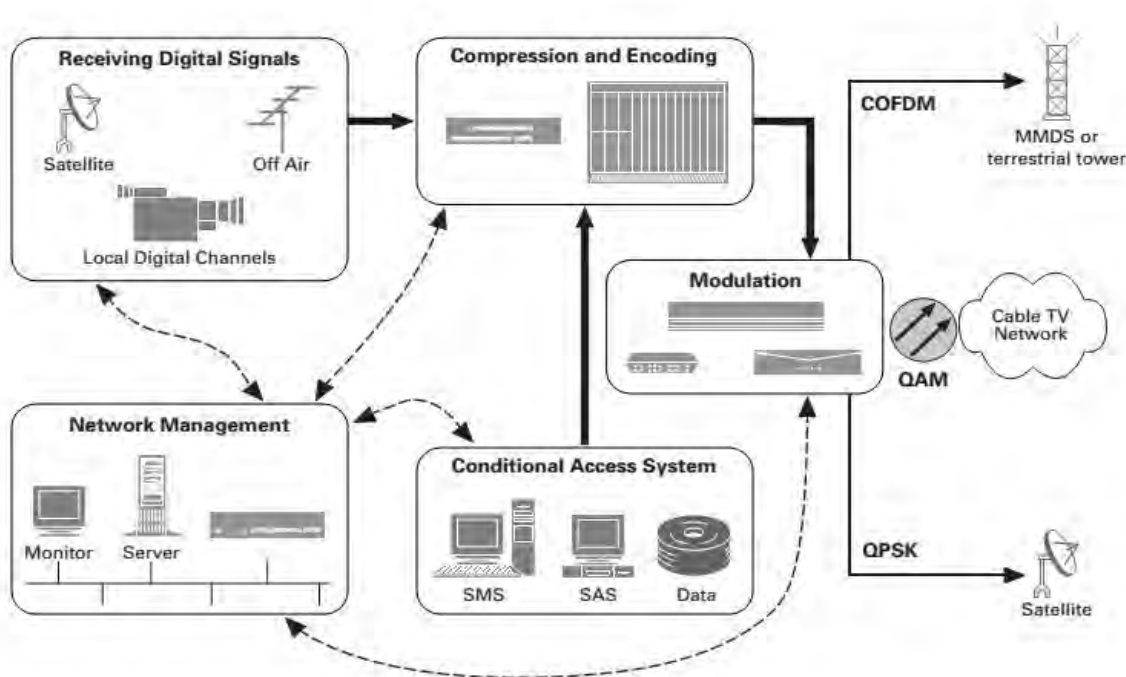


Figure 1- 1: Basic building blocks of a digital broadcasting system [4].

Digital TV broadcasting is a relatively recent development in TV broadcasting history. The building blocks of digital TV system are compression and encoding, digital modulation, network management, and conditional access system (Figure 1-1 above).

- **Compression and Encoding** - Compression enables delivery of high quality video and audio to consumers using a small amount of network bandwidth. Its main goal is to minimize the storage capacity of information.
- **Digital Modulation** - The modulation technique used by TV operators will depend on the geography of the franchise area and the overall network architecture. The three major types of digital modulations used in digital TV are Quadrature Amplitude Modulation (QAM), Quadrature Phase Shift Keying (QPSK), and Coded Orthogonal Frequency Division Multiplexing (COFDM). MMDS and other terrestrial operators mainly use the COFDM modulation scheme because it operates extremely well in heavily built-up areas like cities [4].
- **Network Management and Conditional Access System** control the overall digital information flow.

1.2. Issues in Broadcast Coverage Planning

Coverage planning is an integral part of the general planning of any wireless communication service in general and TV broadcasting planning in particular. As a service is often intended to a certain specific area, it should cover that area in economically efficient manner with good quality of service.

Many parameters like heights of the transmitter and receiver antennas, output power, number of transmitters, and location of transmitters are important as coverage is determined by these factors. Coverage planning involves determining these parameters for efficient and good quality of service in a specific area.

Mostly, coverage planning is carried out in two phases: system dimensioning and detailed coverage planning [3]. System dimensioning involves the first stage of estimating coverage simpler but less precise propagation models that only consider generalized environmental data, usually in the form of categories like urban, sub-urban, and rural. It is important to simplify the process of adjusting and tuning parameters for reasonable coverage planning.

After the general estimation of coverage with system dimensioning, more complex propagation models that consider better environmental data are used for detailed planning. Detailed planning is done so that path loss from the transmitter to each cell on the covered area, according to the precision of the digital environmental data, is predicted. Those cells that have path loss higher than the maximum threshold value are assumed to be areas not covered by the service.

1.3. MMDS: Brief History and Technological Overview

MMDS is one among the most common television broadcasting services. It operates mostly at 2.5-2.7 GHz frequency range. It is the result of decades long researches to realize broadcast at higher frequencies terrestrially. It evolved from metropolitan distribution system (MDS) and Instructional Television Fixed Service (IFTS) in the US starting from the late 1960's [5].

It has been highly popular and regulated by the Federal Communication Committee (FCC) of the United States since the mid 1980's. After series of amendments of the regulation, it became possible for a wireless cable system to offer up to thirty-one 6 MHz channels in the 2.5 to 2.7 GHz band (which was solely used for IFTS) [5].

After that, MMDS has evolved to become a well established, proven, mature TV distribution technology which has taken its place alongside cable, broadcast and satellite as a medium for transporting television programs direct to homes and to cable head-ends. Since 1984, TV delivery by MMDS systems has been developed in various countries throughout the world. Australia, Canada, France, Hong Kong, South Africa, Scandinavia, Eastern Europe and Latin America are among several other countries and regions throughout the world [5].

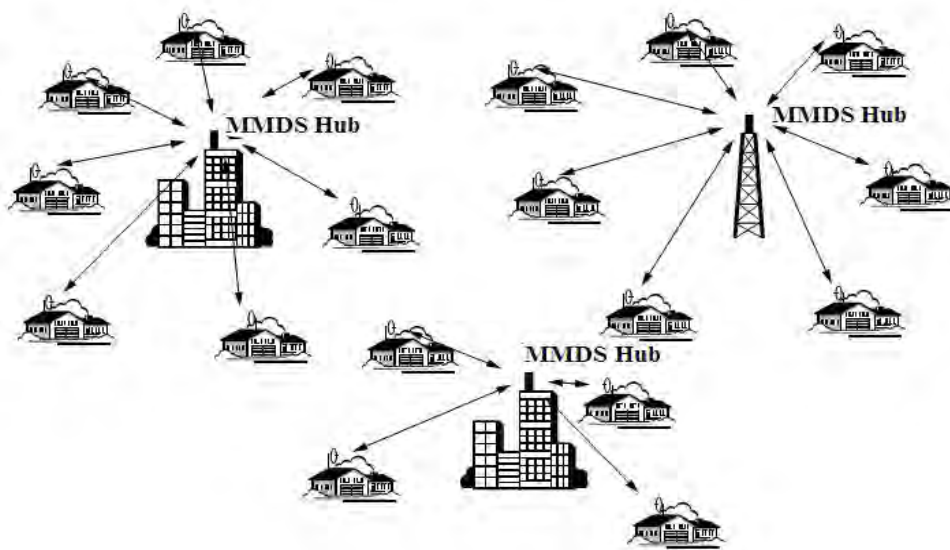


Figure 1- 2: MMDS network diagram [3].

Currently, MMDS has been an acronym that denotes the use of frequencies in the 2.5 to 2.7 GHz band for analog and digital TV broadcasting. Analog versions of these systems are used worldwide in many countries, and have served as inexpensive alternatives to cable TV services. Digital versions of the service have also been developed recently. Figure 1-2 above depicts what MMDS network seems. Each MMDS hub transmits for a certain area depending on coverage parameters. A region that is intended to get MMDS service may be covered by one or multiple

transmitter hubs accordingly. Even though not indicated in Figure 1-2, hubs are connected with the source either with highly directional microwave links or through optical fiber.

Around the world, the spectrum allocation for MMDS differs among countries. In Canada, the MMDS allocation is 90 MHz of spectrum, in the USA 186 MHz of spectrum is typically available to larger operators, and around the world, between 186 MHz and 200 MHz is used within the 2.5 to 2.7 GHz band [6]. The MMDS frequency for Ethiopia is discussed in Section 4.3 at the topic about frequency.

MMDS analog service with 200 MHz band provides about 30 channels of programming to subscribers. Digital MMDS increases the number of channels to more than 300. Digital MMDS also reduces the line-of-sight restrictions by providing a more efficient signal that will require less signal strength at the set-top box. Digital signals will need about 100 times less signal strength than analog signals, which translates to a substantial increase in the range of service area. Where an analog signal degrades with distance, the digital signal will remain constant and perfect as long as it can be received. In addition to more channels, digital MMDS customers will also be able to receive a variety of Internet, telephony, and interactive TV based services.

MMDS is preferable for certain specific cases. Terrestrial wireless fixed access systems like MMDS, as opposed to competing access methods such as fiber based, copper-based, cable-based, and satellite based systems or hybrids, have specific advantages against each of these systems. For fiber, copper and cable-based systems, local content and programming are available; however two-way high data rate capacity requires a build-out of the existing infrastructure. Build-out takes time and money [7].

A wireless system such as MMDS is a cost effective solution for service providers to extend their cable coverage to the immediate rural area. Cable services such as high-speed Internet, TV and video on-demand are commonly found in cities and towns. Service providers can extend services to the immediate surrounding rural area using a wireless system such as MMDS. It is less expensive than using cable or fiber due to the average distance between subscribers.

On another perspective, Middle Eastern countries such as Saudi Arabia, Kuwait, Jordan and Dubai all see wireless cable as a means of countering the access to Western programming made possible by direct satellite broadcasting [6].

In addition, using satellite broadcasting to provide social and domestic services for small areas like towns and cities is not economical. Therefore, MMDS can be a good solution for relatively small areas, such as cities and towns that need multiples of channels for different purposes.

Addis Ababa is one of these cities that need broadcast services with multiple channels. The reason is that the city is inhabited by people with diverse identities and hosts many international conferences and diplomatic activities.

1.4. Status of Broadcast Systems in Addis Ababa

The existing terrestrial broadcasting systems in the country, more specifically in the capital city, hardly satisfy global broadcasting standards in service quality and coverage. Though few government-owned television and radio services are being delivered through terrestrial and satellite broadcasting, it will not be economical to provide diversified multiple channels through this way as satellite broadcasting is not economically viable.

Despite these problems, the interest of the inhabitants of the city for more qualified and diversified channels has been intensifying for the past few years. One can see with what rate satellite receiver antenna are being mounted in the city even by people with low income. Services accessed through these satellite antennas are from satellites like Arabsat which broadcast international news, entertainment and other services that focus mostly on global issues.

1.4.1. History of Broadcasting in Addis Ababa

In Ethiopia, radio broadcasting started around 1933 by the then Ethiopian postal, telegraph and telephone office. This broadcasting was first transmitted in and around Addis Ababa. This radio

broadcasting was later transferred to a broadcast station around Nifase Silk area on Sep. 10 1935 [8].

During the Italian occupation, the enemy was using radio broadcasting for propaganda purpose. This service was, after Italian withdrawal, expanded to Asmara and Harar in six languages. The wide scale expansion of radio broadcasting for educational purpose by the Ministry of Education in 1983 was notable in Ethiopian broadcast history.

Television broadcasting in Ethiopia started in 1962, in connection with the establishment of Organization for African Unity (OAU) in Addis Ababa that year. The television station was formally established in 1964. Since that time, television broadcasting has been expanding to cover the whole country.

In 1998, the government approved a Broadcast Decree that will facilitate the growth of broadcasting in Ethiopia. Number 178/91 of this decree ordered establishment of an organizational body to manage and facilitate wireless broadcasting. It was finally established in 2001 with a name ‘Ethiopian Broadcast Authority (EBA)’ [8].

1.4.2. Brief Topographic and Demographic Description of Addis Ababa City



Figure 1- 3: Satellite map of Addis Ababa city [10].

The city of Addis Ababa is over a hundred years old. It was established in the late 19th century by Emperor Menelik II as the permanent capital of the then emerging modern Ethiopian state [9].

Addis Ababa is a city established at an average elevation of about 2,500 meter above sea level. Because of the presence of mountainous areas and hills, the elevation difference between different parts of the city reaches 1000 meter. The city covers a total area of about 540 km². The terrain platform of the city is very irregular and it has its own impact on high frequency coverage planning as these kinds of services need near line-of-sight propagation [2]. The center of the city lies on an undulating topography with some flat land areas. The topography is undulating and form plateau in the northern, western and southwestern parts of the city, while gentle morphology and flat land areas characterize the southern and southeastern parts of the city [11].

The population of Addis Ababa was 2,739,551 according to the 2007 population census and it is now estimated to reach about 4 millions. About 27 percent of the estimated urban population of the country lives in Addis Ababa, and this qualifies the city as the country's foremost urban center. The city is also a diplomatic center as it is inhabited by many African and international organizations.

The purpose, scope, methodology, and other preliminary issues of MMDS coverage planning for Addis Ababa city will be presented in the following subsections of this chapter.

1.5. Statement of the Problem

It is a fact that, in this information era, people are using modern communication technologies to maintain and develop their values and satisfy their information needs. Television broadcasting programs play important role in this respect.

In addition, the country is in its effort to bring about fast economic growth. The importance of media to create a civilized society is unquestionable. Much educational, news, cultural, entertainment and other television channels with more of domestic contents are needed for the country in general, and for Addis Ababa in particular.

Currently, only little government owned television channels are operational [8]. The digitalization of already existing analog TV is underway by the government of Ethiopia. It will in fact increase the available channels, though there is no complete information on the work yet.

MMDS is one possible solution for Addis Ababa city. Its local nature and ease of installation makes it preferable for the city. It can provide about 33 analog TV channels and more than 300 digital TV channels. Unlike satellite and cable TV broadcasting, it is inexpensive and can swiftly be installed. In addition, as MMDS can be modified to provide other interactive services like broadband internet, it has a promising future for the flourishing vibrant city [7].

1.6. Objectives

1.6.1.General Objective

The overall objective of this thesis is to carry out MMDS coverage planning for Addis Ababa.

1.6.2. Specific Objectives

Specifically, the thesis intends to accomplish the followings:

- Understanding the procedures in carrying out coverage planning for the general fixed wireless broadband (FWB) systems and MMDS, in particular;
- Choosing the best empirical propagation models for MMDS system dimensioning and detailed planning. This step also involves identifying the various input and output parameters required for the planning;
- Identifying the current broadcast system in Addis Ababa along with expected needs and demands of its residents;
- Implementing the propagation models using Matlab software and carrying out coverage planning; Changing the grid format digital terrain map data into formats, that can be manipulated with Matlab, is one major activity in this step;
- Analyzing and discussing results and coming up with possible recommendations.

1.7. Methodology

- Review of books, reputable articles and journals, and International Telecommunications Union Radio Sector (ITU-R) publications related to MMDS planning;
- Selecting two propagation models: one for system dimensioning and the other for the actual detailed planning,
- Simulating these models,
- Simulating coverage using Digital Terrain Map (DTM) of Addis Ababa city through MatLab Software,
- Analyzing and discussing simulation results.
- Finally, providing recommendations and showing forth further works.

1.8. Scope and Limitation

1.8.1. Scope of the Thesis

This thesis is MMDS coverage planning simulation work based on the available DTM. The scopes include:

- The thesis reviews available MMDS related previous works and the best propagation models are chosen for the plan;
- Using MatLab simulation and the available DTM, path loss map of Addis Ababa city is predicted ;
- The simulation results are analyzed and discussed.

Optimization of the planning parameters and experimental verification of the predicted results is beyond the scope of this thesis.

1.8.2. Limitation of the Thesis

The thesis is done based on a DTM which has a precision in terms of its elevation data of 5x5 m and it does not include 3D building data. Therefore, the environmental information is not precise enough to use physical propagation models that are very accurate in their signal strength prediction.

Therefore, the prediction results in this work may not be very accurate if they are compared with measured data from field experiments. But, the prediction is still very reliable as the empirical ITU-R 1546-5 model we used for the detailed planning is well respected for its reliability in high frequency broadcast field strength predictions [12].

1.9. Contribution of the Thesis

The thesis has very important contribution to realize MMDS in Addis Ababa. As coverage planning is a very crucial stage of any wireless service planning, the work done in this thesis will be used as a part of overall MMDS plan that may be developed and implemented by interested body.

In addition, as MMDS is a fixed wireless broadband (FWB) service, this work can be a good input to plan other services that operate around MMDS frequency.

1.10. Thesis Layout

The thesis layout is framed in such a way that it shall give progressive understanding of the planning process and the final results. The first Chapter presents introduction about the thesis and states the problem, the objective of the work, scope and limitation, and finally the methodology followed in the work.

As the first phase of the work is naturally reviewing related works, Chapter 2 and Chapter 3 are devoted for this purpose. Chapter 2 presents some details about propagation models, propagation phenomena and discusses five empirical models that are widely used for fixed wireless

broadband (FWB) systems coverage planning system dimensioning. In Chapter 3 discusses ITU-R P.1546-5 propagation model, which is used for the detailed coverage planning in this thesis work.

Analysis and discussion of results is discussed in Chapter 4. In the first section of this Chapter, the performance comparison of the five empirical models discussed in Chapter 2 to select one model that was used for system dimensioning is presented. In the other subsequent sections of the chapter, the main results of the planning and its graphical representation are discussed. Finally, recommendations are presented in the last chapter, Chapter Five.

Chapter Two: Propagation Models for MMDS Broadcast System Dimensioning

Chapter Two: Propagation Models for MMDS Broadcast System Dimensioning

2.1. Introduction

In wireless communication, *propagation loss* occurs when an EM signal propagates from a transmitter to a receiver. The main causes for this loss are reflection, diffraction, absorption by objects in the environment, and scattering [13]. But, even in the absence of these factors, there is free space path loss as the distance travelled by the signal from its source increases. Variations of transmitter and receiver antenna heights also produce losses [14].

A fundamental element of wireless communication system planning is predicting the signal strength at some location that results from a transmitter at some other location. Accurate characterization of the radio channel, through key parameters and mathematical models, is important for predicting signal coverage, analysis of interference from different systems, and determining the optimum location for installing transmitting antennas [15].

Propagation modeling is an effort to predict what happens to signals en route from the transmitter to the receiver. Traditionally, ‘propagation models’ is the term applied to those algorithms and methods used to predict the median signal level at the receiver [3]. Such models typically predict the path loss along a link or the effective coverage area of the transmitter. A propagation model is also called a *path-loss calculation* [15, 16].

There are different models to calculate path loss [17]. The best propagation model for a particular study depends on the type of communication system, the area where it will be used and any particular regulatory standards that may apply.

The most common approaches to propagation modeling are *empirical models* that use measurement data to define a model path loss equation and *physical models* that use physical radio wave principles such as free space transmission, reflection or diffraction [16].

2. 2. Classification of Propagation Models

Studies have been carried out in the past several decades that have created propagation models of different kinds. In this section, following the classification in [3], we briefly review representative classes of propagation models that are used for fixed broadband link design.

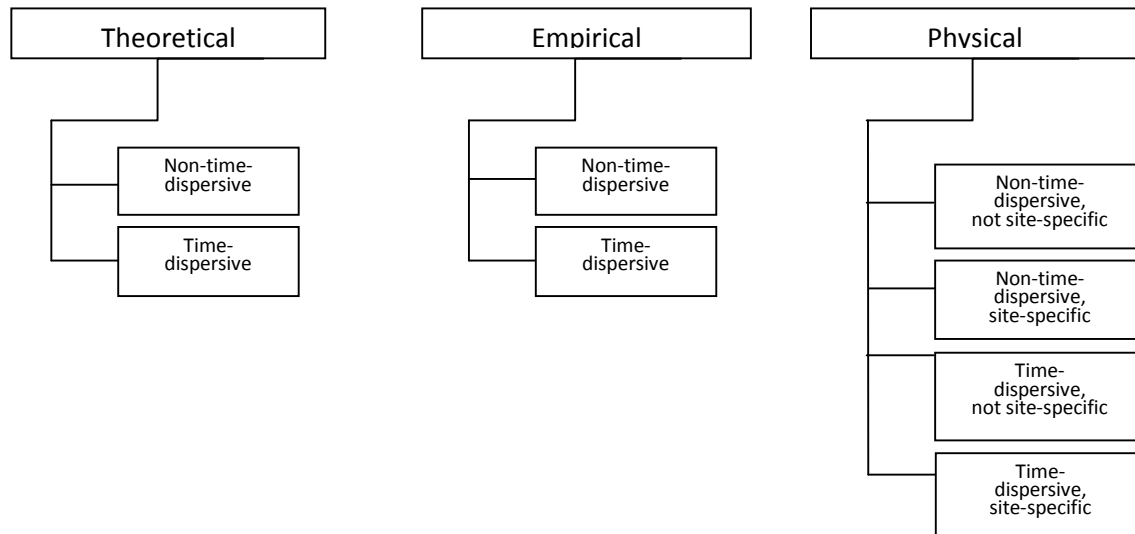


Figure 2- 1: Classification of Propagation Models [3].

The three main categories are *theoretical*, *empirical*, and *physical models* as shown in figure 2-1. Each of the categories is briefly described in the followings sub-sections.

2.2.1 Theoretical Models

Models in this category are based on some theoretical assumptions about the propagation environment. They do not directly use information about any specific environment, although the assumptions may be based on measurement data or physical laws. Theoretical models are useful for analytical studies of the behavior of communication systems under a wide variety of channel response circumstances, but because they do not deal with any specific propagation information, they are not suitable for planning communication systems to serve a particular area. Theoretical

models have relatively little application to fixed broadband wireless systems except as they may be applied to predict rain attenuation [3].

2.2.2. Empirical Models

Empirical models are based on measurement or observations of signal performance in real propagation environments. Their use for *dimensioning* non-line-of-sight (NLOS) point-to-multipoint systems is widespread.

The accuracy and usefulness of such empirical models depend on the environment in which the original data for the model were taken and how universally applicable that environment is. An example is the Okumura-Hata model in which propagation path loss is defined for urban, suburban, and open environments. However, one needs to characterize if the ‘urban’, ‘suburban’, and ‘open’ environments under study are reasonably similar to those areas where the measurement data were taken during the development of these models.

In spite of their area dependency, empirical models are widely used because they are simple and allow rapid computer calculation. Some of the models that are used in fixed wireless broadband design will be discussed in Section 2.3.

However, they are used for detailed system planning only when the environmental data available is not precise enough to use physical models. ITU-R P.1546-5 model is one of those empirical models that can be used for detailed planning in such cases.

2.2.3 Physical or Deterministic Models

Physical models rely on the basic principles of physics rather than statistical outcomes from experiments to find the EM field at a point. Deterministic models often require complete 3-D map of the propagation environment as the models trace the path of the signal across the terrain according to the EM propagation principles. An example of a deterministic model is ray tracing model. These models require complex algorithms and relatively powerful computing devices.

2.3. Propagation Phenomena at Microwave Frequency Band

Owing to the use of microwave frequencies for MMDS television broadcasting, direct reception of TV signals is limited to around line-of-sight distances. For extending broadcast service, relay stations that receive the signal via microwave links or coaxial cable and rebroadcast the signal to the extended regions are needed. A chain of such terrestrial relay stations can cover wide areas. Moreover, satellite television is becoming a wide ranging and powerful mass communication.

As radio waves propagate in the earth's environments, they may undergo changes in their paths due to the following phenomena:

- As radio waves propagate in the earth's environments, they may undergo changes in their paths due to earthly structures; i.e., they may be reflected by the ground, mountains, buildings, etc.;
- Refracted and change their direction as they pass through the layers of the atmosphere which has different densities due to heat, moisture content, etc. or different degree of ionization;
- Diffracted around tall massive objects to bend around in their shadows; absorbed and attenuated as they pass through media-containing water vapor, oxygen, etc.
- Absorbed by the atmosphere and attenuated by rain.

Let us see each of them briefly.

2.3.1. Reflection

At low, medium and high frequencies, the radio waves pass through large solid objects of dimensions smaller than their wavelengths, as the attenuation factor rises with increase in frequencies. The VHF, UHF, and microwave frequencies find it progressively difficult to pass through such objects.

Ultimately, the object reflects the signal waves back, with the efficiency of reflection increasing with frequency. It follows that reflections at microwave frequencies will be more numerous than that at lower frequencies, but the problem can more readily be overcome by using directional antennas at microwave propagation that can be oriented to favor the direct signal and reject the reflected ones (9). Figure 2-2 below shows a reflection phenomenon on a rugged surface.

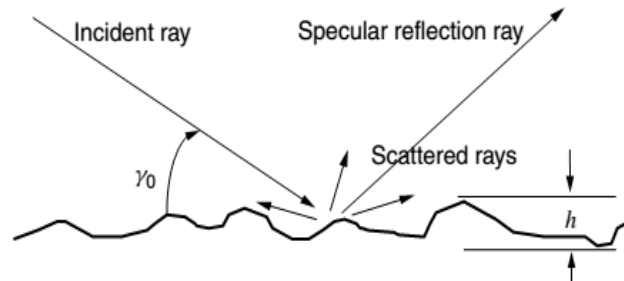


Figure 2- 2: Reflection from a rough surface [3].

At the point of reflection, phase angle changes up to 180° can occur depending on the plane of polarization and angle of incidence, besides some absorption of the signal [3].

2.3.2. Refraction

In general, the temperature of the air in the troposphere decreases about 2°C for every 300 m increase in height above ground [3]. Because of this temperature fluctuation, the wave front propagation direction bends downwards towards the earth's surface as the wave travels through the atmosphere. This bending process is known as *refraction*. Atmospheric refraction is very important in television broadcasting in that it extends the radio coverage horizon [2].

2.3.3. Diffraction

Diffraction occurs when there is a partial blocking of a portion of the wave front by an object of some kind. When radio waves encounter an edge of an obstacle, the dimensions of which are of the order of the wavelength, there is reception of the waves behind the obstacle. This is due to

the spherical wave fronts from points in the unobstructed side. They produce a succession of interference fringes that become weaker as one moves away from the edge of the obstacle. The MMDS signals may be received in this manner behind tall buildings and hills [2].

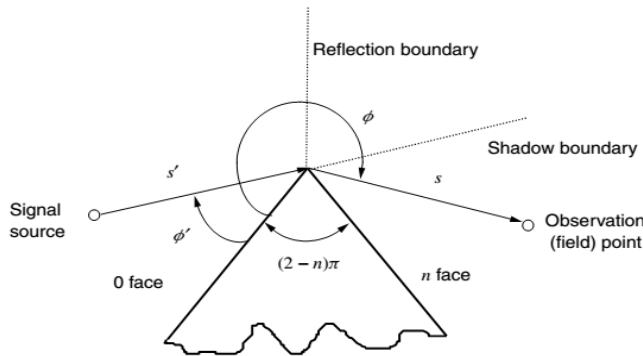


Figure 2- 3: 2D of view wedge diffraction geometry [3].

2.3.4. Atmospheric Absorption

The atmosphere is made up of a collection of gases. At certain frequencies, the gases can also directly attenuate the EM wave, in addition to refraction.

Figure 2-4 shows a graph of the atmospheric absorption loss as a function of frequency. We note that attenuation increases with an increase in frequency. The peaks in the attenuation in Figure 2-4 have resulted in certain frequency bands being considered less desirable than others for wireless communication purposes. As it can be read from the figure, the absorption loss for MMDS is around 0.008 dB/km.

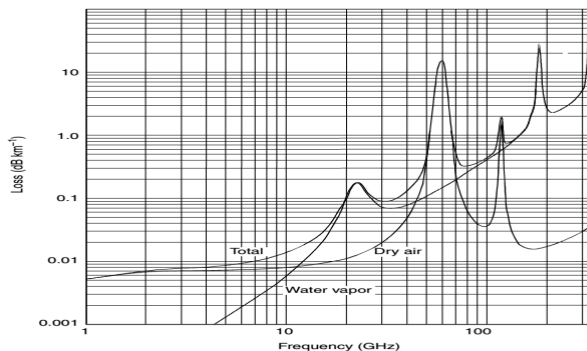


Figure 2- 4: Attenuation versus frequency due to the atmospheric gases [3].

2.3.5. Rain Attenuation and Depolarization

Rain is one of the challenging phenomena to be considered in EM wave propagation for fixed broadband wireless systems. In fact, in many systems and in many locations, attenuation due to rain is the single factor limiting the range of high-reliability microwave links.

Rain attenuation in dB/km as a function of frequency is shown in Figure 2-5 for several different rain rates.

As EM wave propagation is a complex and multidimensional phenomena, the elements of propagation briefed above are not exhaustive; they are the important and the highly relevant ones. These elements are considered in the development of propagation models that are used for TV broadcast and other wireless systems. These propagation models are discussed in chapter three.

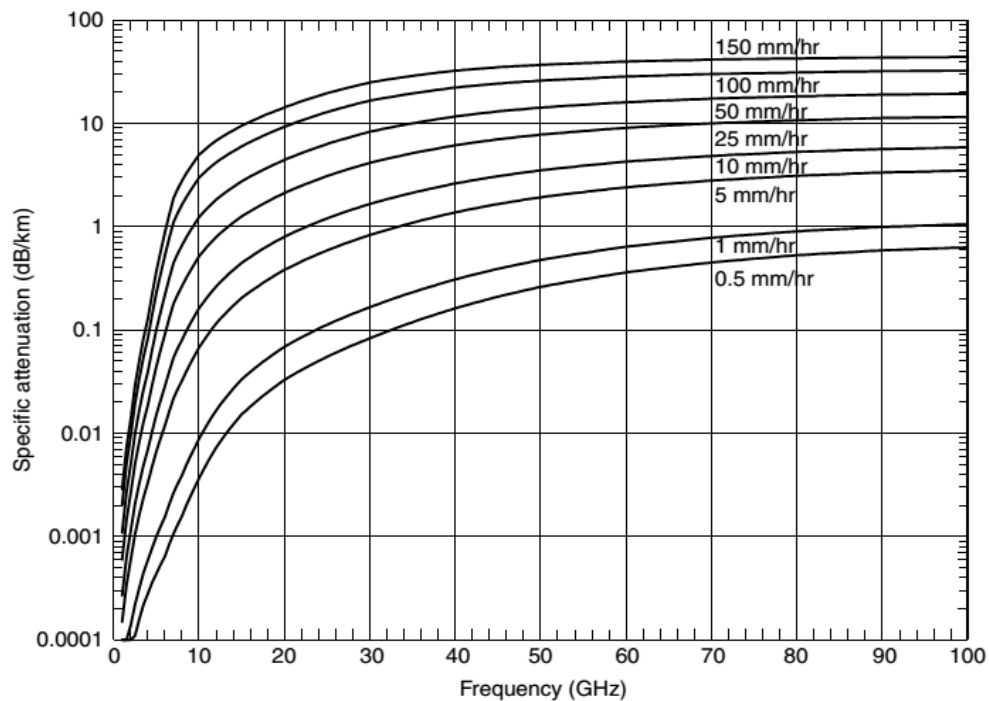


Figure 2- 5: Specific attenuation due to rain in dB/km versus frequency for vertical polarization ($\tau = 90$ degrees) and a horizontal propagation path ($\theta = 0$ degrees) [3].

2.4. Propagation Models for MMDS Coverage Planning System Dimensioning

As discussed in Section 2.2.2, most empirical propagation models are used to estimate the coverage area a transmitter can cover with specified parameters like transmitter antenna height, power output, receiver antenna height, and so on. This process of estimating coverage area as a starting point for further detailed planning with a more complex propagation model is called *system dimensioning*.

Propagation models discussed in this section are empirical models that are widely used for system dimensioning around 2.5 GHz frequency band. The following five empirical models were chosen from literatures based on this merit and one among them was selected for this work in Section 4.2 and, was used for system dimensioning.

2.4.1. Free Space Path Loss (FSPL) Model

For Free Space Path Loss model (FSPL), the propagation environment is assumed as free space. It was derived by Herald T. Friis, a Danish-American radio engineer, one of the pioneers of radio wave propagation modeling in 1945 [15]. Path loss in free space, PL defines how much strength of the signal is lost during propagation from transmitter to receiver without any obstruction in free space. FSPL model is dependent on frequency and distance. The calculation is done by using the following equation [13]:

$$PL = 32.45 + 20\log_{10}(d) + 20\log_{10}(f) \quad (2.1)$$

where PL is path loss in dB, f is frequency in MHz, d is the distance between transmitter and receiver in kilometer. This model can be used in a clear line-of-sight microwave link and also in satellite communication. It is the foundation for all other models [15].

2.4.2. IEEE 802.16 (SUI) Model

This model is developed by Institute of Electrical and Electronics Engineers (IEEE) working group 802.16 for fixed broadband systems below 11 GHz. It is informally known as Stanford University Interim (SUI) model [3]. The SUI models were specifically defined for use in the US MMDS frequency band from 2.5 to 2.7 GHz [18, 19]. According to the categorization in Section 2.1, this model is classified with the empirical models. The main difference from other models is that the path loss exponent is treated as a random variable in addition to the shadowing effects [20]. It is derived from the extension of HATA model with frequency larger than 1900MHz. The correction parameters are allowed to extend this model up to 3.5GHz band [21].

The model covers three most common terrain categories. They are designated A, B and C.

- Type A is associated with maximum path loss and is appropriate for hilly terrain with moderate to heavy foliage densities;
- Type B is characterized with either mostly flat terrains with moderate to heavy tree densities or hilly terrains with light tree densities;
- Type C is associated with minimum path loss and applies to flat terrain with light tree densities [14].

The basic path loss formula with correction factors is given as [13]:

$$PL = A + 10\gamma \log_{10} \left(\frac{d}{d_0} \right) + X_f + X_h + s \quad \text{for } d > d_0 \quad (2.2)$$

where, d is the distance between transmitter antenna and receiver antenna in meter, $d_0=100\text{m}$ and s is a log distributed factor that is used to account the effect for the shadow fading owing to trees and other obstacles having value between 8.2 dB and 10.6 dB [13].

The parameter A is defined as:

$$A = 20 \log_{10} \left(\frac{4\pi d_0}{\lambda} \right) \quad (2.3)$$

and the path loss exponent γ is given by:

$$\gamma = a - b \times h_b + (c/h_b) \quad (2.4)$$

where the parameter h_b is the transmitter antenna height above ground in meters. This is between 10 m and 80 m [13]. The constants a , b , and c depend upon the types of terrain that are given in Table 2-1. The value of parameter γ is 2 for free space propagation in an urban area, $3 < \gamma < 5$ for urban NLOS environment, and $\gamma > 5$ for indoor propagation [13].

Table 2- 1: Numerical Values for the SUI Model Parameters [5].

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

The correction factor for frequency above 2 GHz, X_f and the correction for receiver antenna height, X_h for the models are expressed in [3, 14]:

$$X_f = 6.0 \log_{10}(f/2000) \quad (2.5)$$

$$X_h = -10.8 \log_{10}(h_r/2000) \quad \text{for terrain types A and B,} \quad (2.6a)$$

$$X_h = -20.0 \log_{10}(h_r/2000) \quad \text{for terrain type C} \quad (2.6b)$$

where f is the operating frequency in MHz, and h_r is the receiver antenna height in meter.

2.4.3. COST-231 Hata Model

Some research was done by Cooperate in Science and Technology (COST) 231 group in the early 1990's, where the group took some measurements from some European cities and came out with a number of well-validated models from their measurements. COST-231 Hata model was devised as an extension to the Hata-Okumura model. The COST-231Hata is widely used for predicting path loss in mobile wireless systems. It is designed to be used in the frequency band from 1500 MHz to 2000 MHz, and it also contains corrections for urban suburban and rural environments [14].

Cost-231 Hata model was developed for use with receiver antenna heights up to 10m and transmitter heights of 30-200 m. However, due to its simplicity and extensive usage, this model

is selected for this study in the MMDS band [19]. Although its frequency range is outside that of the measurements, its simplicity and the availability of frequency correction factors in the path loss formula below has made it to be taken among those models that may be used for path loss prediction at this frequency band. The basic path loss equation for this COST-231 Hata Model can be expressed as [21]:

$$PL = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - ah_m + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) + c_m \quad (2.7)$$

where, h_b is transmitter antenna height and h_r is receiver antenna height both in meters.

The parameter c_m has different values for different environments like 0 dB for suburban and 3 dB for urban areas and the remaining parameter ah_m is defined in urban areas as:

$$ah_m = 3.20(\log_{10}(11.75h_r))^2 - 4.79 \text{ for } f > 400 \text{ MHz} \quad (2.8a)$$

The value of ah_m in suburban and rural (flat) areas is given by:

$$ah_m = (1.11\log_{10}(f) - 0.7)h_r - (1.5\log_{10}(f) - 0.8) \quad (2.8b)$$

2.4.4. ECC-33 Model

The ECC-33 path loss model, which is developed by Electronic Communication Committee (ECC), is extrapolated from original measurements by Okumura and modified its assumptions so that it more closely represents a fixed wireless access (FWA) system [14]. In this model path loss is given by [13]:

$$PL = A_{fs} + A_{bm} - G_t - G_r \quad (2.9)$$

where A_{fs} is free space attenuation, A_{bm} is basic median path loss, G_t is transmitter height gain factor, and G_r is received antenna height gain factor. They are individually defined as,

$$A_{fs} = 92.4 + 20 \log_{10}(d) + 20 \log_{10}(f) \quad (2.10)$$

$$A_{bm} = 20.41 + 9.83 \log_{10}(d) + 7.894 \log_{10}(f) + 9.56[\log_{10}(f)]^2 \quad (2.11)$$

$$G_t = \log_{10}(h_b/200)[13.98 + 5.8(\log_{10}(d))^2] \quad (2.12)$$

For medium city environments [14],

$$G_r = [42.57 + 13.7 \log_{10}(f)] \log_{10}(h_m) - 0.585 \quad (2.13)$$

Where d is the distance between transmitter and receiver in kilometers, f is frequency in GHz, h_b and h_r are transmitter and receiver antenna heights in meter respectively.

ECC-33 model is one of the most extensively used empirical models for urban environments especially in large and medium size cities. This model was formed in Tokyo city having crowded and tallest buildings [21].

2.4.5 Ericsson Model

Ericsson model, which is provided by Ericsson Company, is also a model that stands on the modified Hata-Okumura model to allow room for changing in parameters according to the propagation environments [22]. Path loss according to this model is given by [13]:

$$PL = a_0 + a_1 \log_{10}(d) + a_2 \log_{10}(h_b) + a_3 \log_{10}(h_b) \log_{10}(d) - 3.2 (\log_{10}(11.75h_r))^2 + g(f) \quad (2.14)$$

where, $g(f)$ is defined by:

$$g(f) = 44.49 \log_{10}(f) - 4.78 (\log_{10}(f))^2 \quad (2.15)$$

where d is distance between transmitter and receiver in kilometers, f is the frequency in GHz, h_b is transmitter antenna height and h_r is receiver antenna height in meters.

The default values of these parameters (a_0 , a_1 , a_2 and a_3) for different terrains are given in Table 2-2 [13].

Table 2- 2: Values of parameter for Ericsson model [14].

Environment	a₀	a₁	a₂	a₃
Urban	36.2	30.2	12.0	0.1
Suburban	43.20	68.93	12.0	0.1
Rural	45.95	100.6	12.0	0.1

The values of parameters a_0 and a_1 in suburban and rural areas are based on the Least Square (LS) method [13].

Chapter Three: A Propagation Model for Detailed Planning

Chapter Three: A Propagation Model for Detailed Coverage Planning

3.1. Introduction

The higher the environmental model (digital terrain map) and propagation model consider details of the actual environment and different propagation phenomena respectively, the closer the path loss prediction becomes to the reality. Different physical propagation models were developed that are based on the principles of EM propagation through a 3D terrain data. Some of them are Freespace+RMD Model (where RMD stands for Reflection and Multiple Diffractions), Longley-Rice Model, the Terrain Integrated Rough Earth Model (TIREM), Anderson 2D Model, Non Line-of-Sight (NLOS) Dominant Ray Path Loss Model, and Ray Tracing Model [3].

For the actual and detailed coverage planning to be done using these physical models, high resolution and very precise environmental data and 3D building map is pertinent on the side of the environmental model. Consideration of complex propagation paths in using these physical models needs highly rigorous calculations with powerful computers. But, such high precision terrain and building database could not be found even from concerned authorities like Ethiopian Mapping Agency. In addition, the huge building and road construction projects dynamics in Addis Ababa City make it less effective to base any high level coverage planning on models that require highly precise environmental database. In addition, even though precise data were found, it would be difficult to do such rigorous calculations with ordinary computers.

In such cases, propagation models that do not require highly precise environmental data, and at the same time use the available data effectively by applying multiple corrections on the path loss prediction are best options. International Telecommunications Union Recommendation (ITU-R P.1546-5) propagation model is recommended by ITU for broadcasting planning in such cases. Because of this, ITU-R P.1546-5 propagation model is used for the actual detailed planning in this thesis work. This model is formulated after extensive field measurements worldwide in different geographical conditions. It is recommended for signal strength predictions at VHF and lower microwave frequencies, and used especially for broadcasting planning [12][8]. The

model is highly used in many European countries for MMDS planning. Because of these reasons, ITU-R P.1546-5 propagation model was used for the detailed coverage planning.

3.2. ITU-R P.1546-5 Model

This model is the recommendation of International Telecommunications Union (ITU) for point-to-area prediction of field strength for broadcasting in the frequency range 30MHz to 3000MHz and for the distance range 1km to 1,000km for effective transmitting antenna heights less than 3 000 m.

The method is based on interpolation/extrapolation from empirically derived predicted field-strength curves as functions of distance, antenna height, frequency and percentage time. The calculation procedure also includes corrections to the results obtained from this interpolation/extrapolation to account for terrain clearance and terminal clutter obstructions.

The next condensed description of the model is extracted from the document prepared by Radio-communication Sector of the International Telecommunication Union [12].

Table 3- 1: List of input parameters and their limits for ITU-R P.1546-5 Model

Parameter	Units	Definition	Limits
F	MHz	Operating frequency	30–3000 MHz
D	Km	Horizontal path length	Not greater than 1000 km
P	%	Percentage time. Defined in Section 3.2.7.	1–50%
h_l	m	Transmitting antenna height as referenced in curves. Defined in Section 3.2.3, Equations (3.3) up to (3.4).	No lower limit, upper limit of 3000 m
h_a	m	Transmitter antenna height above ground. Defined in Section 3.2.3. Limits are defined in	Greater than 1m

		the same place.	
h_b	m	Height of base antenna above terrain height averaged 0.2 d and d km, where d is less than 15 km and where terrain information is available	None – But note this parameter only exists for land paths where $d < 15$ km
h_2	m	Receiving antenna height above ground.	Not less than 1 m, and less than 3 000 m
R_1	m	Representative clutter height (around transmitter)	None
R_2	m	Representative clutter height (around receiver)	None
θ_{tca}	Degrees	Terrain clearance angle	0.55% to 40%
θ_{eff} θ_{eff1} θ_{eff2}	Degrees	Transmitter effective terrain clearance angles. Discussed in Section 3.2.9.	Must be positive

3.2.1. The Propagation Curves

The propagation curves such as Figure 3.1 included in this model represent field-strength values for 1 kW effective radiated power (e.r.p.) at nominal frequencies of 100 (not presented here as it not important for our case), 600 and 2 000 MHz as a function of distance and other various parameters. Interpolation or extrapolation of the values obtained for these nominal frequency values should be used to obtain field-strength values for any given required frequency using the method that is described in Sub-section 6 below.

Since we are predicting path loss for land path at MMDS frequency (2.6 GHz), we will use only the 600 and 2000 MHz land path propagation curves (as extrapolation for the 2600 MHz field strength prediction is done from these two). In fact, we will take the prediction curves that will exceed 50% of the time (the median maximum time availability) as broadcast systems demand as maximum time availability as possible.

3.2.2. Maximum Field-strength Values

For land paths, predicted field strength must not exceed a maximum value, E_{max} , given by:

$$E_{max} = E_{fs} \quad (3.1)$$

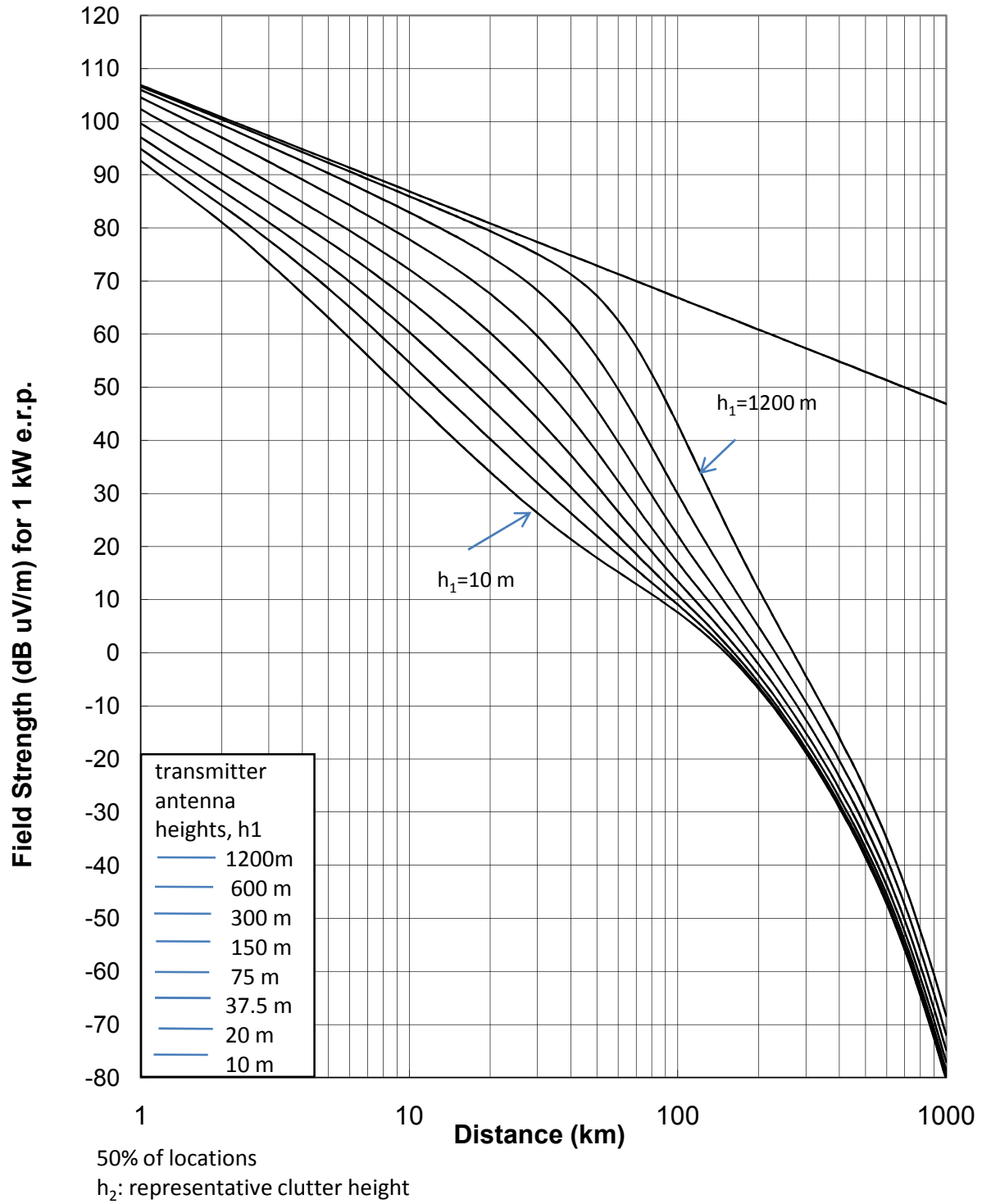
where, E_{fs} is the free space field strength for 1 kW e.r.p. given by:

$$E_{fs} = 106.9 - 20 \log_{10}(d) \quad dB(\mu V/m) \quad (3.2)$$

where d is distance(km).

In principle any correction which increases field strength must not be allowed to produce values greater than these limits for the family of curves and distance concerned.

600 MHz, land, 50% time



(a)

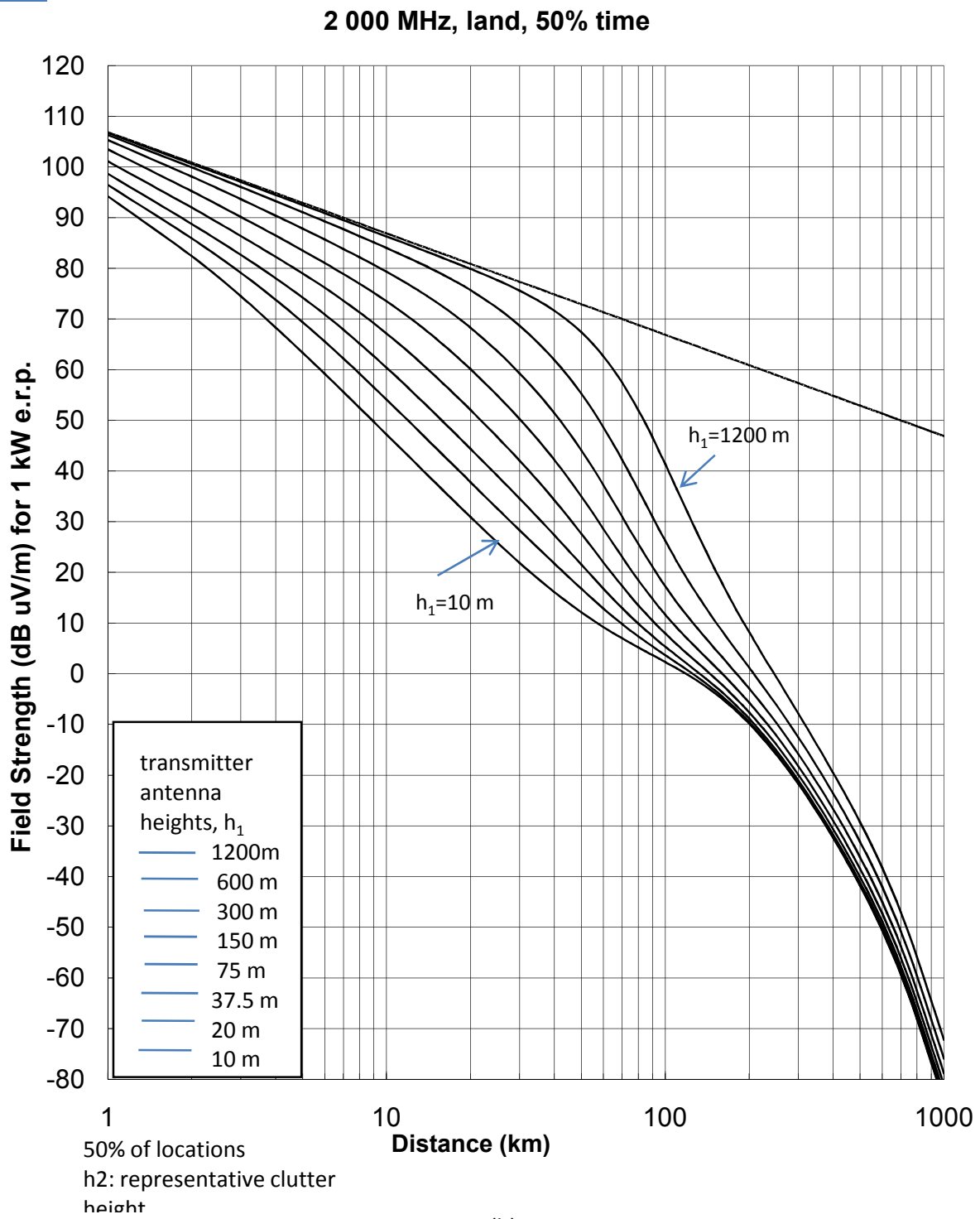


Figure 3- 1: Field strength prediction curve of ITU-R P.1546-5 Rec. Model for land propagation and field strengths exceeded 50% of the time (a) at 600 MHz and (b) 2000 MHz frequency [12].

3.2.3. Determination of Transmitting Antenna Height, h_1

a) Land paths shorter than 15 km

The transmitter antenna height, h_1 is:

$$h_1 = h_b \quad m \quad (3.3)$$

where h_b is the height of the antenna above terrain height averaged between $0.2d$ and d km. Note, it is possible that, using this method to determine h_1 , there will be non-monotonic modeling in the predicted field strength with distance, out to a distance of 15 km.

b) Land paths of 15 km or longer

For these paths:

$$h_1 = h_{eff} \quad m \quad (3.4)$$

where h_{eff} , is defined as the transmitter antenna height in meters over the average level of the ground between distances of 3 and 15 km from the transmitting antenna in the direction of the receiving antenna.

3.2.4. Application of Transmitting Antenna Height, h_1

The value of h_1 controls which curve or curves are selected from which to obtain field-strength values, and the interpolation or extrapolation which may be necessary. The following cases are distinguished.

a) Transmitting antenna height, h_1 , in the range 10 m to 3 000 m

If the value of h_1 coincides with one of the eight heights for which curves are provided, namely 10, 20, 37.5, 75, 150, 300, 600 or 1 200 m, the required field strength may be obtained directly from the plotted curves or the associated tabulations. Otherwise, the required field strength should be interpolated or extrapolated from field strengths obtained from two curves using:

$$E = E_{inf} + (E_{sup} - E_{inf}) \log_{10}(h_1/h_{inf}) / \log_{10}(h_{sup}/h_{inf}) \quad dB(\mu V/m) \quad (3.5)$$

where:

h_{inf} : 600 m if $h_1 > 1\,200$ m, otherwise the nearest nominal effective height below h_1

h_{sup} : 1 200 m if $h_1 > 1\,200$ m, otherwise the nearest nominal effective height above h_1

E_{inf} : field-strength value for h_{inf} at the required distance

E_{sup} : field-strength value for h_{sup} at the required distance.

The field strength resulting from extrapolation for $h_1 > 1\,200$ m should be limited if necessary such that it does not exceed the maximum defined. This model's prediction is not valid for $h_1 > 3\,000$ m.

b) Transmitting antenna height, h_1 , in the range 0 m to 10 m

The field strength at the required distance d km for $0 \leq h_1 < 10$ m is calculated using:

$$E = E_{zero} - 0.1h_1(E_{10} - E_{zero}) \quad dB(\mu V/m) \quad (3.6)$$

where,

$$E_{zero} = E_{10} - 0.5(C_{1020} + C_{h1neg10}) \quad dB(\mu V/m) \quad (3.7a)$$

$$C_{1020} = E_{10} - E_{20} \quad dB \quad (3.7b)$$

$C_{h1neg10}$: the correction C_{h1} in dB calculated using equation below at the required distance for $h_1 = -10$ m.

$$C_{h1} = 6.03 - J(v) \quad dB \quad (3.8)$$

where,

$$J(v) = \left[6.9 + 20 \log_{10} \left(\sqrt{((v - 0.1)^2 + 1)} + v - 0.1 \right) \right] \text{ for } v > -0.7806 \quad (3.9a)$$

$$J(v) = 0 \quad \text{otherwise} \quad (3.9b)$$

$$v = K_v \theta_{eff2} \quad (3.9c)$$

where,

$$\theta_{eff2} = \tan^{-1}(-h_1/9000) \quad \text{degrees} \quad (3.9d)$$

$$K_v = 1.35 \quad \text{for } 100 \text{ MHz}$$

$$K_v = 3.31 \quad \text{for } 600 \text{ MHz}$$

$K_v = 6.00$ for 2 000 MHz.

E_{10} and E_{20} : the field strengths in dB(μ V/m) calculated according to Equation 3.5 at the required distance for $h_1 = 10$ m and $h_1 = 20$ m respectively.

c) Negative values of transmitting antenna height, h_1

It is sometimes possible for the effective transmitting antenna height, h_{eff} , to have a negative value, since it is based on the average terrain height at distances from 3 km to 15 km. Thus h_1 may be negative. In this case, the effect of diffraction by nearby terrain obstacles should be taken into account.

The procedure for negative values of h_1 is to obtain the field strength for $h_1 = 0$ as described above (Equation 3.7), and to add a correction C_{h1} calculated as follows.

The effect of diffraction loss is taken into account by a correction, C_{h1} , given by cases i) or ii) as follows:

- i) In the case that a terrain database is available and the potential for discontinuities at the transition around $h_1 = 0$ is of no concern in the application of this Recommendation, the terrain clearance angle, θ_{eff1} , from the transmitting antenna should be calculated as the elevation angle of a line which just clears all terrain obstructions up to 15 km from the transmitting/base antenna in the direction of (but not going beyond) the receiving antenna.

$$C_{h1} = J(v') - J(v) \quad \text{dB} \quad (3.10a)$$

where, $J(v)$ is given by equation (3.9a):

$$v' = 0.036\sqrt{f} \quad (3.10b)$$

$$v = 0.065\theta_{eff1}\sqrt{f} \quad (3.10c)$$

$$\theta_{eff1} = \tan^{-1}(-h_1/(d \times 1000)) \quad \text{if } d < 15,000m \quad (3.10d)$$

$$\theta_{eff1} = \tan^{-1}(-h_1/(15000)) \quad \text{otherwise} \quad (3.10e)$$

ii) In the case where a terrain database is not available or where a terrain database is available, but the method must never produce a discontinuity in the field strength at the transition around $h_1 = 0$, the (positive) effective terrain clearance angle, θ_{eff2} , may be estimated assuming an obstruction of height h_1 at a distance of 9 km from the transmitting/base antenna. Note that this is used for all path lengths, even when less than 9 km.

That is, the ground is regarded as approximating an irregular wedge over the range 3 km to 15 km from the transmitting/base antenna, with its mean value occurring at 9 km, as indicated in Figure 3-2. This method takes less explicit account of terrain variations, but it also guarantees that there is no discontinuity in field strength at the transition around $h_1 = 0$. The correction to be added to the field strength in this case is calculated using Equation 3.8.

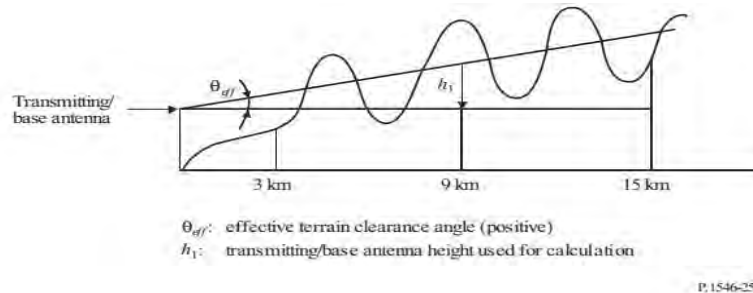


Figure 3- 2: Effective clearance angle for $h_1 < 0$.

The above correction, which is always less than zero, is added to the field strength obtained for $h_1 = 0$.

3.2.5. Interpolation of Field Strength as a Function of Distance

Curves in Figure 3-1 show field strength plotted against distance, d , the range 1 km to 1 000 km. No interpolation for distance is needed if field strengths are read directly from these graphs, i.e., if d coincides with one of the tabulation distances given in Table 3-2. However, if d doesn't coincides with one of the distances in the curve, the field strength, E (dB(μ V/m)), should be linearly interpolated for the logarithm of the distance using:

$$E = E_{inf} + (E_{sup} - E_{inf}) \log_{10}(d/d_{inf}) / \log_{10}(d_{sup}/d_{inf}) \text{ dB}(\mu\text{V/m}) \quad (3.11)$$

where:

d : distance for which the prediction is required

d_{inf} : nearest tabulation distance less than d

d_{sup} : nearest tabulation distance greater than d

E_{inf} : field-strength value for d_{inf}

E_{sup} : field-strength value for d_{sup} .

This model's prediction is not valid for values of d greater than 1 000 km.

3.2.6. Interpolation and Extrapolation of Field Strength as a Function of Frequency

Field-strength values for the required frequency should be obtained by interpolating between the values for the nominal frequency values of 100, 600 and 2 000 MHz. In the case of frequencies below 100 MHz or above 2 000 MHz, the interpolation must be replaced by an extrapolation from the two nearer nominal frequency values. For most paths, interpolation or extrapolation for \log (frequency) can be used. The required field strength, E , should be calculated using:

$$E = E_{inf} + (E_{sup} - E_{inf}) \log_{10}(f/f_{inf}) / \log_{10}(f_{sup}/f_{inf}) \text{ dB}(\mu\text{V}/\text{m}) \quad (3.12)$$

where,

f : frequency for which the prediction is required (MHz)

f_{inf} : lower nominal frequency (100 MHz if $f < 600$ MHz, 600 MHz otherwise)

f_{sup} : higher nominal frequency (600 MHz if $f < 600$ MHz, 2 000 MHz otherwise)

E_{inf} : field-strength value for f_{inf}

E_{sup} : field-strength value for f_{sup} .

The field strength resulting from extrapolation for frequency above 2000 MHz should be limited if necessary such that it does not exceed the maximum value given in Equation 3.1.

Table 3- 2: Values of distances used in the table of field strengths (km)

1	14	55	140	375	700
2	15	60	150	400	725
3	16	65	160	425	750
4	17	70	170	450	775
5	18	75	180	475	800
6	19	80	190	500	825
7	20	85	200	525	850
8	25	90	225	550	875
9	30	95	250	575	900
10	35	100	275	600	925
11	40	110	300	625	950
12	45	120	325	650	975
13	50	130	350	675	1000

3.2.7. Interpolation of Field Strength as a Function of Percentage Time

Field-strength values for a given percentage of time between 1% and 50% time should be calculated by interpolation between the nominal values 1% and 10% or between the nominal values 10% and 50% of time using:

$$E = \frac{E_{sup}(Q_{inf}-Q_t)}{(Q_{inf}-Q_{sup})} + \frac{E_{inf}(Q_t-Q_{sup})}{(Q_{inf}-Q_{sup})} \quad dB(\mu V/m) \quad (3.13)$$

where:

t : percentage time for which the prediction is required

t_{inf} : lower nominal percentage time

t_{sup} : upper nominal percentage time

$$Q_t = Q_i(t/100)$$

$$Q_{inf} = Q_i(t_{inf}/100)Q$$

$$Q_{sup} = Q_i(t_{sup}/100)Q$$

E_{inf} : field-strength value for time percentage t_{inf}

E_{sup} : field-strength value for time percentage t_{sup} .

where $Q_i(x)$ is the inverse complementary cumulative normal distribution function. This model's prediction is valid for field strengths exceeded for percentage times in the range 1% to 50% only. Extrapolation outside the range 1% to 50% time is not valid.

Table 3- 3: Approximate inverse complementary cumulative normal distribution values

q%	$Q_i(q/100)$	q%	$Q_i(q/100)$	q%	$Q_i(q/100)$	q%	$Q_i(q/100)$
1	2.327	26	0.643	51	-0.025	76	-0.706
2	2.054	27	0.612	52	-0.050	77	-0.739
3	1.881	28	0.582	53	-0.075	78	-0.772
4	1.751	29	0.553	54	-0.100	79	-0.806
5	1.645	30	0.524	55	-0.125	80	-0.841
6	1.555	31	0.495	56	-0.151	81	-0.878
7	1.476	32	0.467	57	-0.176	82	-0.915
8	1.405	33	0.439	58	-0.202	83	-0.954
9	1.341	34	0.412	59	-0.227	84	-0.994
10	1.282	35	0.385	60	-0.253	85	-1.036
11	1.227	36	0.358	61	-0.279	86	-1.080
12	1.175	37	0.331	62	-0.305	87	-1.126
13	1.126	38	0.305	63	-0.331	88	-1.175
14	1.080	39	0.279	64	-0.358	89	-1.227
15	1.036	40	0.253	65	-0.385	90	-1.282
16	0.994	41	0.227	66	-0.412	91	-1.341
17	0.954	42	0.202	67	-0.439	92	-1.405
18	0.915	43	0.176	68	-0.467	93	-1.476
19	0.878	44	0.151	69	-0.495	94	-1.555
20	0.841	45	0.125	70	-0.524	95	-1.645
21	0.806	46	0.100	71	-0.553	96	-1.751
22	0.772	47	0.075	72	0.582	97	-1.881

23	0.739	48	0.050	73	-0.612	98	-2.054
24	0.706	49	0.025	74	-0.643	99	-2.327
25	0.674	50	0.000	75	-0.674		

3.2.8. Correction for Receiving Antenna Height

The field-strength values given by the land curves (Figure 3.1) and associated tabulations in this model are for a reference receiving antenna at a height equal to the greater of the representative of the height of the ground cover surrounding the receiving/mobile antenna, R_2 , and 10 m. Examples of reference heights are 20 m for an urban area, 30 m for a dense urban area and 10 m for a suburban area. Where the receiving antenna is on land account should first be taken of the elevation angle of the arriving ray by calculating a modified representative clutter height R_2' , given by:

$$R_2' = (1000dR_2 - 15h_1)/(1000d - 15) \quad m \quad (3.14)$$

where h_1 and R_2 are in units of meters, and horizontal distance d in km. The representative clutter height R_2' is calculated in such way, that it represents the reference point of height for a receiver which is situated 15 m behind the clutter encountering grazing incidence of the ray from the transmitter.

The representative height R_2' represents a reference height at which a receiver would encounter grazing incident ($v = 0$).

Note that for $h_1 < 6.5d + R_2$, $R_2' \approx R_2$.

The value of R_2' must be limited if necessary such that it is not less than 1 m. When the receiving antenna is in an urban environment the correction is then given by:

$$\text{Correction} = 6.03 - J(v) \quad \text{dB} \quad \text{for } h_2 < R_2' \quad (3.15a)$$

$$= K_{h2} \log_{10}(h_2/R_2') \quad \text{dB} \quad \text{for } h_2 \geq R_2' \quad (3.15b)$$

where,

$$v = K_{nu} \sqrt{h_{dif2} \theta_{clut2}} \quad (3.15c)$$

$$h_{dif2} = R_2' - h_2 \quad m \quad (3.15d)$$

$$\theta_{clut2} = \tan^{-1}(h_{dif2}/27) \quad \text{degrees} \quad (3.15e)$$

$$K_{h2} = 3.2 + 6.2 \log_{10}(f) \quad (3.15f)$$

$$K_{nu} = 0.0108f \quad (3.15g)$$

f: frequency (MHz).

In cases in an urban environment where R_2' is less than 10 m, the correction given by Equations 3.15a or 3.15b should be reduced by $K_{h2} \log_{10}(10/R_2')$. Where the receiving/mobile antenna is on land in a rural or open environment the correction is given by Equation 3.15b for all values of h_2 with R_2' set to 10 m.

3.2.9. Cluttered Transmitter Correction

This correction applies when the transmitting terminal is over or adjacent to land on which there is clutter. The correction should be used in all such cases, including when the antenna is above the clutter height. The correction is zero when the terminal is higher than a frequency-dependent clearance height above the clutter.

$$\text{Correction} = -J(v) \quad \text{dB} \quad (3.16a)$$

where $J(v)$ is given by Equations 3.9a or 3.9b,

where,

$$v = K_{nu} h_{dif1} \theta_{clut1} \quad \text{for } R_1 \geq h_a \quad (3.16b)$$

$$= -K_{nu} h_{dif1} \theta_{clut1} \quad \text{otherwise} \quad (3.16c)$$

$$h_{dif1} = h_a - R_1 \quad m \quad (3.16d)$$

$$\theta_{clut1} = \tan^{-1}(h_{dif1}/27) \quad \text{degrees} \quad (3.16e)$$

$$K_{nu} = 0.0108f \quad (3.16f)$$

f: frequency (MHz).

And R_1 is the height of clutter, m above ground level, in the vicinity of the transmitting terminal.

3.2.10. Terrain Clearance Angle Correction

For land paths, and when the receiving antenna is on a land section of a mixed path, if more precision is required for predicting the field strength for reception conditions in specific areas, e.g. in a small reception area, a correction may be made based on a terrain clearance angle.

The terrain clearance angle, θ_{tca} , is given by:

$$\theta_{tca} = \theta \quad \text{degrees} \quad (3.17)$$

where θ is the elevation angle of the line from the receiving antenna which just clears all terrain obstructions in the direction of the transmitter/base antenna over a distance of up to 16 km but not going beyond the transmitting antenna.

The calculation of θ should not take Earth curvature into account. θ_{tca} should be limited such that it is not less than $+0.55^\circ$ or more than $+40.0^\circ$.

Where the relevant terrain clearance angle information is available, the correction to be added to the field strength is calculated using:

$$\text{Correction} = J(v') - J(v) \quad \text{dB} \quad (3.18a)$$

where $J(v)$ is given by equation (2.24a):

$$v' = 0.036f \quad (3.18b)$$

$$v = 0.065\theta_{tca}f \quad (3.18c)$$

θ_{tca} : terrain clearance angle degrees

f : required frequency (MHz).

It should be noted that the land field-strength curves (Figure 3.1) predictions take account of losses due to typical shielding of the receiving antenna by gently rolling terrain. Thus the terrain clearance angle corrections are zero at a small positive angle typical of receiving antenna positions.

3.2.11. Location Variability in Land Area-Coverage Prediction

Area-coverage prediction methods are intended to provide the statistics of reception conditions over a given area, rather than at any particular point. The interpretation of such statistics will depend on the size of the area considered. Extensive data analysis suggests that the distribution of median field strength due to ground cover variations over such an area in urban and suburban environments is approximately lognormal.

Thus for a land receiving antenna location the field strength, E , which will be exceeded for $q\%$ of locations, is given by:

$$E(q) = E(\text{median}) + Q_i\left(\frac{q}{100}\right) \sigma_L(f) \quad \text{dB}(\mu\text{V/m}) \quad (3.19)$$

where,

$Q_i(x)$: inverse complementary cumulative normal distribution as a function of probability;

σ_L : standard deviation of the Gaussian distribution of the local means in the study area. The standard deviation for broadcasting at 2.6 GHz frequency is 5.5 dB as shown in Table 3-4 below.

Table 3- 4: Values of Variability Used in certain Planning Situations

	Standard Deviation (dB)		
	100 MHz	600 MHz	2000 MHz
Broadcasting, Analog	8.3	9.5	-
Broadcasting, Digital	5.5	5.5	5.5

An approximation to function $Q_i(x)$ is given in Table 3-3 above.

3.2.12. Limiting Field Due to Tropospheric Scattering

There is a possibility that the field strength calculated using the methods given till this point is an underestimation, due to not taking full account of tropospheric scattering. If terrain information is available, an estimate of the field due to tropospheric scattering should be calculated using the following procedure. This estimate can then be used as a ‘floor’ to the overall prediction of the field strength.

Calculate the path scattering angle in degrees, θ_s , using:

$$\theta_s = \frac{180d}{\pi ka} + \theta_{eff} + \theta \quad \text{degrees} \quad (3.20)$$

where,

θ_{eff} : the h_1 terminal’s terrain clearance angle in degrees calculated using the method in Section 3.2.4(c) case i), whether or not h_1 is negative (degrees)

θ : the h_2 terminal’s clearance angle in degrees as calculated in Section 3.2.10 above, noting that this is the elevation angle relative to the local horizontal (degrees)

d : path length (km)

a : 6 370 km, radius of the Earth

k : 4/3, effective Earth radius factor for median refractivity conditions.

If θ_s is less than zero, set θ_s equal to zero.

Calculate the field strength predicted for tropospheric scattering, E_{ts} , using:

$$E_{ts} = 24.4 - 20 \log_{10}(d) - 10\theta_s - L_f + 0.15N_0 + G_t \quad \text{dB}(\mu\text{V/m}) \quad (3.21)$$

where:

L_f : frequency-dependent loss

$$= 5 \log(f) - 2.5 (\log(f) - 3.3)^2 \quad (3.22a)$$

$N_0 = 325$, median surface refractivity, N -units, typical of temperate climates

G_t : time-dependent enhancement

$$= 10.1(-\lg(0.02t))^{0.7} \quad (3.22b)$$

d : path length or required distance (km)

f : required frequency (MHz)

t : required percentage of time.

3.2.13. Antenna-Height Difference

A correction is required to take account of the difference in height between the two antennas.

This correction is calculated as follows.

$$\text{Correction} = 20 \log_{10}(d/d_{slope}) \text{ dB} \quad (3.23)$$

where d is the horizontal distance and the slope distance, d_{slope} , is given as follows.

Where terrain information is available, use:

$$d_{slope} = \sqrt{d^2 + 10^{-6}[(h_a + h_{tter}) - (h_2 + h_{rter})]^2} \text{ km} \quad (3.24a)$$

where terrain information is not available, use:

$$d_{slope} = \sqrt{d^2 + 10^{-6}[h_a - h_2]^2} \text{ km} \quad (3.24b)$$

and h_{tter} and h_{rter} are the terrain heights in meters above sea level at the transmitter/base and receiving terminals respectively. Although the correction given by Equation 3.23 is very small except for short paths and high values of h_1 , it is recommended that it is used in all cases to avoid making an arbitrary decision as to precision.

3.2.14. Distances Less Than One Kilo Meter

The foregoing steps describe the method for obtaining field strengths from the curve families for horizontal distances from 1 km to 1 000 km. This process includes interpolation or extrapolation

and various corrections. If the required horizontal distance is 1 km or greater, no further calculation is needed. For paths less than 1 km the model is extended to arbitrarily short horizontal distances as follows:

If the horizontal distance is less than or equal to 0.04 km the field strength, E, is given by:

$$E = 106.9 - 20 \log_{10}(d_{slope}) \quad dB(\mu V/m) \quad (3.25a)$$

Otherwise,

$$E = E_{inf} + (E_{sup} - E_{inf}) \log_{10}(d_{slope}/d_{inf}) \log_{10}(d_{sup}/d_{inf}) \quad dB(\mu V/m) \quad (3.25b)$$

where:

d_{slope} : slope distance given by Equation (3.24a) or (3.24b) for the required horizontal distance d

d_{inf} : slope distance given by Equation (3.24a) or (3.24b) for d = 0.04 km

d_{sup} : slope distance given by Equation (3.24a) or (3.24b) for d = 1 km

E_{inf} : $106.9 - 20 \log(d_{inf})$

E_{sup} : field strength given by steps 1 to 13 for d = 1 km.

3.2.15. Equivalent Basic Transmission Loss

When required, the basic transmission loss equivalent to a given field strength is given by:

$$L_b = 139.3 - E + 20 \log_{10}(f) \quad dB \quad (3.26)$$

where,

L_b : basic transmission loss (dB)

E : field strength (dB($\mu V/m$)) for 1 kW e.r.p.

f : frequency (MHz).

3.2.16. Adjustment for Different Climate Conditions

The curves given in Figure 2-6 are based on measurements in temperate climates. Field strengths in regions of the world where the vertical atmospheric refractivity gradient is significantly different will not, in general, be so accurately predicted. But for areas like Addis Ababa where the vertical atmospheric refractivity gradient is not significantly different (-40.7 N-units/km), the correction for climate condition can be ignored [23].

Chapter Four: Results and Discussions

Chapter Four: Results and Discussions

4.1. Introduction

In this chapter, the results for the planning are presented and discussed. The first result to be discussed is estimation of the area that can be covered with 57dB_m output power transmitter located around Gotera Interchange road near Kebena River Bridge (Figure 4-1). To estimate the area, we have to first estimate the distance radius the signals from the transmitter can travel before their strength go below the threshold value.

To do this, we have to choose a propagation model among the empirical models discussed in Section 2.4 for system dimensioning. This will be done in Section 4.2. Once the model for system dimensioning was selected, the radius of coverage could be determined by carrying out radio link budget calculation. This will be done in Section 4.3.

The next work would be determining the number of transmitters that can cover Addis Ababa city. To do this, the radius of coverage is important to determine the area covered. This will be done in Section 4.4 below.

After the number of transmitters is determined, the next step is to determine transmitter sites that give the best coverage. In fact, determining the optimum location for maximum coverage is a relatively difficult optimization problem which needs advanced optimization methods, which is a bit complex. But, a quasi-optimization with selected high probability locations is possible, and this would be done in Section 4.5.

After determining number of transmitters and the best location among high probability candidate locations for maximum coverage, the final step is to present the actual coverage prediction plan, and to discuss and analyze it. This final step would be done in Section 4.5 with the site selection.

4.2. Performance Comparison of Propagation Models for System Dimensioning

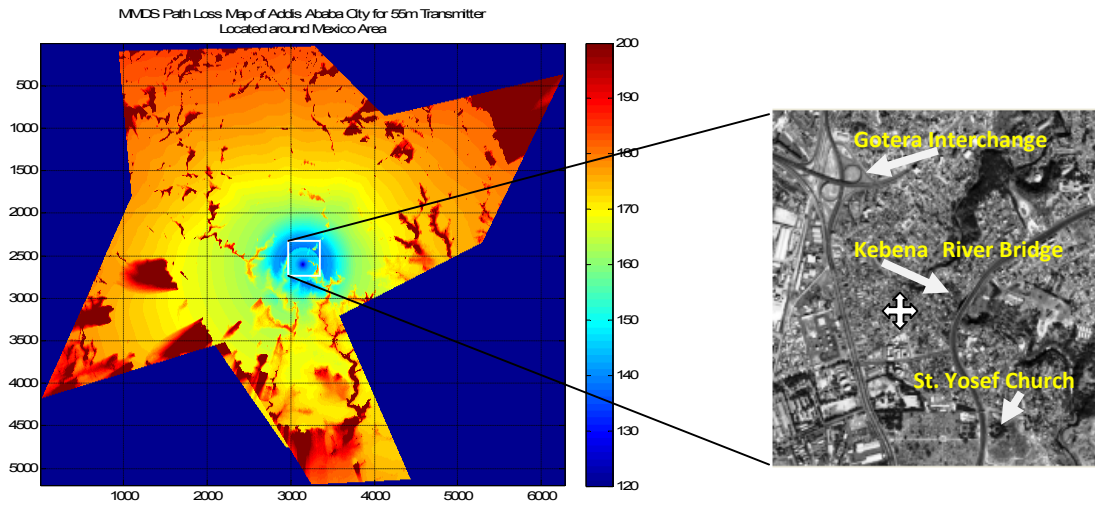
Comparison of propagation models to select the best model that suits for planning a specific communication service (i.e., MMDS, LMDS, VHF/UHF Broadcasting, WiMAX, LTE, etc) in a certain environment essentially involves two phases [3].

The first step is reviewing previous literary works that are done on and around MMDS planning. Then follows selecting some of the models and comparing their performance based on measured field data in the same environment for which the planning is being done [20].

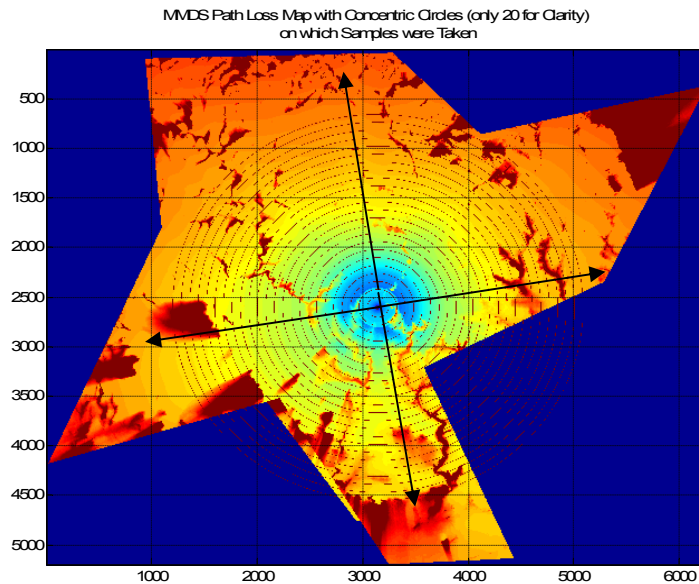
The review presented in Section 2.4 discussed five propagation models that do not take extensive environmental information. Their environmental correction factors take very general classifications. They classify the environment either into urban, sub-urban, and rural or into mountainous, hilly and plain [3].

But, a reliable and near-to-reality coverage planning need to take precise environmental data as environment has a tremendous impact on the signal strength that finally reaches on a certain spot of the area after many reflections, diffractions scatterings and other phenomena [3]. So, modern coverage planning are done using high resolution terrain and other environmental database and powerful software tools that simulate the actual signal propagation path.

As to the empirical propagation models discussed in Chapter 2, though they cannot be used for detailed coverage planning, they are very important for system dimensioning [3]. As discussed, system dimensioning involves smartly estimating planning parameters that can cover the required area in economically efficient manner having good quality of service. One among these five models, which is more preferred for the specific environment should be chosen for this purpose. The best means to choose is to compare its path loss prediction against actual measured data. If that is not possible, the second option is to compare its prediction against path loss data predicted by the model by which the detailed planning is done.



(a)



(b)

Figure 4- 1: (a) Path Loss Prediction Map for 55m transmitter located around St. Josef Church; (b) Concentric circles (only 20 for clarity) on which 50 sample path loss values are taken. The slanted pair of axes is to show four points in each circle whose values are averaged to give the value for each sample.

Taking the second option, to choose a propagation model among the five ones discussed in Section 2.4, ITU-R P.1546-5 model prediction was simulated with 2.6 GHz and 57dB output power transmitter from 55 meter height transmitter at the heart of Addis Ababa city. This prediction was compared with the predictions of the five models. All predictions were done based on Matlab simulations of all the models through a relatively large chain of codes. The simulation map is shown in Figure 4-1 (a) and (b) above.

Finally those models, among which one for dimensioning is to be selected, are compared with 50 samples from the ITU-R P.1546-5 model prediction. The Matlab simulation result is shown in Figure 4-2 below.

The entire simulation was done on a terrain elevation map in matrix format. For this purpose, the terrain database which was originally in grid format was changed into a matrix format so that it would be simple for Matlab manipulation. The entire rectangular area that inscribes Addis Ababa city, when changed into matrix, becomes a 5197x6277 matrix that contains 32,621,569 square cells with dimension 5mx5m. The value in each cell is terrain height in that area.

After multiples of time-taking Matlab manipulations based on the multi-conditional ITU-R P.1546-5 prediction steps, we get a matrix with the same size but the values changed into path loss values at that area (Figure 4-1).

From the simulation map in Figure 4-1(a), 50 sample values on concentric circles centered around the transmitter and with 200m radial distance difference are selected (Figure 4-1(b) above). The selection is in such a way that the program commands to revolve around the transmitter and pick four points on each circle that are 90 degree separated and the same distance from the transmitter. The average value is finally taken for the comparison with the other five model's prediction at the same distance (Figure 4-2).

In the comparison (Figure 4-2), 55 meter transmitter height, 57dBm transmitter output power, 10 meter receiver height, and an urban environmental correction was taken for each models.

As it can be seen from the result, all the four models (Cost-231 Hata, ECC-33, Ericsson, and FSPL), except IEEE 806.16 (SUI) model, underestimate path loss. This is because these models are developed and are widely used for frequencies below 2000 MHz (though frequency

correction is done) for which line-of-sight is not critical. But, MMDS is near-line-of-sight service because its operating frequency is higher.

The result shows that IEEE 802.16 (SUI) model is the best option for system dimensioning. As it is seen from the simulation, most of the time, it slightly overestimates. Small overestimation is

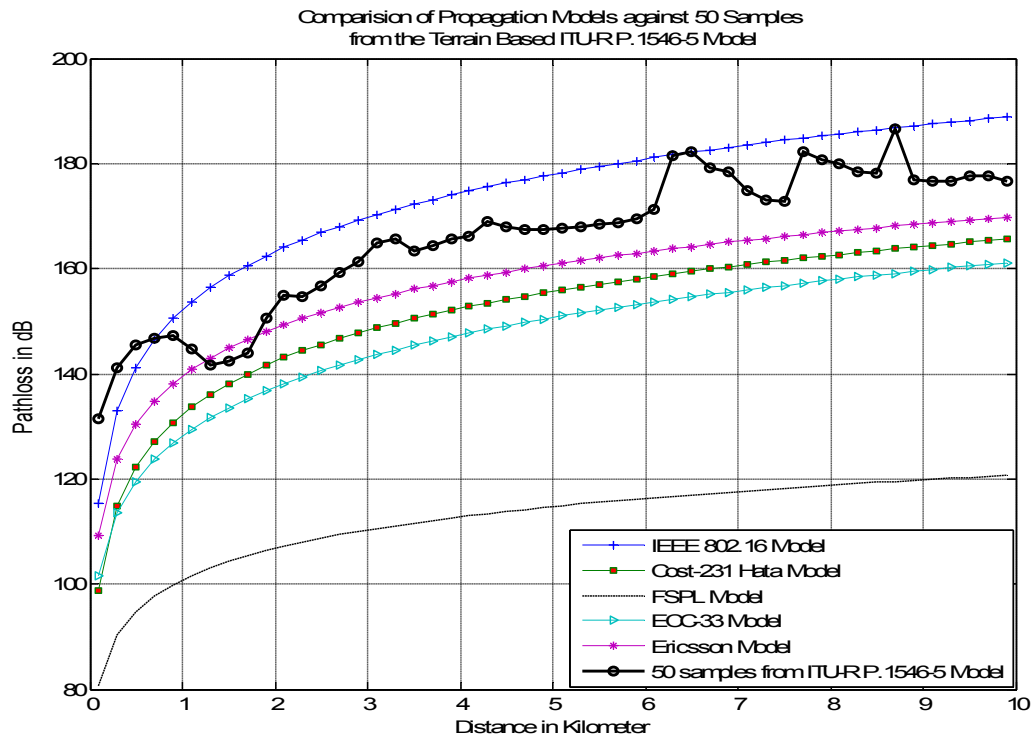


Figure 4- 2: Comparison of propagation models against 50 samples taken from ITU-R P.1546-5 Model

good as long as it is not exaggerated as the plan should consider worst case scenarios where path loss may go beyond the predicted values. So IEEE 802.16 (SUI) model is selected for system dimensioning in this planning. It is interesting that this model was from the beginning developed for frequencies above 1900 MHz and it is specifically used for MMDS planning in the US [22, 24].

4.3. Radio Link Budget Calculation

Parameters that determine link budget result are discussed briefly below [3].

Transmitter Output Power- This is the time-average power of the link transmitter on the transmission channel. By convention, the power level is given in dB relative to one milli-watt, dBmW, or simply dBm. Manufacturers produce transmitters up to 800 Watt output power. We will do the planning with 57dBm and the necessary trade-off will be made with transmitter antenna tower height.

Transmitter Circulator/Multiplexer Loss- Normally the output of a transmitter is combined with the signal from other transmitters operating on other channels. This multiplexing/splitting device (called a circulator for combining/splitting waveguide signals) has some loss associated with it. The loss value in dB is obtained from the equipment manufacturer.

Transmitter Waveguide/Transmission Line Loss- This is the loss in dB from the waveguide or transmission line connecting the transmitter (or circulator) with the antenna. The loss depends on the waveguide type, waveguide length, and frequency. The loss as a function of length for elliptical waveguide type can be read to be about 1.5 dB/100 m [3].

Transmitter Antenna Gain - The transmitter antenna gain value depends on the antenna type (mostly its cross section or aperture size) and is obtained from the antenna manufacturer. By convention, the gain of antennas used in microwave and other fixed broadband wireless systems are usually given in dB relative to an isotropic radiator, denoted as dBi. The transmitter antenna gain chosen for this planning is 24 dB.

Effective Radiated Power (dBmW) - The effective radiated power (ERP) is the sum of the transmitter output power and transmit antenna gain minus the losses from the multiplexer/circulator, waveguide, and radome. Since the radiated power is calculated using the

antenna gain in dBi, the ERP value is denoted as ‘ERP_i’. It has the same units as the transmitter power, or dBmW.

Frequency - This is the operating frequency of the link. This is the nominal center frequency of the channel, which is only used in the link budget to find path loss so it is not necessary to specify it with a great deal of precision. In our case, the nominal center frequency is taken to be 2.6 GHz.

As discussed in Section 1.3, countries have allocated frequency ranges based on their own status and need. For Ethiopia, the MMDS frequency is not yet allocated. It is better to adopt the 2.5-2.7 GHz range based on FCC recommendation because of the following reasons:

- This frequency range is better for broadcasting than the higher frequencies as rain attenuation, multipath, and other factors that increase path loss are stronger at higher frequencies;
- Many researches for MMDS is done in this spectrum therefore it will be easy to know the challenges and provide solutions;
- Experience from developing countries like South Africa and India.
- Equipments are manufactured with relatively cheap cost for it.

So, it will be wise to adopt this spectrum to exploit these advantages.

In fact, some European countries have allocated higher frequency spectrum as their frequency is occupied with other already established services. This is not the case in Ethiopia. Therefore, coverage planning in this work is done considering the Ethiopian MMDS frequency spectrum to be from 2.5 to 2.7 GHz band.

Path Length - The distance from the transmitting antenna to the receiving antenna along the great circle path is the path length. The final target of our link budget calculation is to find the maximum path length the signal can travel before passing the fade margin.

Receiver Antenna Gain - See the discussion for the transmitter antenna gain mentioned earlier. For this planning, the receiver antenna is 10⁰ (3dB) beamwidth, 5⁰H-plane and the one with gain

29dB is chosen considering price issue as an important factor from the side of customers.

Receiver Waveguide/Transmission line loss - See the discussion for the transmitter waveguide/transmission line loss mentioned earlier.

Receiver Circulator/Multiplexer Loss - This is the loss of the circulator/multiplexer used at the receiver.

Receiver Noise Figure - The receiver noise figure in dB is a function of the receiver equipment design. The noise figure value is obtained from the receiver equipment manufacturer. Low noise amplifiers (LNAs) can use special components or cryogenic (cooling) techniques to achieve very low noise figures. Noise figures for standard receivers range from 3 dB at 2.5 GHz to 8 dB at 38 GHz [3] (4). A noise figure of 3.5 dB is considered for this planning.

Receiver Equivalent Noise Bandwidth - The equivalent noise bandwidth of the receiver is the bandwidth necessary to accommodate the digital signal symbol spectrum and symbol rate. The receive filter is designed to provide bandwidth that maximizes the received SNR. For noise power purposes, the receiver filter is modeled as a perfectly band-limited filter with the same noise power characteristics as the actual filter. The bandwidth of this perfectly band-limited filter is the equivalent noise bandwidth. This value is obtained from the receiver equipment manufacturer. In MMDS a bandwidth of 6MHz is common for broadcasting. This value is used for this planning work.

Receiver Noise Threshold - The receiver noise threshold is found from the noise figure and equivalent noise bandwidth. The noise threshold is given as

$$P_N = (F - 1)K_b T_0 B \quad (4.1)$$

where F is the noise figure (as a real number, not dB), K_b is Boltzmann's constant = 1.37×10^{-23} , T_0 is the ambient temperature in degrees Kelvin of the environment, usually taken to be 290 K,

and B is the equivalent noise bandwidth in Hertz given above. With noise figure (F) taken to be 3.5 dB (2.238 as a real number), the receiver noise threshold is calculated to be -132.73 dB.

Required Signal-to-Noise Ratio, SNR - The required SNR value is the SNR value needed at the input of the receiver to achieve a specific signal quality at the output of the receiver. For an analog system, the output quality measure will be an analog SNR. For a digital system, the fundamental measure of output quality is the BER or FER. This value is the design objective, which the link must maintain for a specific percentage of time (link availability). This required SNR is found on, or can be derived from, the equipment specifications. A SNR of 15 dB is considered for this planning as taken from [3]. Some typical values are shown in Table 4.1.

The Thermal Noise Fade Margin - The thermal noise fade margin is the difference between the median signal level at the receiver input and the sum of the receiver noise threshold plus the required SNR. Under nominal link conditions, this difference (fade margin) is present. When the link fades, the probability that the fade depth exceeds the fade margin is the probability that the BER or FER will fall below the minimum value that is considered acceptable performance. In this circumstance, an outage is considered to have occurred. The fade margin is the ultimate result of the link budget calculation. A fade margin of 13.5dB will be taken for this planning as predicted from [3].

The total loss due to circulator/multiplexers and waveguide/transmission lines at the transmitter and receiver is taken to be 5dB as recommended in [3].

Table 4- 1: Nominal Required SNR values by modulation type [3].

Modulation	Net Efficiency (bps/Hz)	Required SNR(dB)
QPSK	1.8(10% overhead)	10
16QAM	3.4(15% overhead)	15
64QAM	4.8(20% overhead)	21
256QAM	6.0(25% overhead)	26

The total link budget calculation is as follows:

$$\begin{aligned} & (\text{Output Power}) + (\text{Transmitter Antenna Gain}) + (\text{Receiver Antenna Gain}) - (\text{Receiver} \\ & \text{Noise Threshold}) - (\text{Signal to Noise Ratio}) - (\text{Basic Path Loss}) - (\text{circulator/multiplexers}+ \\ & \text{waveguide/transmission line}) = (\text{Fade Margin}) \end{aligned} \quad (4.2)$$

Substituting values for each parameter, we get

$$57\text{dBm} + 16\text{dBi} + 29\text{dBi} - (-132.73\text{dB}) - 16\text{dB} - (\text{Basic Path Loss}) - 5\text{dB} = 13.5 \text{ dB}$$

Solving for the Basic Path Loss value, we finally get

$$\text{Basic Path Loss} = \underline{\underline{200.23 \text{ dB}}}.$$

As the propagation model conforming with our planning environment is found to be IEE 802.16 (SUI) model (Section 3.3), the radius of an area that the transmitter can cover without the signal strength passing the fade margin was determined by substituting 200.23dB for path loss and finding the distance, d , that can result in this amount of path loss by IEE 802.16 (SUI) propagation model prediction.

The value of distance, d , that can produce this much loss according to IEEE 802.16 (SUI) model with 55m transmitter and 10m receiver antenna height was calculated to be 20.10 km. With this value at hand, the next step was to determine the number of transmitters and dimension the entire area of Addis Ababa into the ‘territory’ of each transmitter.

4.4. Number of Transmitters

The number of transmitters that can cover a certain area depends on the radius distance value of coverage we discussed in the last section. The next step was determining the number of transmitters.

The area of Addis Ababa city on the digital map that is being used for this planning is about 600 km². But, Addis Ababa is not a regular shaped polygon. The area of Addis Ababa for this planning was considered 700 km² due to irregularity in shape.

A total coverage area of 1.27x10³ km² was calculated for the radius of coverage distance calculated above in Section 4.3, which is far larger than the area we estimated for the city. Therefore, one transmitter was found to be enough for the entire city.

4.5. Transmitter Site Selection

Finding the optimal transmitter position is a very difficult optimization problem that needs advanced methods. Doing this takes tremendous effort. As there are 16,696,061 square areas (5mX5m) in the Addis Ababa terrain grid matrix with altitude value in each cell, finding the optimum position needs applying almost all planning process on each of these points and selecting the position with the best performance of coverage for the final planning.

In such cases, the best method to get a position with highly good performance (but not the optimal) is to use a quasi-optimization technique. This method involves selecting some candidate sites that are likely to give a close-to-optimum performance, carrying out planning for each of them, and selecting the position with the best coverage performance as the final planning transmitter site.

In this MMDS transmitter site selection, 10 sites were selected as candidates for the transmitter site. The selection was based on their topographic merit. As described in Section 1.4.2, Addis Ababa city is founded on a high altitude area with a maximum altitude difference of about 1000 m between two the highest and the lowest points. The altitude ranges from about 2100-3100 meters above sea level.

The first phase of candidate sites selection process was dividing the entire area into three topographic regions (Figure 4-3 below). The first region is part of the city with altitude greater than 2600 meters. The second region is the area with altitude ranging from 2400 to 2600 meters above sea level. The third region is the remaining part of the city.

Location A is selected as it represents the center of the first high altitude topographic region. It is located on Intoto Mountain. Locations B, D, and E are mountains found in the northern part of the city. Locations C and I are chosen based on their centrality in the second altitude region. Finally, locations F and J are chosen to represent the central areas of Addis Ababa city.

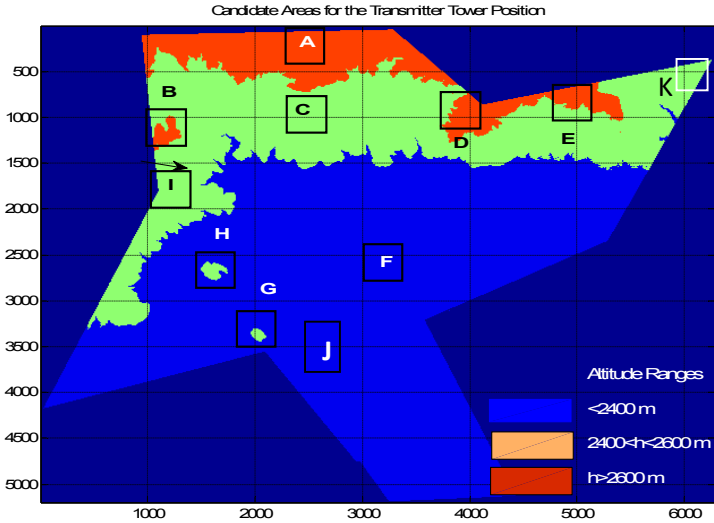
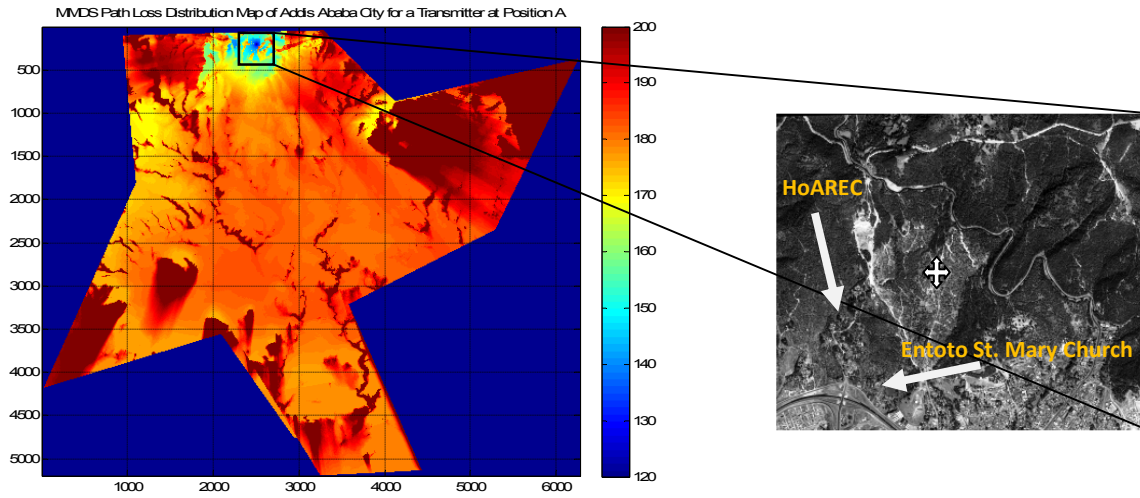
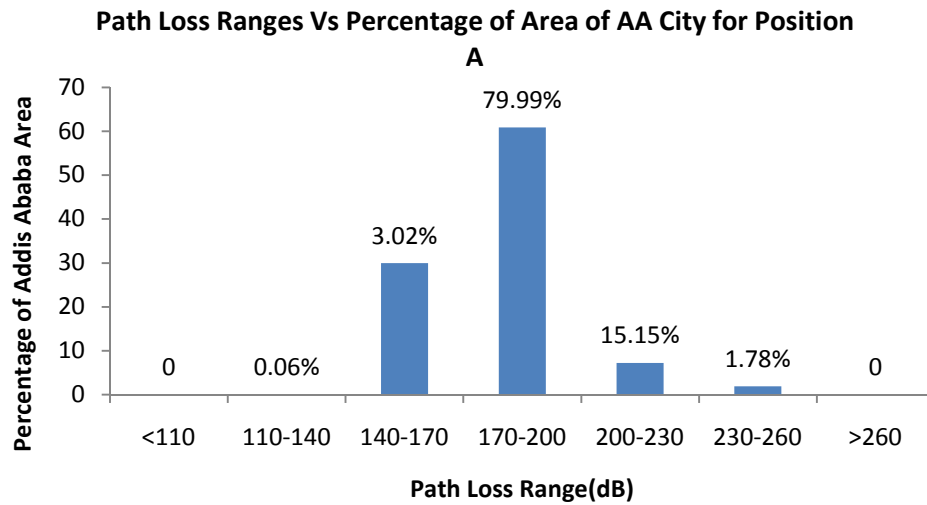


Figure 4- 3: Topographic Map of Addis Ababa with regions of different altitude ranges and the sites selected for transmitter site locations

Path loss prediction was done on these locations which have good reasons to be best locations for maximum coverage if the transmitter is located on them. As the simulation done from 55 meter transmitter height resulted in coverage 90.66% of the area of the city, the following prediction simulations are done from 70 meter transmitter height so that the coverage can be increased. The following figures represent Matlab simulation of path loss prediction map for each of the locations selected above.

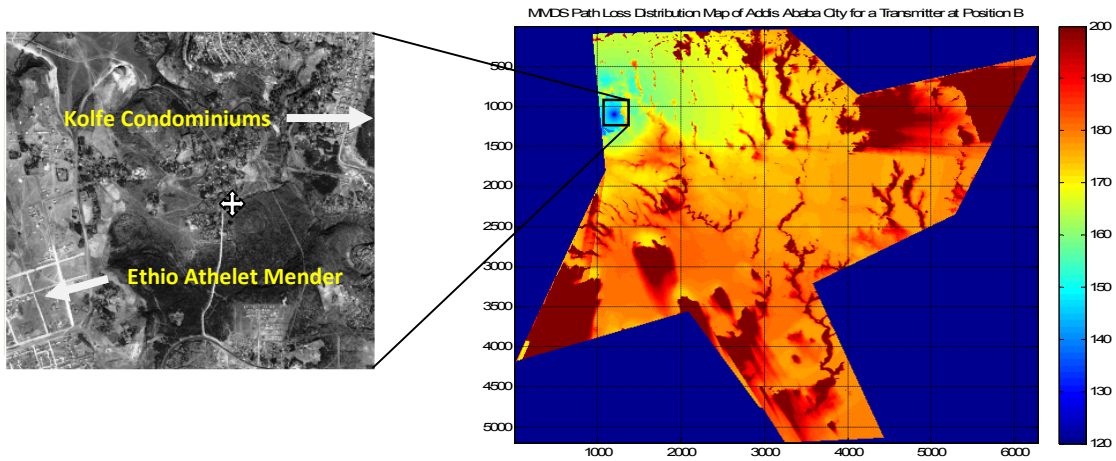


(a)



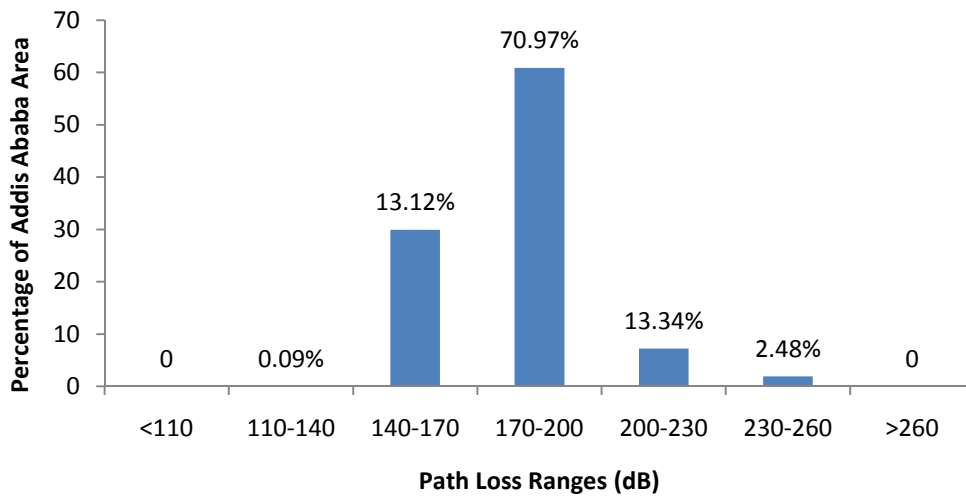
(b)

Figure 4- 4: (a) Path Loss Map of Addis Ababa city with the transmitter located at Position A (around Intoto Mountain); (b) The percentage of the city covered with different path loss ranges.



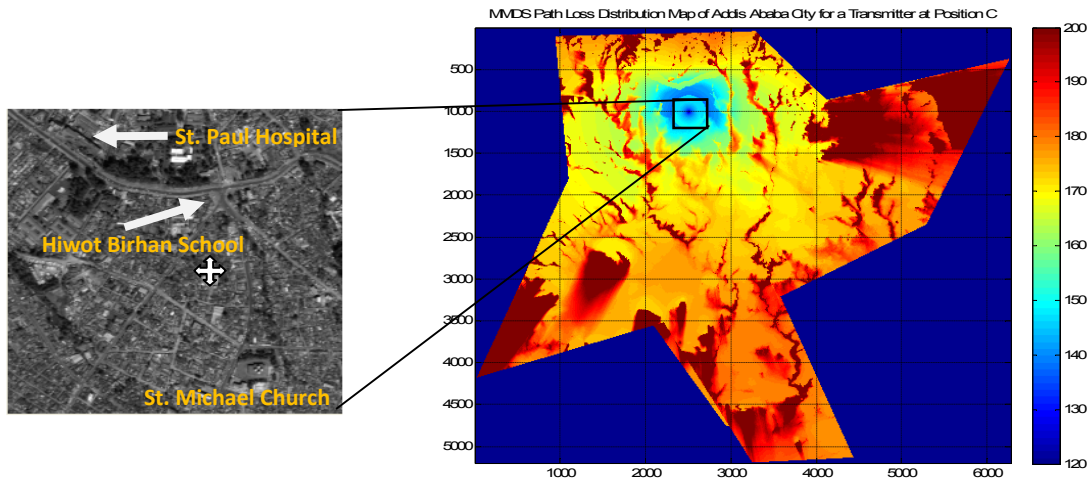
(a)

Path Loss Ranges Vs Percentage of Area of AA City for Position B



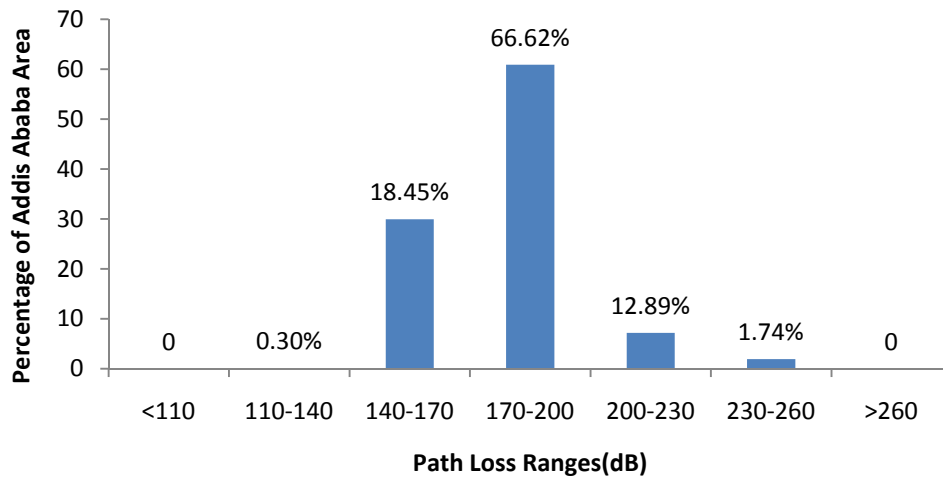
(b)

Figure 4- 5: (a) Path Loss Map of Addis Ababa city with the transmitter located at Position B (around Ethio-Athletic Mender); (b) Percentage of the city covered with different path loss ranges.



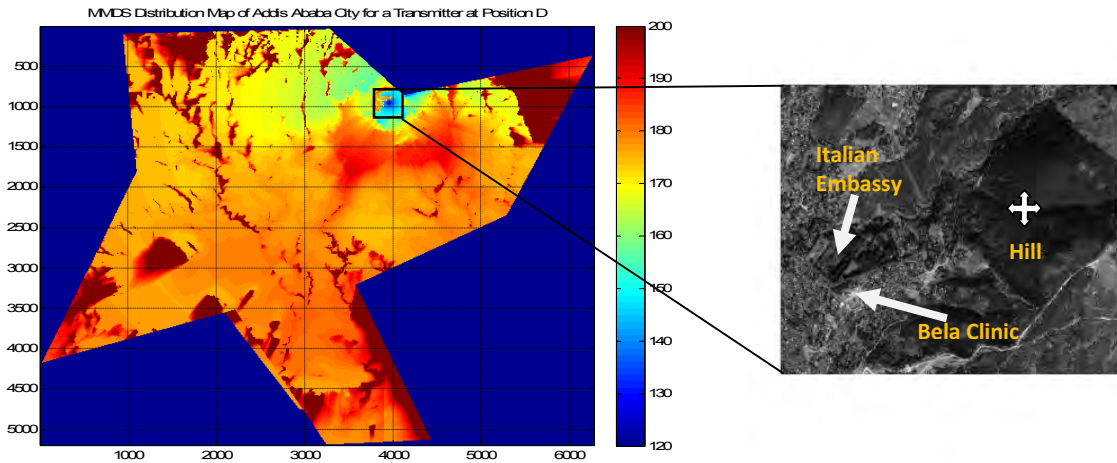
(a)

Path Loss Ranges Vs Percentage of Area of AA City for Position C

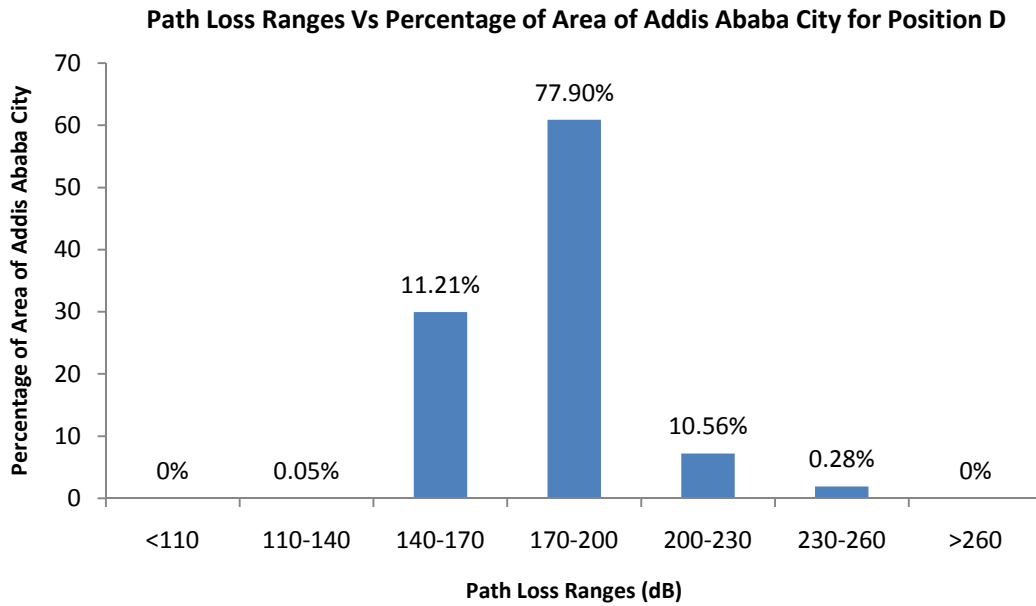


(b)

Figure 4- 6: (a) Path Loss Map of Addis Ababa city with the transmitter located at Position C (around St. Paul Referral Hospital); (b) Percentage of the city covered with different path loss ranges.

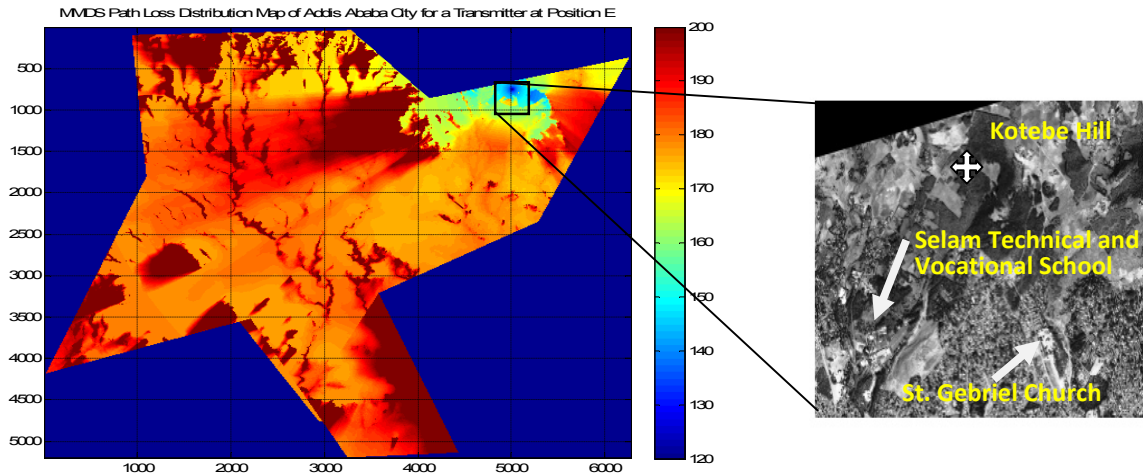


(a)

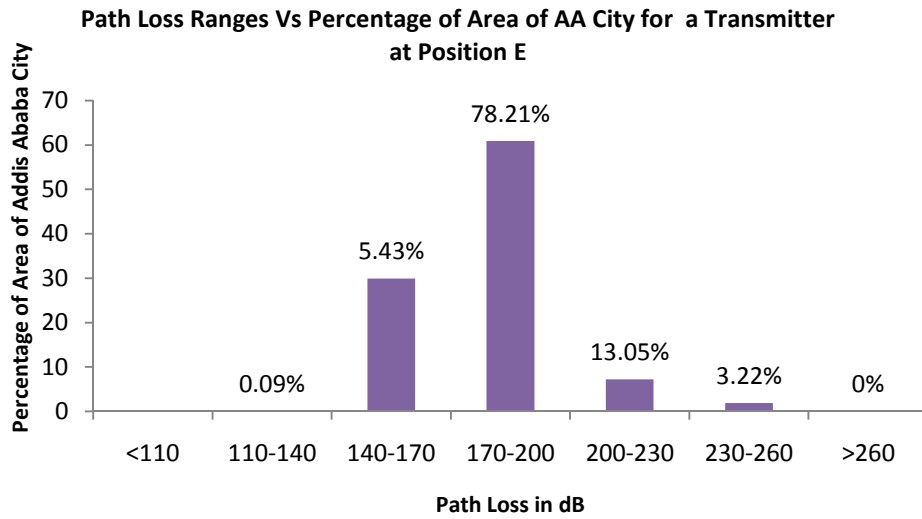


(b)

Figure 4- 7: (a) Path Loss Map of Addis Ababa city with the transmitter located at Position D (a mountainous area near Italian Embassy around Bela area); (b) Percentage of the city covered with different path loss ranges.

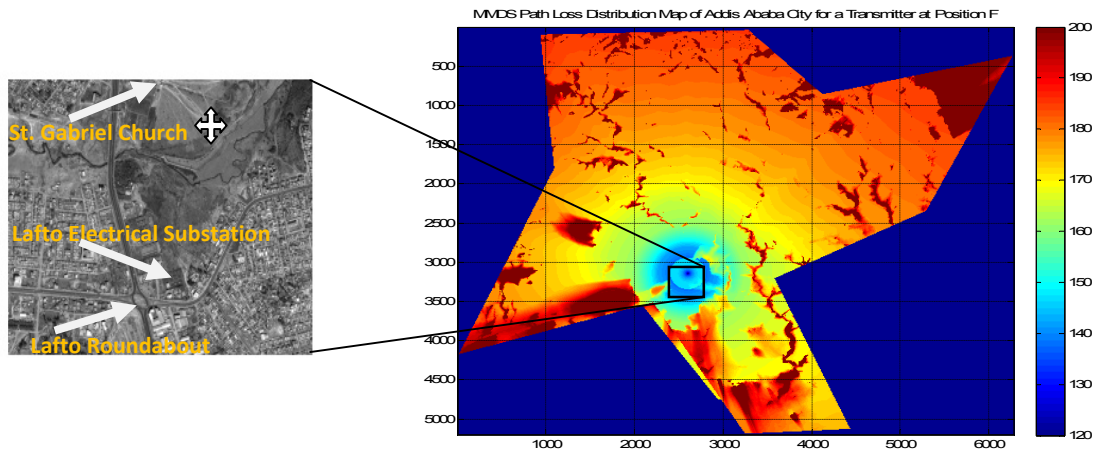


(a)



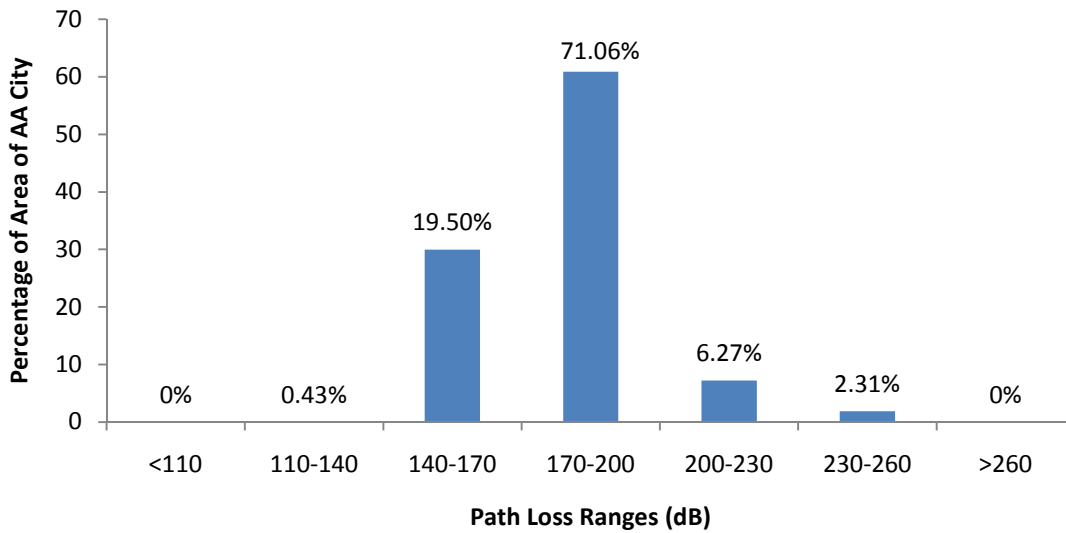
(b)

Figure 4- 8: (a) Path Loss Map of Addis Ababa city with the transmitter located at Position E (a mountainous area near Selam Technical and Vocational School around Kotebe area East of Intoto Mountain); (b) The percentage of the city covered with different path loss ranges.



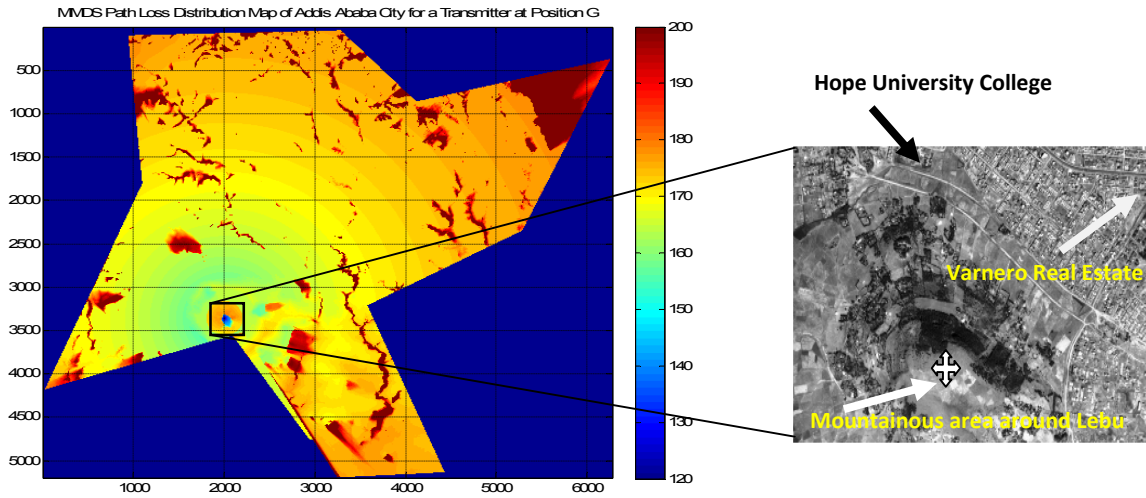
(a)

Path Loss Ranges Vs Percentage of Area of Addis Ababa City for a Transmitter at Position F

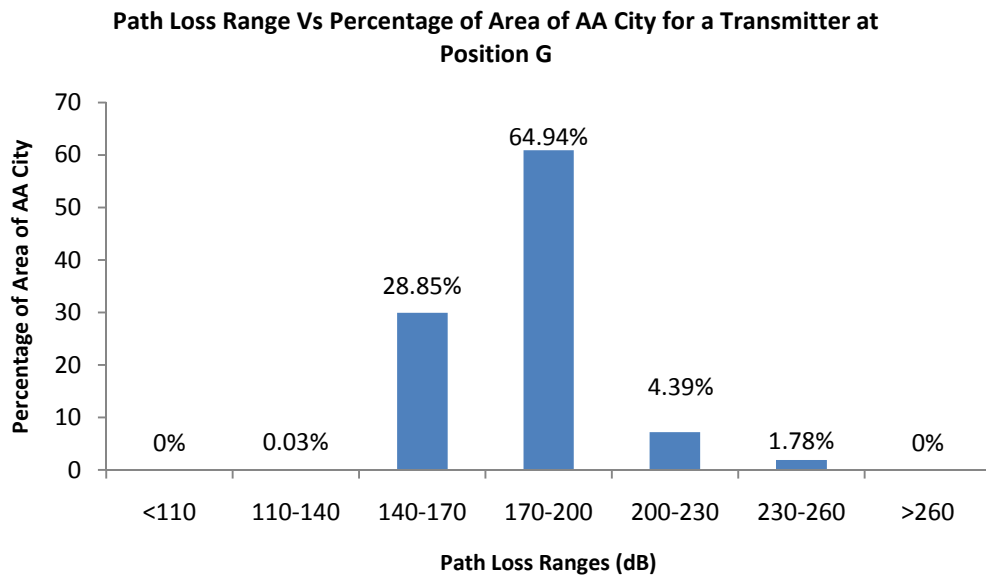


(b)

Figure 4- 9: (a) Path Loss Map of Addis Ababa city with the transmitter located at Position F (area near St. Gabriel Church North of Lafto Roundabout around Lafto area); (b) The percentage of the city covered with different path loss ranges.

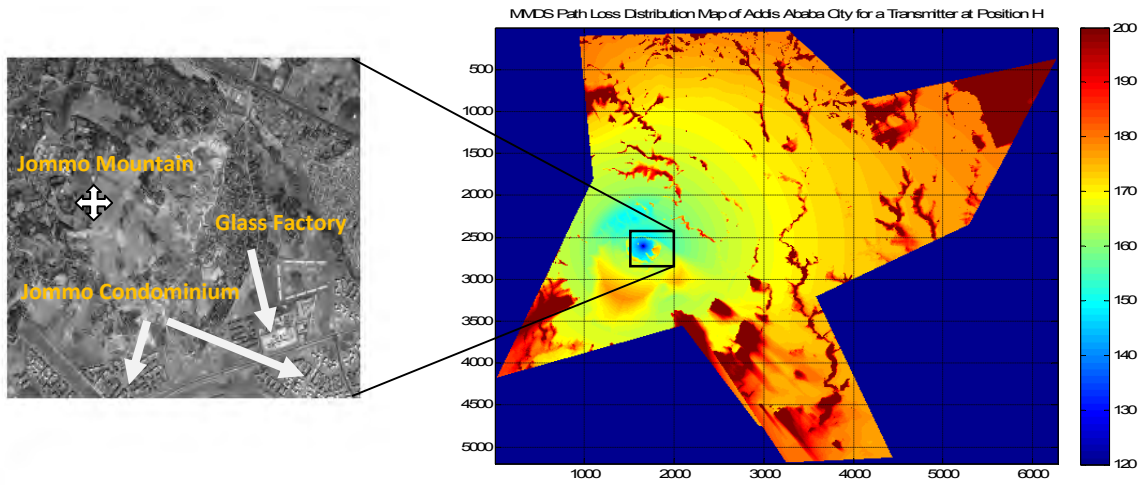


(a)

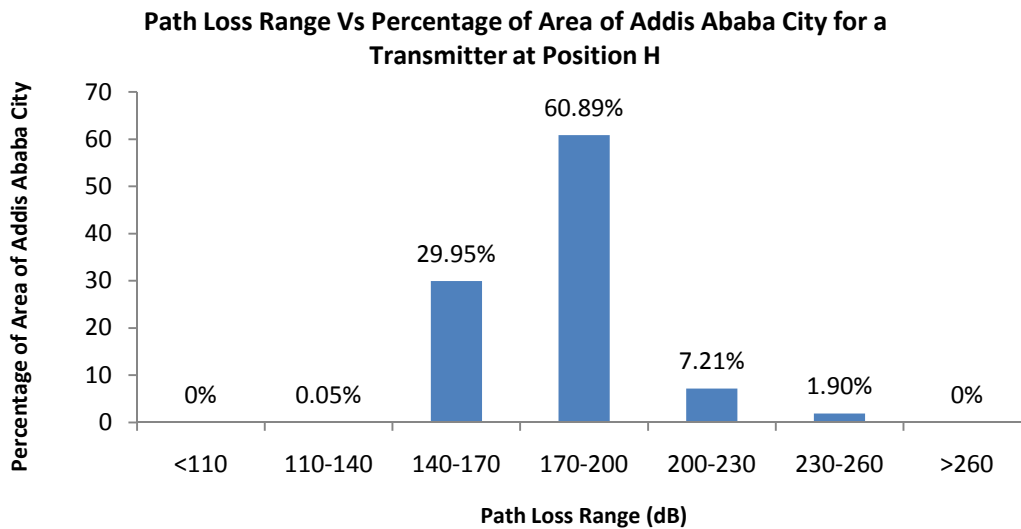


(b)

Figure 4- 10: (a) Path Loss Map of Addis Ababa city with the transmitter located at Position G (mountainous area near Varnero Real Estate around Lebu area); (b) The percentage of the city covered with different path loss ranges.

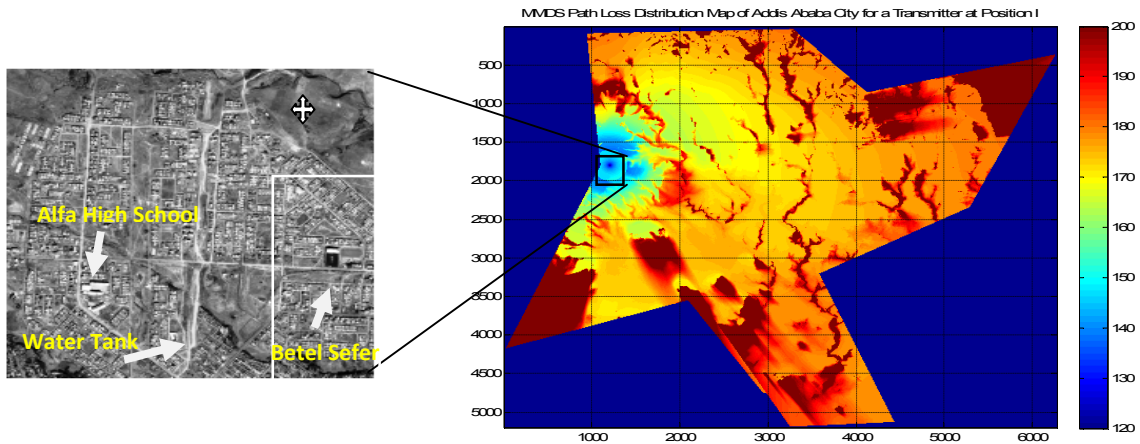


(a)

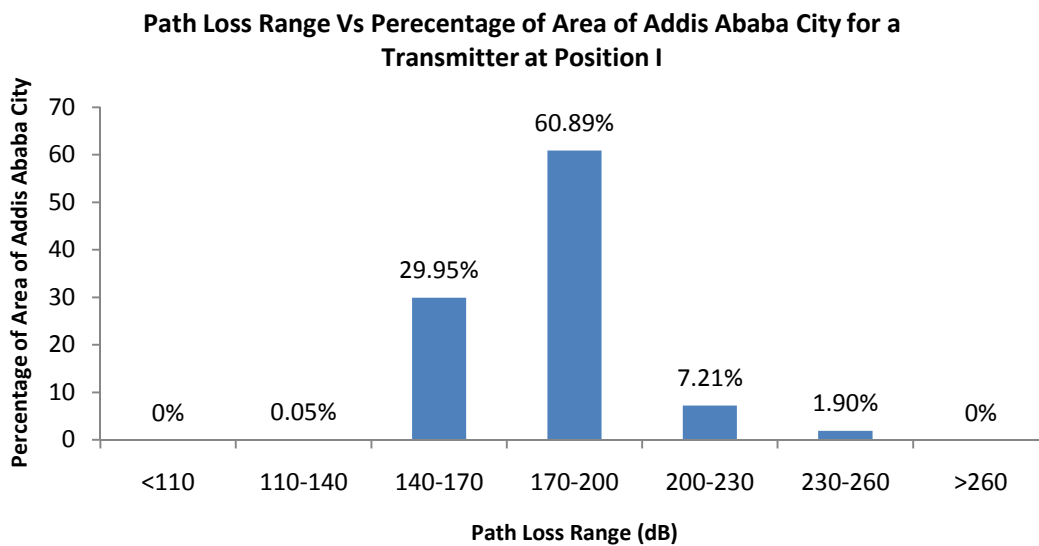


(b)

Figure 4- 11: (a) Path Loss Map of Addis Ababa city with the transmitter located at Position H (mountainous area North of Jommo Condominiums around Jommo area); (b) Percentage of the city covered with different path loss ranges.

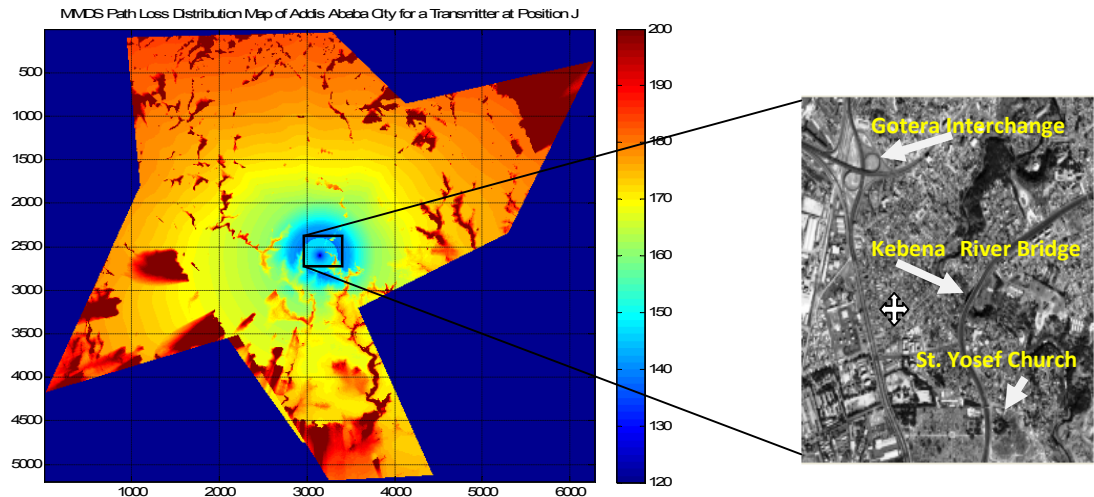


(a)

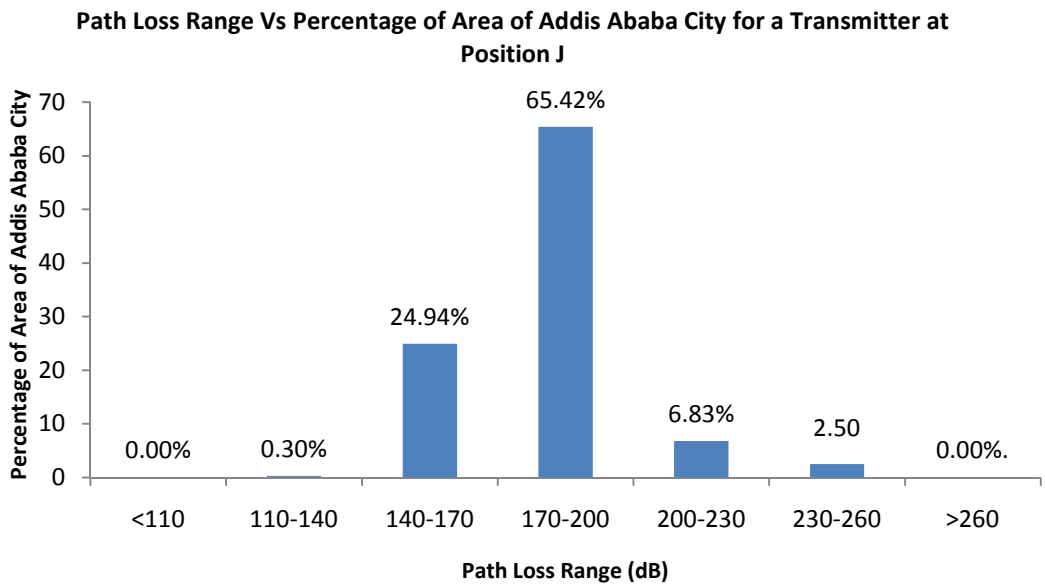


(b)

Figure 4- 12: (a) Path Loss Map of Addis Ababa city with the transmitter located at Position I (mountainous area around Betel Sefer); (b) Percentage of the city covered with different path loss ranges.



(a)



(b)

Figure 4- 13: (a) Path Loss Map of Addis Ababa city with the transmitter located at Position J (area near Kebena River Bridge around Gotera Interchange Road); (b) The percentage of the city covered with different path loss ranges.

From these simulation path loss maps and their respective bar graphs that show percentage coverage of the city, it was readily seen that a transmitter located at Position G had shown best coverage (93.82% of the area of the city below the threshold path loss value). So the planning work with a transmitter at Position G was taken as the final result.

It can be seen from the path loss map of Position G (Figure 4-10 above) that, a portion of the area with no coverage was shadowed by a mountain. In such cases, the planning solution is to extend the coverage by using repeaters [2] (9). A 25 meter repeater was added on the other side of the mountain as shown in Figure 4-14 below. It was found out that the repeater needs to cover 5 km radius on the side of the uncovered area. It was calculated from the IEEE 802.16 model and link budget calculation (Equation 4.2) that the output power to cover this radius is 32dB_m.

With this repeater output power and tower height, a planning was done again for Position G, and the result found was shown in the figure below.

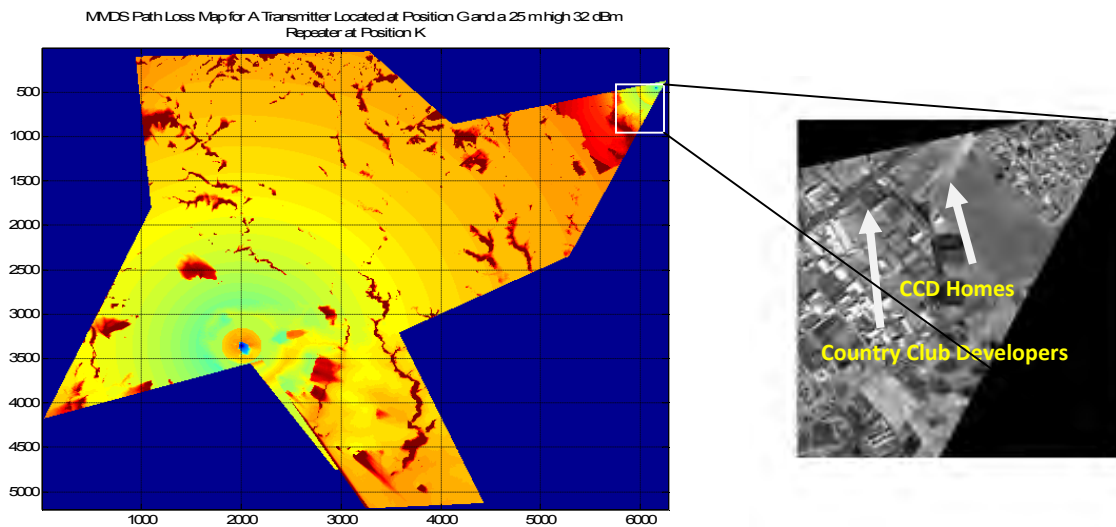
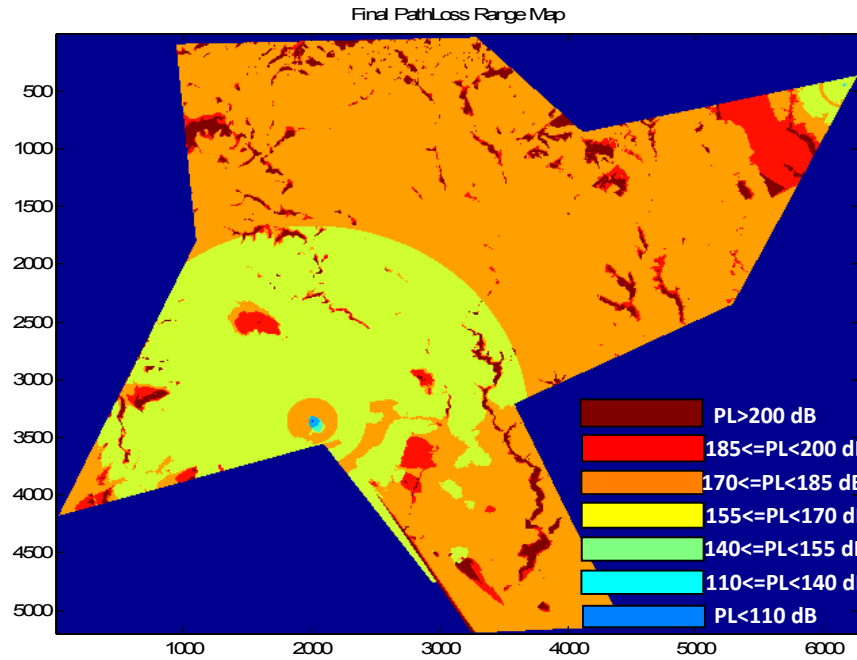


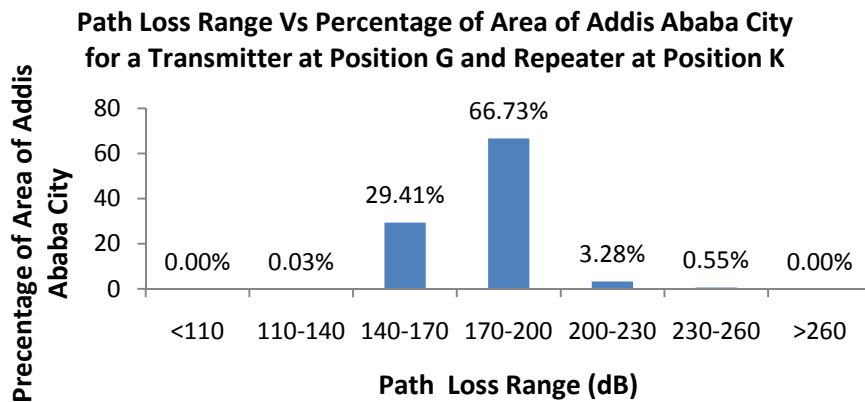
Figure 4- 14: Path Loss Map of Addis Ababa city with the transmitter located at Position G and a repeater at Position K

It can be shown in figure below that the coverage was increased to 96.14% of the city's area. It is also observed from this path loss map that most of the low signal strength (high path loss) areas

are peripheral areas and river surroundings where population density is estimated to be low. In addition, initial coverage planning should give space for further improvement through optimization works. With these considerations, 96.14% coverage is satisfactory. The final coverage map with range of values was shown in Figure 4-15 below.



(a)



(b)

Figure 4- 15: The final MMDS Path Loss Range Map of Addis Ababa city with a 70 m transmitter having 57 dBm output power at Position G and a 25 m repeater with 32 dBm output power at Position K

Chapter Five: Conclusions and Recommendations

Chapter Five: Conclusions and Recommendations

5.1. Conclusions

Fixed Wireless Broadband systems are expanding vigorously as people in our time have a strong demand for large bandwidth communication systems. This has resulted in the installation of numerous FWB systems throughout the world. MMDS is one of these fast growing broadband technologies.

In this thesis, MMDS coverage planning was carried out for Addis Ababa city. Coverage planning was done through propagation models that conform to the precision of the environmental data, and the operating frequency span. Based on literatures reviewed and cross referencing, two propagation models were chosen: one is IEE 802.16 (SUI) model for system dimensioning, and the other is ITU-R P.1546-5 model for the detail planning.

In coverage planning, one of the most important parameters is number of transmitters that can cover the area. In this coverage planning, just one transmitter was enough for the entire Addis Ababa area with output power 57dBm and tower height 70 meter. Since MMDS for broadcasting in relatively small geographic areas is a Single Frequency Network (SFN) the issue of frequency reuse is not considered. In addition, there is no output power restriction as long as it does not cause adjacent channel interference for other services. Thus, the planning was done with these parameters. It is possible to trade-off transmitter tower height with output power and the number of transmitters if building a single 70 meter tower is a great difficulty.

As finding the optimal location for the transmitter to get the best coverage is a very difficult optimization task, this planning was done using a quasi-optimization method of reducing the locations to 10 highly probable sites and doing coverage planning for each of them. Finally, the site with the best coverage was selected. A mountain near Varnero Real Estate in the southwestern part of Addis Ababa is found to be the best position for best possible coverage (93.83%).

As a mountain shadows a small but considerable part of the city at the north-eastern part, a 25 meter height 32dBm repeater was mounted around Country Club Developers and it increased the

total coverage to 96.14% of the city's total area. Most of the 3.86% uncovered areas are surroundings of rivers and gorgeous areas. So, the coverage is highly satisfactory.

5.2. Recommendations

The next step after coverage planning is optimization of planning parameters. In this planning, there are many parameters to be optimized. The number of transmitters, the output power, transmitter tower height, and locations of transmitters need to be optimized for best and economically efficient performance. Though the values for these parameters in this planning are reasonable and quasi-optimized, further refinement using advanced optimization techniques is recommended.

In addition, field measurements need to be done before going to extensive implementation works.

What is done in this thesis is coverage planning for Addis Ababa city. Frequency and capacity plans were not done due to time limitation. These need to be done to make the plan complete. About 200 MHz (2.5-2.7 GHz) frequency band is common in the MMDS frequency allocation of many countries. The plan for the proper usage of these frequencies is recommended to be done.

In addition to its application for one way broadcasting service, MMDS also used for two ways interactive communication services. Providing high speed broadband internet service through Digital MMDS technology is a growing wireless interest. But, the entire planning process should be revised so that it would consider the downlink and uplink signal propagation predictions.

Finally it is recommended for the planning to be done with a more precise 3D digital map using physical models that will predict path loss better. This is recommended for future works on MMDS planning in the city.

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