Addis Ababa University

Addis Ababa Institute of Technology

School of E[redacted]mputer Engineering

Tiblets Kinfe

Coverage Plann[redacted]l Terrestrial Television Broadca[redacted]of Addis Ababa

By

Tiblets Kinfe

Advisor

Dr. -Ing. Dereje Hailemariam

Thesis Submitted to Addis Ababa Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Master of Science in Electrical and Computer Engineering (Communication Engineering)

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Addis Ababa University

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Approval by Board of Examiners

_____	_____	_____
Chairman Department of Graduate Committee	Signature	Date
Dr. -Ing. Dereje Hailemariam	_____	_____
Advisor	Signature	Date
_____	_____	_____
Internal Examiner	Signature	Date
_____	_____	_____
External Examiner	Signature	Date

Declaration

I, the undersigned, declared that this MSc thesis is my original work, has not been presented for fulfillment of a degree in this or any other University and all sources and materials used for the thesis are duly acknowledged.

Tiblets Kinfe _____

Name Signature

Addis Ababa _____

Place Date of Submission

This thesis work has been submitted for examination with my approval as a University Advisor.

Dr. -Ing. Dereje Hailemariam _____

Advisor's Name Signature

Abstract

Digital Terrestrial Television (DTT) is a technological evolution of broadcast television and an advancement over analog television. The analog television system has been in existence in Ethiopia over the years but now Ethiopian Broadcasting Corporation (EBC) is ongoing to deploy DTT transmitter. As technology growth and introduction of different services increases, analog television system encounters with the problems of frequency scarcity, adjacent channel and co-channel interference.

DTT broadcasting system is supplying technique of Single Frequency Network (SFN), in which SFN allotments allow network coverage to be progressively modified adding further transmitters without the need for re-planning frequency use as long as the constraints of the frequency plan are respected. This increases spectrum efficiency.

This thesis focuses on coverage planning of digital terrestrial television broadcasting in case of Addis Ababa city. Propagation models are used to calculate path loss at certain distance from the transmitter by using the digital terrain map of Addis Ababa city. In which two types of propagation models are used, that is from the city models, COST-231 Hata model is used for estimating number of transmitters to cover Addis Ababa city, and ITU-R P1546-5 is used to select the optimum transmitter site using digital terrain map of Addis Ababa city. Hence, a single transmitter with 53 dBm output power and 90 meter transmitter antenna height is used to cover Addis Ababa city. Simulation results of this thesis work shows that 96.7% of Addis Ababa city can be covered by adding a repeater with 30 dBm output power and 30 meter antenna height around Hana Mariam. This can be considered as good coverage since more than 95% of the sub-area is served.

Keywords: *Digital terrestrial television, Propagation models, Coverage planning, System dimensioning and frequency planning.*

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First and foremost I would like to thank God for giving me the strength and ability to pull this through.

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List of Abbreviations

AM	Amplitude modulation
ACATS	Advisory Committee on Advanced Television Service
ATSC	Advanced Television Systems Committee
ATV	Advance television
COFDM	Coded Orthogonal Frequency Division Multiplexing
CCIR	International Radio Consultative Committee
COST	Cooperate in Science and Technology
dB	decibel
DTB	Digital Television Broadcasting
DTTV	Digital terrestrial television
DTV	Digital television
EBU	European Broadcasting Union
ECC	Electronic communication committee
FCC	Federal Communications Committee
FEC	Forward Error Correction
FSPL	Free Space Path Loss
FWA	Fixed Wireless Access
GHz	Giga Hertiz
GPS	Global Positioning System
HDTV	High definition television
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
ITU-R	International Telecommunications Union Radio Sector

LOS	Line of Sight
MHz	Mega Hertiz
MMDS	Multichannel and Multipoint Distribution System
MPEG-2	Moving Pictures Experts Group
MUSE	Multiple sub-Nyquist sampling encoding
NLOS	Non Line of sight
NTSC	National Television Systems Committee
OAU	Organization of African Unity
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
SUI	Stanford University Interim
TV	Television
VHF	Very high frequency
UHF	Ultra high frequency

Chapter One

Introduction

Broadcasting is the distribution of audio and/or video content to a dispersed audience via any electronic mass communication medium. More typically it uses the electromagnetic spectrum (radio waves) in a one to many model [1].

Broadcasting began with Amplitude Modulation (AM) and radio broadcasting which came into popular use starting with the invention of the crystal detector in 1906. Before this, all forms of electronic communication, radio, telephone, and telegraph, were "one-to-one", with the message intended for a single recipient.

Over the air broadcasting is usually associated with radio and television, though in practice radio and television transmissions take place using both wires and radio waves.

As all wireless services, television broadcasting involves transfer of information through electromagnetic signals (radio waves) 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 Very High Frequency (VHF) or Ultra High Frequency (UHF) frequency ranges as television broadcasting requires large bandwidth.

1.1. Background of Television Broadcasting

For almost 60 years, television broadcasters have transmitted signals based on the National Television Systems Committee (NTSC) standard". This technical format, developed and recommended by the National Television Systems Committee, has remained largely unchanged since it was adopted by the Federal Communications Committee (FCC) in 1941 [1]. The most significant modifications have been the introduction of color television in 1953; "ghost canceling" provisions to enhance picture

clarity; the use of a previously unused portion of the transmission signal called the "vertical blanking interval" to send closed captioning; and stereophonic sound.

Although television engineers had long envisioned ways to upgrade the existing NTSC standard, for many years the broadcast community, Congress, and the FCC showed little interest in undertaking such a large, complex challenge. This view changed in the mid-1980s as Japanese consumer electronics firms forged ahead with the development of High Definition Television (HDTV) technology, and as the Multiple sub-Nyquist sampling encoding (MUSE) analog format proposed by NHK, a Japanese company, was seen as a pacesetter that threatened to eclipse U.S. electronics companies. During this period, the FCC considered reassigning some vacant portions of the broadcast spectrum to so-called Land Mobile user's police departments, emergency services, delivery companies, and others. At that point, broadcasters declared their interest in reserving this portion of the spectrum for HDTV [2].

To explore the issues posed by HDTV, the FCC issued its First Notice of Inquiry on Advanced Television Service (ATV) in July 1987 [3] and a few months later, appointed a 25-member advisory panel the Advisory Committee on Advanced Television Service (ACATS). Chaired by former FCC Chairman Richard E. Wiley, ACATS was charged with reviewing the technical issues and recommending an ATV system to the FCC.

The first congressional hearing on HDTV was held in October 1987. This event helped galvanize the ACATS to announce an open competition for development of the best advanced television standard. Until June 1990, the Japanese MUSE standard based on an analog system was the front-runner among the more than 23 different technical concepts under consideration. Then, an American company, General Instrument, demonstrated the feasibility of a digital television signal. This breakthrough was of such significance that the FCC was persuaded to delay its decision on an ATV standard until a digitally based standard could be developed.

In March 1990, when it became clear that a digital standard was feasible, the FCC made a number of critical decisions. First, the Commission declared that the new ATV standard must be more than an enhanced analog signal, but be able to provide a genuine HDTV signal with at least twice the resolution of existing television images. Then, to ensure that viewers who did not wish to buy a new digital television set could continue to receive conventional television broadcasts, it dictated that the new ATV standard must be capable of being "simulcast" on different channels [1].

Digital terrestrial television (DTTV or DTT) is a technological evolution of broadcast television and an advancement over analog television. DTTV broadcasts land based (terrestrial) signals. A terrestrial implementation of digital television (DTV) technology uses an aerial to broadcast to a conventional television antenna (or aerial) instead of a satellite dish or cable television connection.

DTTV is transmitter on radio frequencies through terrestrial space in the same way as standard analog television, with the primary difference being the use of multiplex transmitter to allow reception of multiple channels on a single frequency range (such as a UHF or VHF channel) known.

Digital television provides for more efficient use of the spectrum than analog television as adjacent channel can be used in the same area and the re-use distance between co-channel services is less than for analog services with the same coverage. The use of single frequency networks with multiple transmitters operating on the same frequency within the same region is another way of improving the spectrum productivity of television services. Interference limits the opportunity to take advantage of the spectrum efficient properties of digital television. There is additional requirement to plan the spectrum efficiently to achieve the same coverage objective.

The increasing demand of various fixed and mobile service has placed considerable pressure on the limited frequency spectrum in Ethiopia especially in Addis Ababa city

for the future, as technology is growing continuously and commercial channels are increasing in number through time in the city. In addition to this regard the ITU resolved that all countries migrate to a digital broadcasting regime where one frequency carries up to 20 channels, thereby freeing more spectrum band for the other services [4]. Ethiopian Broadcasting Corporation (EBC) is also planned to deploy digital terrestrial television transmitters in different parts of the country. For the efficient utilization of this resource, as well as for performance assessment of the existing systems, modeling and coverage predictions are essential.

With the increasing need to develop radio communication systems that are more reliable and efficient, there is need for proper radio coverage planning. These planning require the use of adequate propagation models to predict coverage. Broadcasting systems like other radio communication systems comprise of a transmitter, a propagation path and a receiver. The process of signal propagation from the transmitter route to the receiver has been a subject of much research, the focus of more recent work has been on predicting the signal strength [5].

In the design of any broadcasting system, the fundamental task is to predict the coverage of the proposed system. Digital television service coverage's are characterized by a very rapid transition from near perfect reception to no reception at all. Hence, it becomes critical to be able to define which areas are going to be covered and which are not. In the other case it is necessary to increase the transmitter powers or to provide a large number of transmitters in order to guarantee coverage to the last few percent of the worst served small areas [6]. A wide variety of techniques have been developed over the years to predict coverage using what are known as propagation models. Propagation, in this context, means the transmission of signals from the transmitter to the receiver. En route from the transmitter to the receiver, the signal gets weaker and may experiences shadow or multipath effects [7].

1.2. History of Television Broadcasting in Ethiopia

The concept of television was introduced in Ethiopia during the celebrations of the Emperor Haileselassie's Silver Jubilee in 1956 via Telecommunication Pavilion near the old airport. The Emperor commissioned the British Broadcasting Corporation (BBC) to transmit the event in celebration at the old airport exhibition. Transmission ceased to operate right after the celebration because there were no enough infrastructures to support the transmission system.

The experience of the first show of the television left a lasting impression on the Royal families and landlords. Dejazemach Daniel Abebe, one of the sons' of Feudal lords, was among those fascinated by the "magic window." His excitement about television led to Dejazemach Daniel to requesting the Emperor to establish his own television station in 1960. Nevertheless, the Emperor and his council of ministers denied him permission on the pretext that it was not permissible for individuals. Following that request, there were six attempts to launch television stations, but the emperor unequivocally rejected landlords and religious organizations' request to establish private television stations.

At last, television services were started on the occasion of the founding meeting of the Organization of African Unity (OAU) in 1963. Transmission was still in its infant stage, thus a makeshift closed-circuit television system was installed and television sets were fixed in and around the African Hall. Following this events, Ethiopian Television initiated its broadcasting in 1964 in the city hall. A British company called Thomson Television International was responsible for the installation of the television infrastructure [5].

Color television was introduced in 1982 by the military government in order to commemorate the founding of the Workers' Party of Ethiopia (WPE). The current structure and goals of were established 1987 with proclamation 114/87 [8].

1.3. Statement of the Problem

The increasing demand of various fixed and wireless services has placed considerable pressure on the limited frequency spectrum. Digital television broadcasting is one of the wireless services that uses VHF/UHF band of frequencies.

Currently the analogue television system is in existence in our country. Nevertheless, the analogue broadcasting techniques has contributed its own quota to the development of broadcasting industry in Ethiopia and cannot be overemphasized. As technology grows and different services introduces this faces frequency scarcity and interference. DTT transmission technology set to be a technical solution to the many technical challenges inherent in the analogue terrestrial system.

Digital terrestrial television broadcasting system is supplying technique of Single Frequency Network this increases spectrum efficiency. EBC is working to install DTT transmitters all over the country including Addis Ababa this needs coverage analysis and study of propagation models. This thesis is focused on coverage planning of digital terrestrial television broadcasting in case of Addis Ababa city.

1.4. Objective of the thesis

1.4.1. General objective

The main objective of this thesis is to carry out coverage planning of digital terrestrial television broadcasting in case Addis Ababa city.

1.4.2. Specific objectives

- To study and select appropriate propagation models that can be used for predicting coverage distance of specific transmitter.
- To select number and site of transmitter for maximum coverage.

- To review frequency planning networks.
- To simulate coverage of Digital Terrain Map (DTM) of Addis Ababa city using MATLAB Software.
- Finally providing recommendations and showing forth future works

1.5. Methodology

- Literature review: reading books, journals, papers, articles, white papers, reviewing different propagation models and simulation tools
- System design: this involves determining the different parameters for system design like, output power, number of transmitter, location of transmitter, heights of transmitter and receiver antennas as coverage is determined by these factors. Analyzing various signal propagation models that are used in the digital television broadcasting frequency range and coverage distance of single transmitter is determined by link budget analysis.
- Simulation: to predict coverage by first converting the Digital Terrain Map (DTM) of Addis Ababa into text file using MapInfo software and then simulate using Matlab Software at different sites.
- Analysis and interpretation of the simulation results.

1.6. Contribution of the thesis

This thesis work conducts all the coverage planning of digital television broadcasting for Addis Ababa city. During the coverage planning, the number of transmitters and the specific site of transmitters is estimated by predicting the signal strength of each point using propagation models. EBC is working to implement digital terrestrial television transmitters all over the country including Addis Ababa. Finally the results and conclusions of this thesis may use as reference. This will also have further significance for future researches as well as actual deployments.

1.7. Thesis layout

The thesis work is done in such a way that it gives a clear flow and understanding regarding the subject matter. Chapter one presents the statement of problem, objectives, methodology, contribution of the thesis and a short introduction with problem explanation. Chapter two presents the theoretical overview of digital terrestrial television broadcasting (DTB) and it includes some introduction about building blocks of DTB such as, compression and encoding, transport and service multiplexing, RF transmission, channel coding and modulation; and Chapter three and four focuses on the different propagation models such as, city models, foliage models and terrain models used for system dimensioning and International Telecommunication Union (ITU) 1546.5 model for detailed coverage planning. Chapter five of this thesis outlines the types of frequency planning, that is multiple frequency networks and single frequency networks. The practical planning simulations, results and discussions are included in Chapter six; and the results are presented with reasonable explanation. Finally conclusion is presented followed by points of recommendation in Chapter seven.

Chapter Two

Overview of Digital Terrestrial Television Broadcasting (DTTB)

2.1 Introduction

Television signals were initially distributed only as terrestrial television using high powered radio frequency transmitters to broadcast the signal to individual television receivers. Alternatively television signals are distributed by co-axial cable or optical fiber, satellite systems and via the internet. Until the early 2000s, these were transmitted as analog signals but countries started switching to digital.

In the era of rapid development of technology, digital products bring excitement and convenience to our modern life. Digital Television is one of them and to be considered as the most significant development technique in television technology because of features such as better picture resolution and the more efficient use of spectrum. In addition the characteristic of DTB compared to traditional analog television can be treated as advantages in main aspects like, capacity of data, Forwarding Error Correcting (FEC) coding, and channel estimation & correction.

Digital television broadcasting standards are planned to replace the current analog ones in most parts of the world. Digital television broadcasting commonly designed to operate in the IV and V bands corresponding to the analog television bands, so that the users do not change their antennas and the favorable UHF propagation characteristics are maintained. Specifically, the whole frequency band used by DTTB is 470 - 862 MHz, however the band is not intended to be fully used. The frequency band 790 - 862 MHz, called Digital Dividend, is intended to be used for mobile applications or for special digital television services [2]. Thus, the central frequency is 630 MHz. Therefore, several countries practically do not take into account this band for the deployment of the digital

television broadcasting scheme, using only the UHF frequency band 470 - 790 MHz, which corresponds to channels 21 - 60 of the analog channel allocation, while the channels 61 - 69, are committed for Digital Dividend applications [4].

2.2 Building Blocks of Digital Television Broadcasting System

A TV operator normally receives content from a variety of sources, including local video, and satellite channels. The content needs to be prepared for transmission to the customer's home by passing the signal through a digital broadcasting system. The content to be prepared for transmission passes through the following components. In the block diagram below the audio and video sources are output sources of a computer terminal, a microphone, a television camera, a remote sensor in telemetry system. This output source is given to the digital television transmitter to convert into waveforms that are suitable for broadcasting on the channel [9]. The function of the transmitter is subdivided as given in the block diagram below.

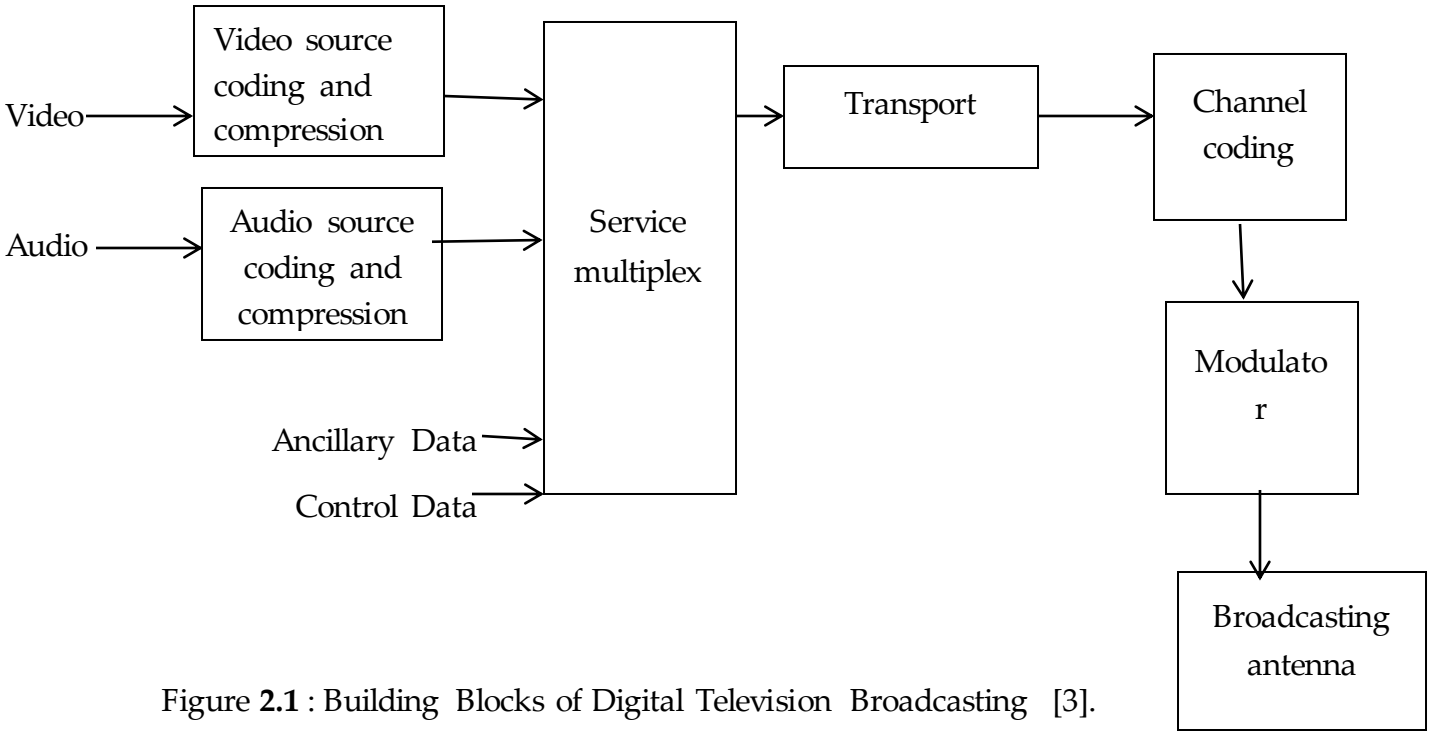


Figure **2.1** : Building Blocks of Digital Television Broadcasting [3].

2.2.1 Compression and Encoding

Central to a digital video-broadcasting network is the compression system, whose job is to deliver high quality video and audio to consumers using a small amount of network bandwidth. The main goal of any compression system is to minimize the storage capacity of information. This is particularly useful for service providers who want to "squeeze" many digital channels into a digital stream.

A compression system consists of encoders and multiplexers. Encoders are devices used to digitize, compress, and scramble a range of audio, video, and data channels. Digital encoders allow TV operators to broadcast several high quality video programs over the same bandwidth that was formerly used to broadcast just one analog video program.

Once the signal is encoded and compressed, an (Moving Pictures Experts Group) MPEG-2 stream is transmitted to the multiplexer. This group has defined a range of compression standards and file formats, including the MPEG-2 video animation system. MPEG-2 is generally accepted in 190 countries worldwide as the standard for digital video compression. There are two major MPEG standards available on the market today: MPEG-1 and MPEG-2.

The MPEG-1 file format is normally used by interactive TV developers to create TV "stills" and has a quality level slightly less than conventional video cassette recorders. The MPEG-2 file format is used in a digital broadcasting environment and features CD-quality audio complemented with a high screen resolution. Once the signal has been compressed into MPEG-2 format, the multiplexer combines the outputs from the various encoders together with the security and program information and data into a single digital stream [10].

2.2.2 Transport and Service Multiplexing

Transport and Multiplexing refers to the means of dividing each bit stream into packets of information, the means of uniquely identifying each packet or packet type, and the

appropriate methods of interleaving or multiplexing video bit stream packets, audio bit stream packets, and data bit stream packets into a single transport mechanism. The structure and relationships of these essence bit streams is carried in service information bit streams, also multiplexed in the single transport mechanism. In developing the transport mechanism, interoperability among digital media—such as terrestrial broadcasting, cable distribution, satellite distribution, recording media, and computer interfaces was a prime consideration. The DTV system employs the MPEG-2 Transport Stream syntax for the packetization and multiplexing of video, audio, and data signals for digital broadcasting systems. The MPEG-2 transport stream syntax was developed for applications where channel bandwidth or recording media capacity is limited and the requirement for an efficient transport mechanism is paramount.

2.2.3 RF Transmission

RF Transmission refers to channel coding and modulation. The channel coder takes the digital bit stream and adds additional information that can be used by the receiver to reconstruct the data from the received signal which, due to transmission impairments, may not accurately represent the transmitted signal. The modulation (or physical layer) uses the digital bit stream information to modulate a carrier for the transmitted signal [9].

2.2.3.1 Channel Coding

This is the process of adding controlled redundancy to the output of the source encoder, to counter the effects of noise. The most used ones in digital television systems are the Reed–Solomon coder, which encodes the information in blocks, and the Viterbi coder, which uses convolutional encoding [7].

2.2.3.2 Modulation

Once the digital signal has been processed by the multiplexer, it is now time to amalgamate the video, audio, and data with the carrier signal in a process called modulation. The unmodulated digital signal outputted from the multiplexer has only

two possible states, either a "zero" or a "one." By passing the signal through a modulation process, a number of states are added, which increases the data transfer rate. 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 modulation are Quadrature Amplitude Modulation, Quadrature Phase Shift Keying, and Coded Orthogonal Frequency Division Multiplexing.

2.2.3.2.1 Quadrature Amplitude Modulation (QAM)

QAM is a relatively simple technique for carrying digital information from the TV operator's broadcast center to the customer. This form of modulation modifies the amplitude and phase of a signal to transmit the MPEG-2 transport stream. QAM is the preferred modulation scheme for cable companies because it can achieve transfer rates up to 40 Mbits/sec [11].

2.2.3.2.2 Quadrature Phase Shift Keying (QPSK)

QPSK is more immune then QAM to electromagnetic noise and is normally used in a satellite environment or on the return path for a cable television network. QPSK works on the principle of shifting the digital signal so that it is out of phase with the incoming signal. QPSK will improve the robustness of a network, however, this modulation scheme is only capable of transmitting data at 10 Mbits/sec.

2.2.3.2.3 Coded Orthogonal Frequency Division Multiplexing (COFDM)

COFDM operates extremely well in heavily built-up areas where digital transmissions become distorted by obstacles such as buildings, bridges, and hills. COFDM is different to QAM because it uses multiple signal carriers to transfer information from one node on the network to another. At the moment, COFDM may be implemented with either 2,000

(2K) or 8,000 (8K) carrier signals. European terrestrial and MMDS operators mainly use the COFDM modulation scheme. In contrast, COFDM has not been deployed in the United States because the ATSC has defined a digital terrestrial system that meets the needs of a less rugged geographical terrain [12].

2.3 Issues of Coverage planning in Digital Television Broadcasting

The term "coverage" is typically used to represent all the points where the electromagnetic field strength is higher than the minimum theoretical required value. The intention of coverage planning is to make terrestrial broadcasting of television programmes a more attractive proposition to meet competition from cable and satellite transmission [13]. The terrestrial service area planner specifies transmitter characteristics and calculates coverage areas, taking into account interference from other transmitter and noise. 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 [14]. A high probability of interference-free reception within a particular subarea results in high costs for the network operator higher transmission power, additional main transmitters and gap-fillers.

The propagation of a broadcast signal from a single transmitter to a receiving location is considered as a statistical process, which takes account of the various propagation conditions that have to be considered at a specific distance from the transmitter. The parameters for this statistical process are based on the ITU-R propagation curves [13] which represent the results of numerous field measurements. The coverage was

described as “good” if at least 95 % of the sub-area is served for 99 % of the time and as “acceptable” if at least 70 % of the sub-area is served for 99 % of the time [7].

Mostly coverage planning is carried out two phases: system dimensioning and detailed coverage planning [15]. 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.

Chapter Three

Propagation Models for DTB System Planning

3.1 Introduction

In the design of any broadcasting system, the fundamental task is to predict the coverage of the proposed system. Digital television service coverage's are characterized by a very rapid transition from near perfect reception to no reception at all. Hence, it becomes critical to be able to define which areas are going to be covered and which are not. This is predicted by using propagation models. Propagation models predict coverage by predicting path loss.

Accurate estimation of propagation path loss is a key factor for the good design of any broadcasting systems. Such needs are of a great concern of broadcasting system designers to optimize system parameters such as number and locations of transmitters, power coverage and interference level. Optimization of these parameters will increase the efficiency of quality of service, reduce undesirable power losses, increase coverage area, and determine best arrangements of transmitter sites.

The three very basic radio propagation mechanisms are actually the key to analysis of any radio propagation modeling based study. These are: reflection, diffraction & scattering.

Reflection. It occurs when the electromagnetic wave strikes against a smooth surface, whose dimensions are large compared with the signal wavelength.

Diffraction. It occurs when the electromagnetic wave strikes a surface whose dimensions are larger than the signal wavelength, new secondary waves are generated. This phenomenon is often called shadowing, because the diffracted field can reach the receiver even when shadowed by an impenetrable obstruction (no line of sight).

Scattering. It happens when a radio wave strikes against a rough surface whose dimensions are equal to or smaller than the signal wavelength.

Propagation models can be broadly classified into three types namely Empirical, Deterministic and Stochastic [16].

Empirical:-

An empirical model is based on observation and measurements alone. These models are mainly used for predict the path loss. It can be further classified into two sub part namely non time dispersive and time dispersive. The Stanford University Interim model is one of the perfect examples of time dispersive models. The models like Hata model, COST-231 Hata model, ITU – R model are the best example of non-time dispersive models.

Deterministic:-

Deterministic models are deployed laws of governing electromagnetic wave propagation for determination of received signal power at a particular location. These kinds of models often require a complete 3D map of the propagation environment. Ray-tracing models are the best example of the deterministic model.

Stochastic:-

These models are used in terms of random variables. Stochastic models are the least accurate but this model requires the least information about the environment and use much less processing power to generate predications. These are mostly used for predication at above 1.8GHz.

3.2 Classification of Propagation Models

Many applications require RF or microwave propagation from point to point very near the earth's surface and in the presence of various impairments. Examples of such applications include cellular telephones, public service radio, pagers, broadcast television and radio stations, and differential GPS transmitters. Propagation loss over terrain, foliage, and or buildings may be attributed to various phenomena, including diffraction,

reflection, absorption, or scattering [17]. In this chapter, several different models are considered for determining the median path loss as a function of distance and conditions. As seen from the figure below propagation models classified into outdoor and indoor propagation models. Outdoor propagation models farther classified into city models, foliage models and terrain models.

The indoor environment is considerably different from the typical outdoor environment and in many ways is more hostile. Modeling indoor propagation is complicated by the large variability in building layout and construction materials. Therefore indoor propagation models calculates the path loss due to the large variability in building layout and construction materials. There are number of different indoor propagation models but it is not the concern of this paper. Details of outdoor propagation models is discussed below and selects one model for system dimensioning which is discussed in Section 2.3. Once the model for system dimensioning was selected, the radius of coverage could be determined by carrying out radio link budget calculation in Section 6.4.

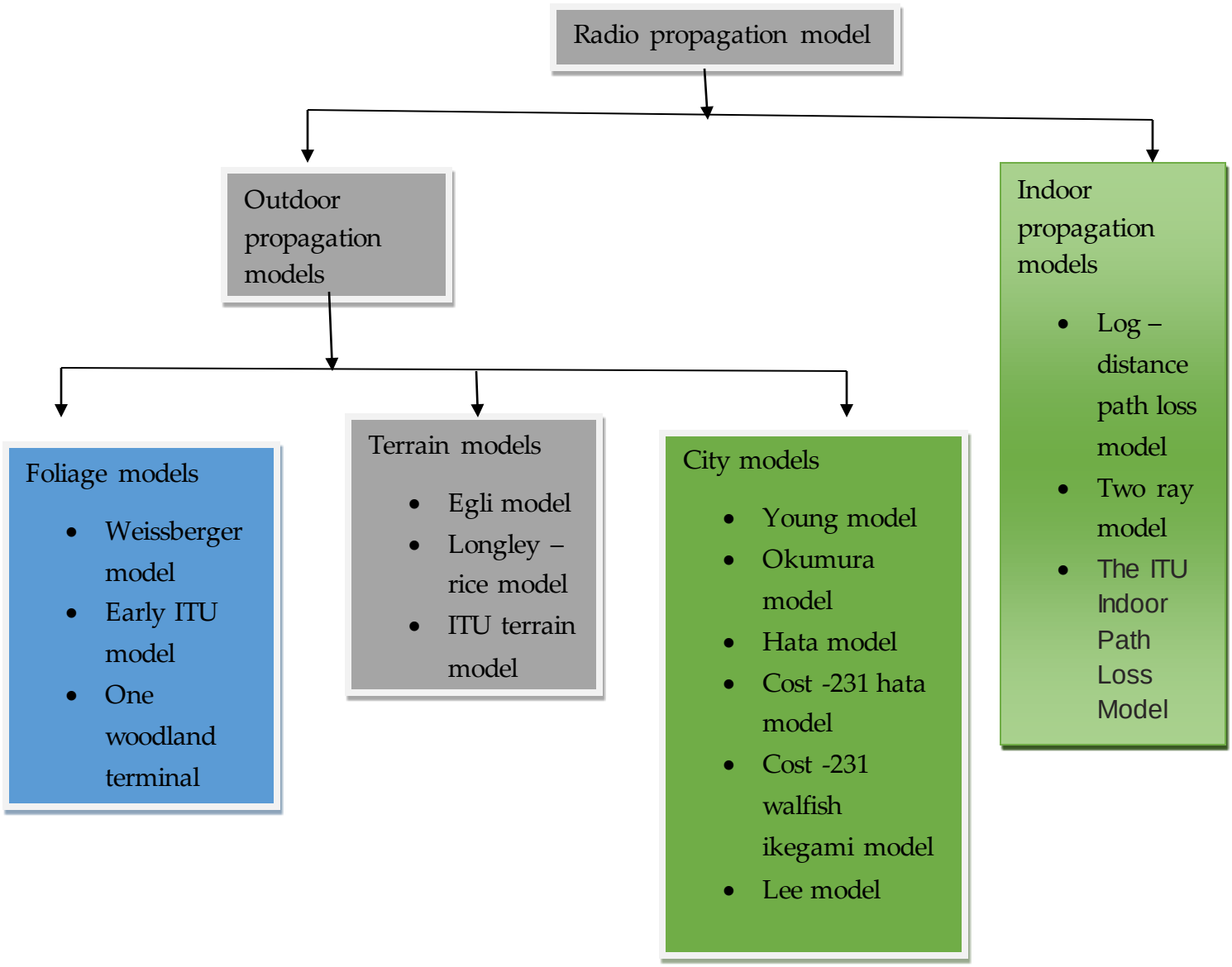


Figure 3.1: Block diagram of classification of propagation models.

3.2.1 Outdoor Propagation Models

Propagation models are used to estimate coverage distance of a specific transmitter by predicting the path loss between the transmitter and receiver. This process of estimating coverage area as a starting point for further detailed planning with a more complex propagation model is called system dimensioning. After reviewing the different types of outdoor propagation models, one model is selected to estimate the number of transmitters to cover Addis Ababa city.

3.2.1.1 Free Space Path Loss (FSPL) Model

The free space propagation model is used to predict received signal strength when the transmitter and receiver have a clear, unobstructed line-of-sight path between them. As with most large-scale radio wave propagation models, the free space model predicts that received power decays as a function of the Transmitter-Receiver separation distance raised to some power (i.e. a power law function). It is given by the equation:

$$\mathrm{PL} = 20\log\left(\frac{4\pi \mathrm{d}}{\lambda}\right) \tag{3.1}$$

$$= 32.45 + 20\log f + 20\log d\ dB \tag{3.1}$$

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.

3.2.1.2 City Models

3.2.1.2.1 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]. 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 [18]. The SUI model describes three types of terrain, they are terrain A, terrain B and terrain C.

Terrain A can be used for hilly areas with moderate or very dense vegetation. This terrain presents the highest path loss. Terrain A can be taken as a dense populated urban area. Terrain B is characterized for the hilly terrains with rare vegetation, or flat terrains with moderate or heavy tree densities. This is the intermediate path loss scheme. We consider

this model for suburban environment. Terrain C is suitable for flat terrains or rural with light vegetation, here path loss is minimum [19]

Table 3.1: Different Terrains and their Parameters **[4].**

Parameters	Terrain A	Terrain B		Terrain C	
A	4.6	4		3.6	
b(1/m)	0.0075	0.0065		0.005	
c(m)	12.6	17.1		20	

The basic path loss formula with correction factors is given as

$$PL = A + 10n\log\left(\frac{d}{d_0}\right) + X_f + X_h + s \qquad for\ d > d_0 \tag{3.3}$$

Where

PL: Path loss in dB

d: Distance between transmitter and received

d_0 : Is the reference distance (here its value is 100)

X_f: Correction for frequency above 2 GHz

X_h: Correction for receiving antenna height [m]

S: Correction for shadowing [dB]

n: Path loss exponent

A: Is the free space path loss given as:

$$\mathrm{A} = 20\log_{10}(4\pi d_0/\lambda) \tag{3.4}$$

λ Is the wavelength

Path loss exponent is given by:

$$\mathrm{n} = a - bh_t + \left(\frac{c}{h_t}\right) \tag{3.5}$$

Where the parameter $h_t$is the transmitter antenna height above ground in meters. This is between 10m and 80m.

The frequency correction factor X_f and the correction for receiver antenna height X_h for the models are expressed in:

$$X_f = 6.0log10\left(\frac{f}{2000}\right) \tag{3.6}$$

$$X_h = -10.8log10\left(\frac{hr}{2000}\right) \qquad for\ terrain\ type\ A\ and\ B \tag{3.7}$$

X_h=-20.0log10(hr/2000) $\qquad for\ terrain\ type\ c$ (3.8)

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

3.2.1.2.2 Okumura Model

Okumura model is an empirical model based on extensive measurements made in Japan at several frequencies in the range from 150–1920 MHz (it is also extrapolated up to 3000 MHz). Okumura's model is basically developed for macro cells with cell diameters from 1 to 100km. The heights of the BS antenna are between 30–1000m. The Okumura model takes into account some of the propagation parameters such as the type of environment and the terrain irregularity. The basic prediction formula is as follows:

$$L_{mean}(dB) = L_f + A_{m,\ u}(f,d) - G(h_{te}) - \mathrm{G}\ (h_{re}) - G_{AREA} \tag{3.9}$$

Where

- L_{mean}: Median path loss in [dB]
- L_f: Free space path loss in [dB]
- $A_{m,\ u}(f,d)$: Median attenuation relative to free space in [dB]
- $G(h_{te})$: Base station antenna height gain factor in [dB]

- G (h_{re}): Mobile station antenna height gain factor in [dB]
- G_{AREA}: Gain due to the type of environment in [dB]
- f: Frequency in [MHz]
- h_{te}: Transmitter antenna height in [m]
- h_{re}: Receiver antenna height in [m]
- d: Distance between transmitter and receiver antenna in [km]

Where $L_f = -20\log\left(\frac{\lambda}{4\pi d_0}\right)$, $G(h_{te})m = 20\log\left(h_{\frac{te}{200}}\right)$ *and*

$G(h_{re}) = 10\log\left(h_{\frac{re}{3}}\right)$

3.2.1.2.3 Okumura-Hata Model

The hata model is an empirical formulation of the graphical path loss data provided by okumura, and is valid from 150MHz to 1500MHz.Hata presented the urban area propagation loss as a standard formula and supplied correction equations for application to other situations. The standard formula for median path loss in urban areas is given by

$$L_{50}(urban)(dB) = 69.55 + 26.16logf_c - 13.82logh_{te} - a(h_{re}) + (44.9 - 6.55logh_{te})logd \quad (3.10)$$

Where,

$f_c -$ frequency (in MHz) from 150 to 1500MHz,

$h_{te} -$is the effective transmitter (base station) antenna height (in meters) ranging from 30m to 200m , $h_{re} -$ is the effective receiver (mobile) antenna height (in meters) ranging from 1m to 10m, d is the T-R separation distance (in km)

$a(h_{re})$is the correction factor for effective mobile antenna height which is a function of the size of the coverage area.

For a small to medium sized city, the mobile antenna correction factor is given by

$$a(h_{re}) = (1.1logf_c - 0.7)h_{re} - (1.56logf_c - 0.8)dB \quad (3.11)$$

And for large city, given by

$$a(h_{re}) = 8.29(log1.54h_{re})^2 - 1.1\ dB \qquad \text{for } f_c \leq 300 \text{ MHz}$$
$$a(h_{re}) = 3.2(log11.75h_{re})^2 - 4.97\ dB \qquad \text{for } f_c \geq 300 \text{ MHz} \tag{3.12}$$

To obtain the path loss in suburban area the standard Hata formula modified as

And for path loss in open rural areas the formula is modified as

$$L_{50}(dB) = L_{50}(urban) - 4.78(logf_c)^2 - 18.33logf_c - 40.98 \tag{3.13}$$

Although Hata's model does not have any of the path-specific corrections which are available in okumura's model. The predictions of the Hata model compare very closely with the original Okumura model,as long as d exceeds 1km. This model is well suited for large cell mobile systems, but not personal communications systems (PCS) which have cells on the order of 1km radius.

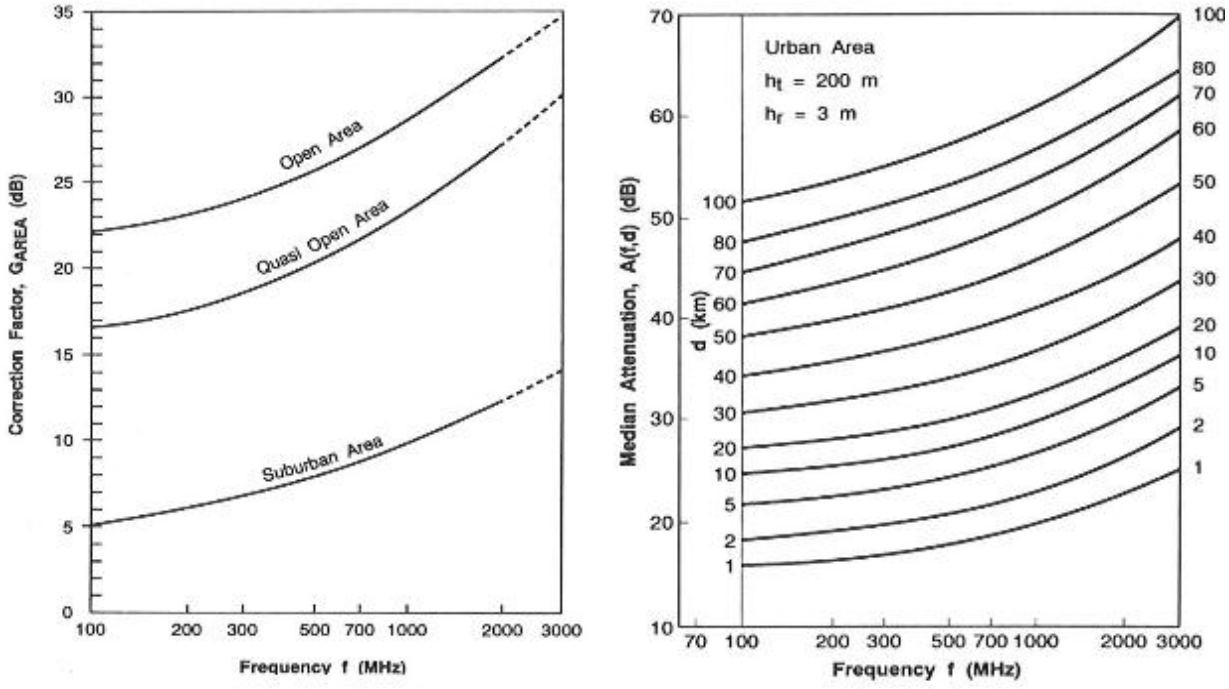


Figure 3.2: Correction Factor for Different Terrain and the Median Attenuation Relative to Free Space [19].

3.2.1.2.4 Cost -231 Hata Model

Hata model is used for the frequency range of 150 MHz to 2000 MHz to predict the median path loss. It also contains corrections for urban, suburban and rural (flat) environments. Although its frequency range is outside that of the measurements, its simplicity and the availability of correction factors has seen it widely used for path loss prediction at this frequency band [19]. With receiving antenna heights up to 10m and transmitting antenna heights of 30m-200m.

$$L_{50}(urban) = 46.3 + 33.9logf_c - 13.82logh_{te} - a(h_{re}) + (44.9 - 6.55logh_{te})logd + C_M \quad (3.14)$$

Where the parameters are, h_{te} is transmitter antenna height and h_{re} is receiver antenna height both in meters.

f_c= [MHz] Frequency

d = [Km] Distance between transmitter and receiver antenna

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 $a(h_{re})$ is defined in urban areas as:

$$a(h\_re\ ) = 3.2(\log 11.75h\_re\ )\text{^}2 - 4.97 \text{ dB} \quad \text{for } f\_c \geq 400 \text{ MHz} \quad (3.15)$$

The value of $a(h_{re})$ in suburban and rural (flat) areas is given by:

$$a(h_{re}) = (1.11\log(f) - 0.7)h_{re} - (1.5\log(f) - 0.8) \quad (3.16)$$

3.2.1.2.5. COST -231-Walfish-Ikegami Model

This model is a combination of J. Walfisch and F. Ikegami model. The COST 231 project further developed this model. Now it is known as COST 231 Walfisch-Ikegami model [19]. It distinguishes different terrain with different proposed parameters. This model

considers additional characteristics of the urban environment, namely, heights of buildings h_{roof}, width of roads w, building separation b, and road orientation with respect to the direct radio path ϕ, these parameters are shown in the figure below:

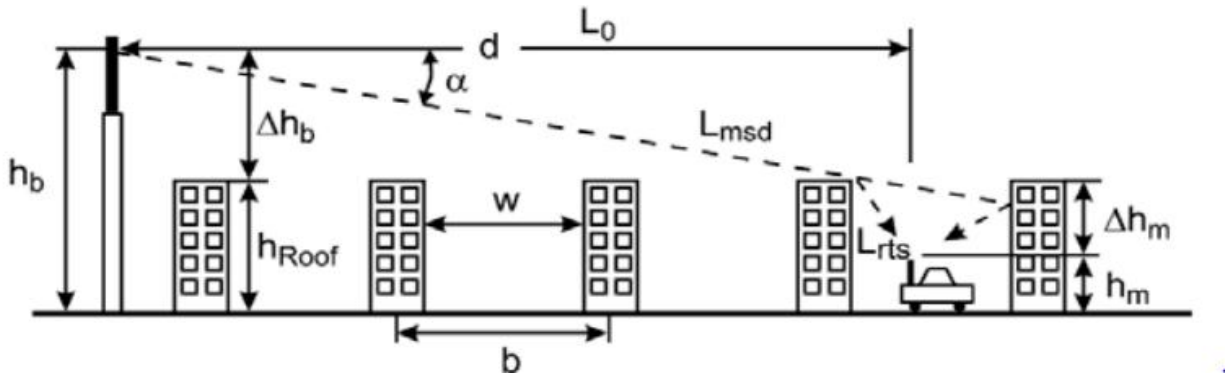


Figure 3.3: Parameters of the COST-231 Walfish-Ikegami Model **[19].**

NLOS case, path loss consists of three terms: the free space path loss Lo, the multi-screen loss L_{msd} along the propagation path, and attenuation from the roof edge to the receiver, L_{rts}(rooftop- to-street diffraction and scatter loss):

$$P_L dB = \begin{cases} P_{L0} + L_{rts} + L_{msd} \ \ for\ L_{rts} + L_{msd} > 0 \\ P_{L0}\ for\ \ L_{rts} + L_{msd} \ \leq 0 \end{cases} \tag{3.17}$$

The free space path loss is: $P_{L0}dB = 32.45 + 20logd + 20logf_c$

Ikegami derived the diffraction loss L_{rts} as:

$$L_{rts} = -16.9 - 10logw + 10logf_c + 20log\Delta h_r + L_{ori} \tag{3.18}$$

w – is the width of the street in meters, and

Δh_r is the difference between the building height hRoof and the height of the receiver h_r

$\Delta hr = h_{Roof} - h_r$

Orientation of the street is taken into account by an empirical correction factor L_{ori}:

$$L_{ori} = \begin{cases} 10 + 0.354\omega & \text{for } 0^0 \leq \omega \leq 35^0 \\ 2.5 + 0.075(\omega - 35) & \text{for } 35^0 \leq \omega \leq 55^0 \\ 4.0 - 0.114(\omega - 55) & \text{for } 55^0 \leq \omega \leq 90^0 \end{cases} \tag{3.19}$$

Here ϕ is the angle between the street orientation and the direction of incidence in degrees

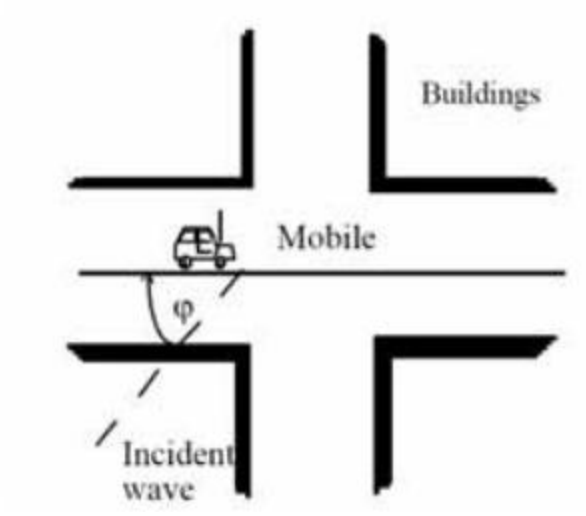


Figure 3.4: Street Orientation Angle [19].

Multi-screen loss L_{msd} is obtained by modeling building edges as screens. The multi-screen loss is

$$L_{msd} = L_{bsh} + K_a + K_b log d + K_f log f_c - 9 log b \tag{3.20}$$

Here b is the distance between two buildings (in meters) and:

$$L_{bsh} = \begin{cases} 18 \log(1 + \Delta h_t) & for\ h_b > h_{Roof} \\ 0 & for\ h_b < h_{Roof} \end{cases} \tag{3.21}$$

$$k_a = \begin{cases} 54 & for\ h_t > h_{Roof} \\ 54 - 0.8\Delta h_t & for\ d \geq 0.5Km\ and\ h_t \leq h_{Roof} \\ 54 - \dfrac{0.8\Delta h_t d}{0.5} & for\ d < 0.5km\ and\ h_t = h_{Roof} \end{cases} \tag{3.22}$$

$$\Delta h_t = h_t - h_{Roof} \tag{3.23}$$

And h_t is the height of the transmitter. The path loss depends on frequency and distance as given via the parameter k_a and k_f.

$$k_d = \begin{cases} 18 & for\ h_t > h_{Roof} \\ 18 - 15\Delta h_t / h_{Roof} & for\ h_t < h_{Roof} \end{cases}$$

$$k_f = \begin{cases} 0.7\left(\dfrac{f_c}{925} - 1\right) & \text{for medium – size cities suburban areas with average veg} \\ 18 - \dfrac{15\Delta h_t}{h_{Roof}} & \text{for metropolitan area} \end{cases} \tag{3.24}$$

3.2.1.2.5 Ericsson 9999 Model

This model also stands on the modified Hata-Okumura model to allow room for changing in parameters according to the propagation environments [19]. Hata model is used for frequencies up to 1900 MHz In this model, we can adjust the parameters according to the given scenario. The path loss as evaluated by this model is described as:

$$PL = a_0 + a_1 \log(d) + a_2 \log(h_b) + a_3 \log(h_b) \log(d) - 3.2(log(11.75hr)^2) + g(f) \quad (3.25)$$

$$\mathrm{g(f)} = -44.49 \log(f) - 4.78(\log(f))^2 \quad (3.26)$$

The values of a_0, a_1, a_2 and a_3 are constant but they can be changed according to the scenario (environment). The defaults values given by the Ericsson model for urban areas are a_0 = 36.2, a_1 = 30.2, a_2 = 12.0 and a_3= 0.1. The parameter f represents the frequency. The default values of these parameters (a_0, a_1, a_2 and a_3) for different terrains are given in Table 3.2 below.

Table 3.2: Values of Parameters for Ericsson Model **[19].**

Environment	a_0	a_1	a_2	a_3
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

3.2.1.2.6 ECC-33 Model

One of the most extensively used empirical propagation models is the Hata-Okumura model, which is based on the Okumura model. This model is a well-established model for the UHF band. Recently, through the ITU-R Recommendation P.529, ITU encouraged this model for further extension up to 3.5 GHz. The original Okumura model does not provide any data greater than 3 GHz. Based on prior knowledge of Okumura model, an extrapolated method is applied to predict the model for higher frequency greater than 3

GHz. The tentatively proposed propagation model of Hata-Okumura model with report is referred to as ECC-33 model. In this model path loss is given by:

$$PL = A_{fs} + A_{bm} - G_t - G_r \tag{3.27}$$

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,

$$\begin{aligned} A_{fs} &= 92.4 + 20\ \log(d) + 20\ \log(f) \\ A_{bm} &= 20.41 + 9.83\log(f) + 7.894\log(f) + 9.56(\log(f))^2 \\ &= 20.41 + 9.83\log(f) + 7.894\log(f) + 9.56(\log(f))^2 \\ G_t &= \log\left(\frac{h_t}{200}\right)[13.98 + 5.8(\log(d))^2] \end{aligned} \tag{3.28}$$

For medium city environments

$$G_r = [42.57 + 13.7\ \log(f)][\log(h_r) - 0.585] \tag{3.29}$$

Where d is the distance between transmitter and receiver in kilometers, f is frequency in GHz, h_t 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 [18].

3.2.1.3 Terrain Models

For ground-based communications, the local terrain features significantly affect the propagation of electromagnetic waves. Terrain is defined as the natural geographic features of the land over which the propagation is taking place. It does not include vegetation or man-made features [17]. Terrain models include, Egli model, Longley-rice model, ITU terrain model.

3.2.1.3.1 Egli Model

This model, was derived from real-world data on UHF and VHF television transmissions in several large cities. It predicts the total path loss for a point-to-point link. Typically used for outdoor line-of-sight transmission, this model provides the path loss as a single quantity. The Egli model for median path loss over irregular terrain is:

$$P_{R50} = G_B G_M \left[\frac{h_B h_M}{\mathrm{d}^2}\right]^2 \left[\frac{40}{\mathrm{f}}\right]^2 \quad (3.30)$$

Where,

P_{R50}= 50th percentile receive power [W]

G_B= Absolute gain of the base station antenna.

G_M= Absolute gain of the mobile station antenna.

h_B= Height of the base station antenna. [m]

h_M= Height of the mobile station antenna. [m]

d = Distance from base station antenna. [m]

f = Frequency of transmission. [MHz]

3.2.1.3.2 Longley-Rice Model

The Longley–Rice model is a very detailed model that was developed in the 1960s and has been refined over the years. The model is based on data collected between 40MHz and 100GHz, at ranges from 1 to 2000km, at antenna heights between 0.5 and 3000m, and for both vertical and horizontal polarization. It has two modes, point-to-point and area. The point-to-point mode makes use of detailed terrain data or characteristics to predict the path loss, whereas the area mode uses general information about the terrain characteristics to predict the path loss.

3.2.1.3.3 ITU Terrain Model

The ITU terrain loss model is a radio propagation model that provides a method to predict the median path loss for a telecommunication link. Developed on the basis of diffraction theory, this model predicts the path loss as a function of the height of path blockage and the First Fresnel zone for the transmission link.

$$A = 10 - 20c_N \tag{3.31}$$

$$c_N = \frac{\mathrm{h}}{F_1} \tag{3.31a}$$

$$h = h_L - h_o \tag{3.31b}$$

$$F_1 = 17.3\sqrt{\frac{d_1 d_2}{fd}} \tag{3.31c}$$

Where,

A = Additional loss (in excess of free-space loss) due to diffraction (dB)

C_N= Normalized terrain clearance

h =The height difference (negative in the case that the LOS path is completely obscured) (m)

h_L= Height of the line-of-sight link (m)

h_O= Height of the obstruction (m)

F_1= Radius of the first Fresnel zone (m)

d_1= Distance of obstruction from one terminal (km)

d_2= Distance of obstruction from the other terminal (km)

= Frequency of transmission (GHz)

d= Distance from transmitter to receiver (km)

3.2.1.4 Foliage Models

Most terrestrial communications systems require signals to pass over or through foliage at some point. This section presents a few of the better-known foliage models. These

models provide an estimate of the additional attenuation due to foliage that is within the line-of-sight (LOS) path. There are different types of foliage models. These are:

3.2.1.4.1 Weissberger's Model

Weissberger's modified exponential decay model applies when the propagation path is blocked by dense, dry, leafed trees. It is important that the foliage depth be expressed in meters and that the frequency is in GHz. Weissberger's modified exponential decay model is given by:

$$L = \begin{cases} 1.33\mathrm{f}^{0.284}\mathrm{d}^{0.588}, & if\ 14 < d \leq 400 \\ 0.45\mathrm{f}^{0.284}d\ , & if\ 0 < d \leq 14 \end{cases} \quad (3.32)$$

Where L The path loss. Unit: decibel (dB) f is the frequency of transmission. Unit: megahertz (MHz) and d the depth of foliage along the link: Unit: meter (m).

This model covers the frequency range from 230MHz to 95GHz.

3.2.1.4.2 Early ITU Vegetation Model

The early ITU foliage model was adopted by the CCIR (the ITU's predecessor) in 1986. While the model has been superseded by a more recent ITU recommendation, it is an easily applied model that provides results that are fairly consistent with the Weissberger model [17]. The model is given by:

$$L = 0.2\mathrm{f}^{0.3}\mathrm{d}^{0.6} \quad (3.33)$$

Typical application of this model is to predict the path loss for microwave links.

3.2.1.4.3 Updated ITU Vegetation Model

One of the key elements of the updated model, which should also be considered in applying other models is that there is a limit to the magnitude of the attenuation due to foliage, since there will always be a diffraction path over and/or around the vegetation [5]. There are two types of updated ITU vegetation models

a. Terrestrial Path with One Terminal in Woodland

This model is for the excess attenuation due to vegetation is in one terminal. The path loss is given by:

$$A_v = \mathrm{A}\left[1 - e^{-dy/A}\right] \tag{3.34}$$

A_v = Attenuation due to vegetation. Unit: decibel (dB)

A = Maximum attenuation for one terminal caused by a certain foliage. Unit: decibel (dB)

d= Depth of Foliage along the path. Unit: Meter (m)

y= Specific attenuation for short vegetations. Unit: decibel/meter (dB/m)

It is applicable for frequency below 5 GHz.

b. Single Vegetative Obstruction

If neither end of the link is within woodland, but there is vegetation within the path, the attenuation can be modeled using the specific attenuation of the vegetation. For this model to apply, the vegetation must be of a single type, such as a tree canopy, as opposed to a variety of vegetation. When the frequency is at or below 3GHz, the vegetation loss model is:

$$A = \begin{cases} d^{\gamma}, frequency < 3GHz \\ R_f d + k\left[1 - e^{\frac{(R_f - R_i)d}{k}}\right], \quad frequency > 5GHz \end{cases} \tag{3.35}$$

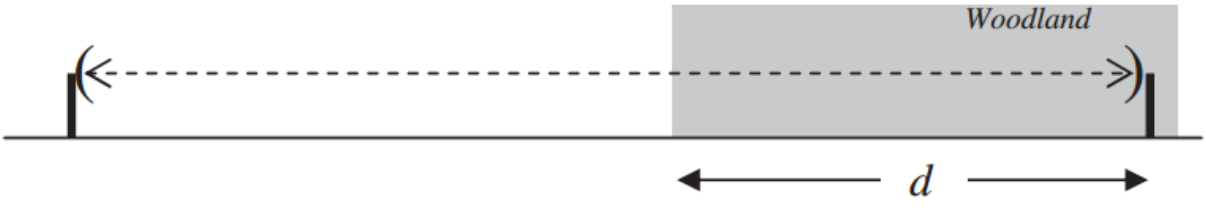


Figure 3.5: Propagation Path with One Terminal in Woodland for ITU Model **[17]**.

Where,

A = The Attenuation due to vegetation. Unit: decibel (dB).

d = Depth of foliage. Unit: Meter (m).

γ= Specific attenuation for short vegetative paths. Unit: decibel per meter (dB/m).

R_i= The initial slope of the attenuation curve.

R_f= The final slope of the attenuation curve.

f =The frequency of operations. Unit: gigahertz (GHz).

k= Empirical constant.

$$R_i = af \tag{3.35a}$$

$$R_f = af^c \tag{3.35b}$$

Where, a, b and c are empirical constants

$$k = k_0 - 10\log\left[A_0\left(1 - e^{-\frac{A_i}{A_0}}\right)\left(1 - e^{R_f f}\right)\right] \tag{3.35c}$$

Where,

k_0= Empirical constant (given in the table below).

R_f= Empirical constant for frequency dependent attenuation.

A_0= Empirical attenuation constant (given in the table below).

A_i = Illumination area.

$$A_i = \min(w_T, w_R, w)\, x \min\left(h_T, h_R, h\right)$$

$$= \min\left(2d_T\ tan\ a_{T/2}, 2d_R\ tan\ a_{R/2}, w\right) x \min\left(2d_T\ tan\ e_{\frac{T}{2}}, 2d_R\ tan\ e_{\frac{R}{2}}, h\right) \tag{3.35d}$$

Where,

w_T= Width of illuminated area as seen from the transmitter. Unit: meter (m)

w_R = Width of illuminated area as seen from the receiver. Unit: meter (m)

w = Width of the vegetation. Unit: meter (m)

h_T=Height of illuminated area as seen from the transmitter. Unit: meter (m)

h_R= Height of illuminated area as seen from the receiver. Unit: meter (m)

h = Height of the vegetation. Unit: meter (m)

a_T = Azimuth beamwidth of the transmitter. Unit: degree or radian

a_R= Azimuth beamwidth of the receiver. Unit: degree or radian

e_T= Elevation beam width of the transmitter. Unit: degree or radian

e_R = Elevation beam width of the receiver. Unit: degree or radian

d_T = Distance of the vegetation from transmitter. Unit: meter (m)

d_R = Distance of the vegetation from receiver. Unit: meter (m)

This model is applicable to scenarios where no end of the link is completely inside foliage, but a single plant or tree stands in the middle of the link.

In conclusion, from the above discussions of different categories of propagation models, one model is selected from the city models for system dimensioning. This model takes the total path loss calculated using link budget analysis for the computation of coverage radius. After all computation and radius is computed the number of transmitters are estimated using area of Addis Ababa city. Detailed planning is done using the ITU [6]recommended models for terrestrials broadcasting planning i.e. rec. ITU- 1546-5 model. The details about this model is given in the chapter four below.

Chapter Four

Propagation Model for Detailed Coverage Planning

4.1 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.

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. 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.

4.2 ITU-R P.1546-5 Model

This Recommendation describes a method for point-to-area radio propagation predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz. It is intended for use on tropospheric radio circuits over land paths, sea paths and/or mixed land-sea paths up to 1 000 km length for effective transmitting antenna heights less than 3 000 m.

The method is based on interpolation/extrapolation from empirically derived 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. This model gives guidance to engineers in the planning of terrestrial radio communication services in the VHF and UHF bands.

The next condensed description of the model is extracted from the document prepared by Radio communication Sector of the International Telecommunication Union[r-1546]

Table 4.1: 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 4.2.7.	1–50%
h1	M	Transmitting antenna height as referenced in curves. Defined in Section 4.2.3, Equations (4.3) up to (4.4).	No lower limit, upper limit of 3000 m
h_a	M	Transmitter antenna height above ground. Defined in Section 4.2.3. Limits are defined in the same place.	Greater than 1m
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
h2	M	Receiving antenna height above ground.	Not less than 1 m, and less than 3 000 m
R1	M	Representative clutter height (around transmitter)	None

R2	M	Representative clutter height (around receiver)	None
Θtca	Degrees	Terrain clearance angle	0.55% to 40%
θ_{eff} θ_{eff1} θ_{eff2}	Degrees	Transmitter effective terrain clearance angles. Discussed in Section 4.2.9.	Must be positive

4.2.1 Maximum Field-Strength Values

A field strength must not exceed a maximum value E_{max} given by:

$$E_{max} = E_{fs} \qquad \text{dB}(\mu\text{V/m}) \qquad \text{for land paths} \tag{4.1}$$

$$E_{max} = E_{fs} + E_{se} \qquad \text{dB}\left(\mu\frac{\text{V}}{\text{m}}\right) \qquad \text{for sea paths} \tag{4.2}$$

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

$$E_{fs} = 106.9 - 20\log(\text{d}) \qquad dB\left(\mu\frac{\text{V}}{\text{m}}\right) \tag{4.2a}$$

and E_{se} is an enhancement for sea curves given by:

$$E_{se} = 2.38\left\{1 - \exp\left(-\frac{d}{8.94}\right)\right\}\log\left(\frac{50}{\text{t}}\right) \qquad \text{dB} \tag{4.2b}$$

Where:

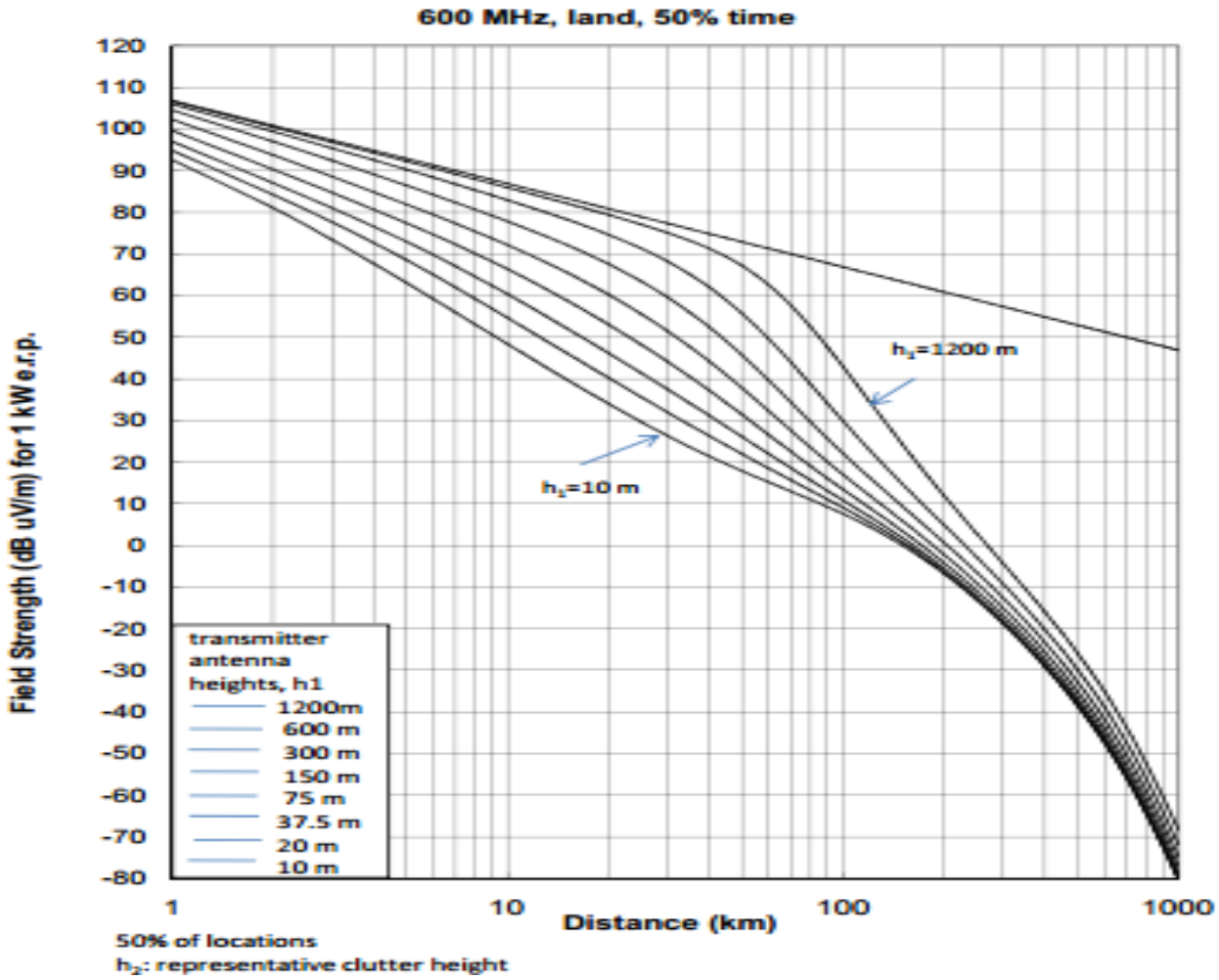
d: distance (km)

t: percentage time.

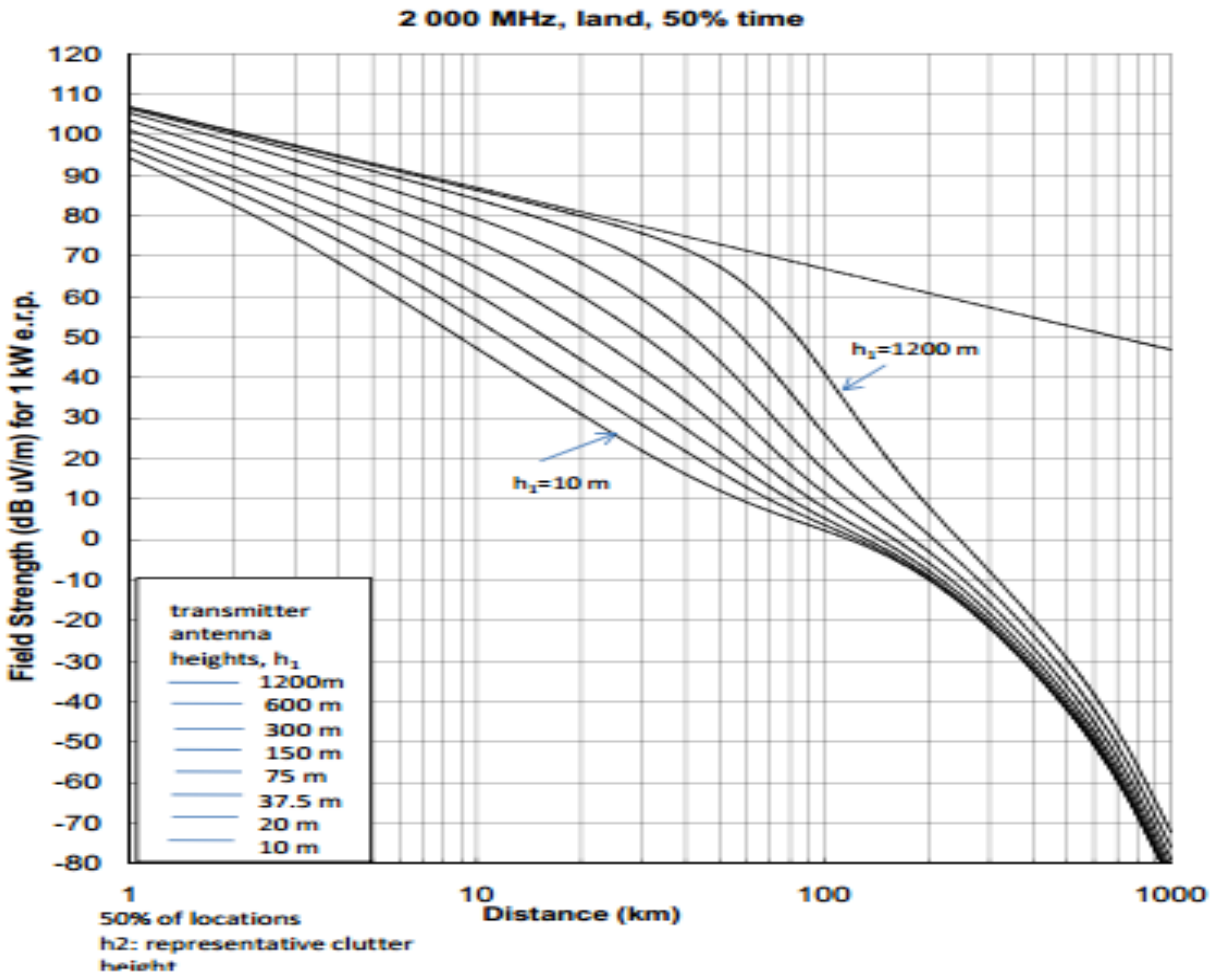
In principle any correction which increases a field strength must not be allowed to produce values greater than these limits for the family of curves and distance concerned. The curves in Figs 1 to 3 represent field-strength values exceeded at 50% of the locations within any area of approximately 500 m by 500 m and for 50% of the time for a frequency range of 300 MHz to 1000MHz, for land paths.

4.2.2 The Propagation Curves

The propagation curves such as Figure 2 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 4.2.6 below. Since we are predicting path loss for land path at DTB frequency range (470-864 MHz), we will use only the 600 and 2000 MHz land path propagation curves (as interpolation for the specific frequency 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.


600 MHz, land, 50% time
Field Strength (dB uV/m) for 1 kW e.r.p.
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
1
10
100
1000
Distance (km)
h2=1200 m
h2=10 m
transmitter antenna heights, h1
1200m
600 m
300 m
150 m
75 m
37.5 m
20 m
10 m
50% of locations
h2: representative clutter height

(a)



(b)

Figure 4.1: 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 **[20].**

4.2.3 Determination of Transmitting Antenna Height, h1

It depends on the type and length of the path and on various items of height information, which may not all be available. For sea paths is the h1 height of the antenna above sea level. For land paths, the effective height of the transmitting antenna, h1, is defined as its 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. Where the value of effective transmitting antenna height h1, is not known it should be estimated from

general geographic information. This Recommendation is not valid when the transmitting antenna is below the height of surrounding clutter.

4.2.3.1. Land Paths Shorter than 15 km

Where no terrain information is available when propagation predictions are being made, the value of h1 is calculated according to path length d as follows:

$$h_1 = \begin{cases} h_a \ m, & for \quad d < 3 \ km \\ h_a + \dfrac{(h_{eff} - h_a)(d-3)}{12} \ m & for \ 3 \ km < d < 15 \ km \end{cases} \tag{4.3}$$

Where h_a is the antenna height above the ground.

Where terrain information is available when propagation predictions are being made transmitter height becomes

$$h_1 = h_b \quad m \tag{4.4}$$

Where h_b is the height of the antenna above terrain height averaged between 0.2 d and d km.

4.2.3.1 Land Paths of 15 km or Longer

For these paths:

$$h_1 = h_{eff} \qquad m \tag{4.5}$$

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.

4.2.4 Application of Transmitting Antenna Height, $\boldsymbol{h_1}$

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.

4.2.4.1 Transmitting Antenna Height, $\boldsymbol{h_1}$, 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:

$$\mathrm{E} = E_{inf} + \left(E_{sup} - E_{inf}\right)\log\left(\frac{h_1}{h_{inf}}\right) \qquad dB\left(\mu\frac{\mathrm{V}}{\mathrm{m}}\right) \tag{4.6}$$

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

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 value defined in section 4.2.1.

This Recommendation is not valid for h_1> 3 000 m.

4.2.4.2 Transmitting Antenna Height, h_1, in the Range 0 m to 10 m

The method when $h1$ is less than 10 m depends on whether the path is over land or sea. For this thesis work considers only over land. The field strength at the required distance d km for 0≤ $h1$ < 10 m is calculated using:

$$\mathrm{E} = E_{Zero} + 0.1h_1\left(E_{h1neg10} - E_{zero}\right) \qquad dB\left(\mu\frac{\mathrm{V}}{\mathrm{m}}\right) \tag{4.7}$$

Where

$$E_{Zero} = E_{10} + 0.5\left(C_{1020} + C_{h1neg10}\right) \qquad dB\left(\mu\frac{\mathrm{V}}{\mathrm{m}}\right) \tag{4.7a}$$

$$C_{1020} = E_{10} - E_{20} \qquad dB \tag{4.7b}$$

$C_{h1neg10}$: The correction $Ch1$ in dB calculated using equation (4.8) below at the required distance for $h1 = -10$ m.

E_{10} & E_{20}: The field strengths in dB (μV/m) calculated according to § 4.1 above at the required distance for $h1 = 10$ m and $h1 = 20$ m respectively.

Note that the corrections C_{1020} and $C_{h1neg10}$ should both evaluate to negative quantities.

4.2.4.3 Negative Values of Transmitting Antenna Height, h1.

For land paths it is possible for the effective transmitting/base antenna height heff to have a negative value, since it is based on the average terrain height at distances from 3 km to 15 km. Thus h1 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 h1 is to obtain the field strength for h1 = 0 as described in Section 2.2, and to add a correction C_{h1} calculated as follows.

1) In the case that a terrain database is available and the potential for discontinuities at the transition around h1 = 0 is of no concern in the application of this Recommendation, the terrain clearance angle, θeff1, from the transmitting/base antenna should be calculated as the elevation angle of a line which just clears all terrain obstructions up to 15 km from the transmitting antenna in the direction of (but not going beyond) the receiving antenna.

$$C_{h1} = J(v') - J(v) \quad dB \quad (4.8)$$

$$\mathrm{J}(v) = \left[6.9 + 20\log\left(\sqrt{((v-0.1)^2+1)} + v - 0.1\right)\right] \quad for\ > -0.7806 \quad (4.9)$$

$$\mathrm{J}(v) = 0 \quad otherwise$$

$$v' = 0.036\sqrt{f} \quad 4.9a)$$

$$v = 0.065\theta_{eff1}\sqrt{f} \quad (4.9b)$$

$$\theta_{eff1} = \tan^{-1}(h1/(d \times 1000))\ if\ d < 15{,}000m \quad (4.9c)$$

$$\theta_{eff1} = \tan^{-1}(-h1/(15000))\ \ otherwise \quad ZXD\ (4.9d)$$

2) 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 h1 = 0, the (positive) effective terrain clearance angle, θeff2, may be estimated assuming an obstruction of height h1 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 antenna, with its mean value occurring at 9 km, as indicated in Figure 4.2. 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 h1 = 0. The correction to be added to the field strength in this case is calculated using:

$$C_{h1} = 6.03 - J(v) \tag{4.10}$$

here: $J(v)$ is given by equation (4.8)

$$v = K_v \theta_{eff2} \tag{4.11}$$

And

$$\theta_{eff2} = \arctan\left(-\frac{h1}{9000}\right) \quad degrees \tag{4.12}$$

$K_v = 1.35$ for 100MHz

$K_v = 3.31$ for 600 MHz

$K_v = 6.00$ for 2000 MHz

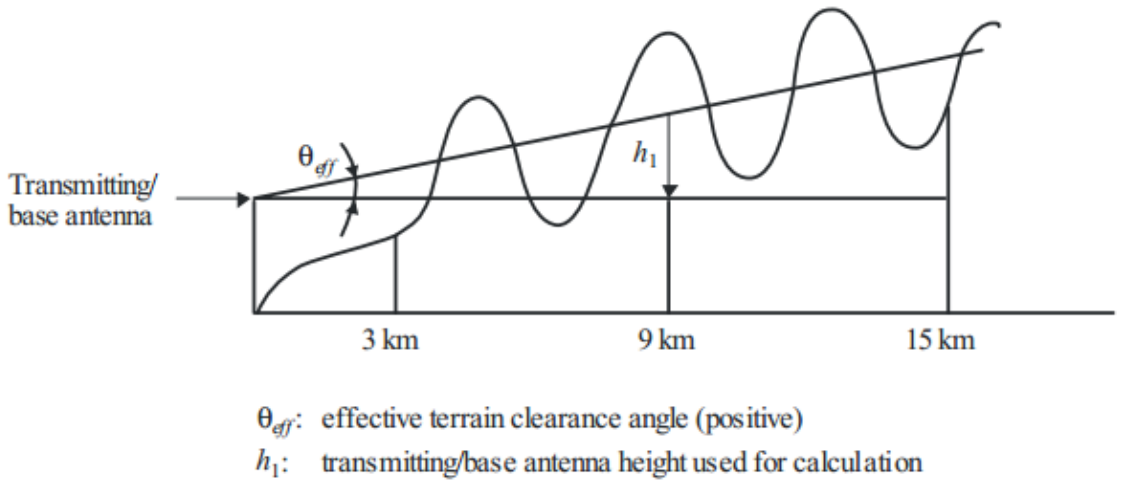


Figure 4.2: Effective clearance angle for h1 **< 0**

The above correction, which is always less than zero, is added to the field strength obtained for ***h*1**= 0.

4.2.5 Interpolation of Field Strength as a Function of Distance

Figure 4.1 in section one 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. For greater precision, and for computer implementation, field strengths should be obtained from the associated tabulations. In this case, d doesn't coincides with one of the tabulation distances given in Table 1, the field strength, E (dB (μV/m)), should be linearly interpolated for the logarithm of the distance using:

$$\mathrm{E} = E_{inf} + \left(E_{sup} - E_{inf}\right)\log\left(d/d_{inf}\right)/\log(d_{sup}/d_{inf}) \qquad dB\left(\mu\frac{\mathrm{V}}{\mathrm{m}}\right) \tag{4.13}$$

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.

Table 4.2 Values of distances used in the table of field strengths (km**) [20]**

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

4.2.6 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. In this thesis work filed strength is calculated by interpolating the filed strength between 600 MHz and 2000 MHz frequencies. The required field strength, E, should be calculated using:

$$\mathrm{E} = E_{inf} + \left(E_{sup} - E_{inf}\right)\log\left(f/f_{inf}\right)/\log(f_{sup}/f_{inf}) \qquad dB\left(\mu\frac{\mathrm{V}}{\mathrm{m}}\right) \qquad (4.14)$$

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 forf_{sup}.

The field strength resulting from extrapolation for frequency above 2 000 MHz should be limited if necessary such that it does not exceed the maximum value given in Equation 4.1

4.2.7 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:

$$\mathrm{E} = E_{sup}(Q_{inf} - Q_t)/(Q_{inf} - Q_{sup}) + E_{inf}\left(Q_t - Q_{sup}\right)/(Q_{inf} - Q_{sup}) \qquad dB\left(\mu\frac{\mathrm{V}}{\mathrm{m}}\right) \quad (4.15)$$

Where:

t: Percentage time for which the prediction is required

t_{inf}: Lower nominal percentage time

t_{sup} : Upper nominal percentage time

$$Q_t = Q_i\left(\frac{\mathrm{t}}{100}\right) \qquad (4.15a)$$

$$E_{inf} = Q_i\left(\frac{t_{inf}}{100}\right) \qquad (4.15a)$$

$$Q_{sup} = Q_i\left(\frac{t_{sup}}{100}\right) \quad (4.15a)$$

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 Recommendation 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 4.3: Approximate inverse complementary cumulative normal distribution values[20]

q%	$\boldsymbol{Q_i(q/100)}$	**q%**	$\boldsymbol{Q_i(q/100)}$	**q%**	$\boldsymbol{Q_i(q/100)}$	**q%**	$\boldsymbol{Q_i(q/100)}$
1	2.327	26	0.643	51	–0.025	76	–0.706
2	2.054	27	0.61 2	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	–0.1 00	79	–0.806
5	1 .645	30	0.524	55	–0.1 25	80	–0.841
6	1 .555	31	0.495	56	–0.1 51	81	–0.878
7	1 .476	32	0.467	57	–0.1 76	82	–0.915
8	1 .405	33	0.439	58	–0.202	83	–0.954
9	1 .341	34	0.41 2	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 .1 75	37	0.331	62	–0.305	87	–1 .1 26
13	1 .1 26	38	0.305	63	–0.331	88	–1 .1 75
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	0.91 5	43	0.1 76	68	–0.467	93	–1 .476
19	0.878	44	0.1 51	69	–0.495	94	–1 .555
20	0.841	45	0.1 25	70	-0.524	95	–1 .645
21	0.806	46	0.1 00	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		

4.2.8 Correction for Receiving Antenna Height

The field-strength values given by the land curves and associated tabulations in this Recommendation 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 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:

$$R_2 = \frac{1000dR_2 - 15h_1}{1000\mathrm{d} - 15} \tag{4.16}$$

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 gracing incident ($\nu = 0$).

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

The value of R2′ 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:

$$\text{correction} = 6.03 - J(v) \qquad dB \qquad for\ h_2 < R_2' \qquad (4.16a)$$

$$= K_{h_2} \log\left(\frac{h_2}{R_2'}\right) \qquad dB \qquad for\ h_2 \geq R_2' \qquad (4.16b)$$

Where $J(v)$ is given in equation (4.9)

And

$$v = K_{nu}\sqrt{h_{dif\ 2}\,\theta_{\text{clut 2}}} \qquad (4.17)$$

$$h_{dif\ 2} = R_2' - h_2 \qquad m \qquad (4.17a)$$

$$\theta_{clut\ 2} = \arctan\left(\frac{h_{dif\ 2}}{27}\right) \qquad degrees \qquad (4.17b)$$

$$K_{h\ 2} = 3.2 + 6.2\log(f) \qquad (4.17c)$$

$$K_{nu} = 0.0108\sqrt{f} \qquad (4.17d)$$

*f: frequency (*MHz*).*

In cases in an urban environment where $R2'$ is less than 10 m, the correction given by equation (4.16a) or (4.16b) should be reduced by $K_{h\,2}\log(10/R_2')$ .Where the receiving antenna is on land in a rural or open environment the correction is given by Equation 4.16b for all values of $h2$ with $R2'$ set to 10 m.

4.2.9 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.

$$\text{correction} = -J(v) \qquad dB \tag{4.18}$$

Where $J(v)$ is given by equation (4.8)

$$v = \begin{cases} K_{nu}\sqrt{h_{dif\ 1}\theta_{\text{clut 1}}} & for \quad R_1 \geq h_a \\ -K_{nu}\sqrt{h_{dif\ 1}\theta_{\text{clut 1}}} & otherwise \end{cases} \tag{4.19}$$

$$h_{dif\ 1} = h_a - R_1 \qquad m \tag{4.19a}$$

$$\theta_{clut\ 1} = \arctan\left(\frac{h_{dif\ 1}}{27}\right) \qquad degrees \tag{4.19b}$$

$$K_{nu} = 0.0108\sqrt{f}, f\text{: frequency (MHz).} \tag{4.19c}$$

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

4.2.10 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:

$$\theta_{tca} = \theta \qquad \text{degrees} \tag{4.20}$$

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 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° or more than +40.0°.

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

$$\text{Correction} = J(v') - J(v) \qquad dB \tag{4.21}$$

Where $J(v)$ is given by equation (4.9)

$$v' = 0.036\sqrt{f} \tag{4.21a}$$

$$v = 0.065\theta_{tca}\sqrt{f} \tag{4.21b}$$

where θ_{tca}: Terrain clearance angle (degrees)

f: Required frequency (MHz).

It should be noted that the land field-strength curves (Figure 4.1) 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.

4.2.11 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:

$$\text{E(q)} = E(median) + \text{Q}_i\left(\frac{q}{100}\right)\sigma_L(f) \qquad dB(\mu\text{V/m}) \tag{4.22}$$

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 digital broadcasting is 5.5 dB as shown in Table below

Table 4.4: Values of Variability Used in certain Planning Situations **[20]**

	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 Qi (x) is given in Table 4.3 above.

4.2.12 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, θs, using:

$$\theta_s = \frac{180d}{\pi ka} + \theta_{eff} + \theta \quad \text{degrees} \tag{4.23}$$

Where,

θ_{eff}: The h1 terminal's terrain clearance angle in degrees calculated using the method in Section 4.2.4.(c) case 1), whether or not h1 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: 6370 km, radius of the Earth

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

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

Calculate the field strength predicted for tropospheric scattering, Ets, using:

$$E_{ts} = 24.4 - 20\log(d) - 10\theta s - L_f + 0.15N_0 + G_t \qquad dB(\mu\frac{V}{m}) \qquad (4.24)$$

Where: L_f: $frequency - dependent\ loss$

$$L_f = 5\log(f) - 2.5(\log(f) - 3.3)^2 \qquad (4.24a)$$

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

G_t: Time dependent enhancement.

$$G_t = 10.1(-\log(0.02t))^{0.7} \qquad (4.24b)$$

d: Path length or required distance(km)

f: Required frequency (MHz).

t: Required percentage of time.

4.2.13 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.

$$\text{correction} = 20\log\left(\frac{d}{d_{slope}}\right) \qquad dB \qquad (4.25)$$

Where d is the horizontal distance and the slope distance, d_{slope}, is given as follows. Where terrain information is available, use:

$$d_{slope} = \sqrt{d^2 + 10^{-6}[(h_a + h_{tter}) - (h_2 + h_{rter})]^2} \qquad km \qquad (4.25a)$$

Where terrain information is not available, use:

$$d_{slope} = \sqrt{d^2 + 10^{-6}[h_a - h_2]^2} \qquad km \qquad (4.25b)$$

And h_{tter} and h_{rter} are the terrain heights in meters above sea level at the transmitter and receiving terminals respectively. Although the correction given by Equation 4.25 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.

4.2.14 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:

$$\mathrm{E} = 106.9 - 20\log(d_{slope}) \qquad dB\left(\mu\frac{V}{m}\right) \qquad (4.26)$$

$$\mathrm{E} = E_{inf} + \left(E_{sup} - E_{inf}\right)\log(d_{slope}/d_{inf})\log(d_{sup}/d_{inf}) \qquad dB\left(\mu\frac{\mathrm{V}}{\mathrm{m}}\right) \qquad (4.27)$$

Where:

d_{slope}: Slope distance given by Equation (4.25a) or (4.25b) for the required horizontal distance d

d_{inf}: Slope distance given by Equation (4.25a) or (4.25b) for d = 0.04 km

d_{sup} : Slope distance given by Equation (4.25a) or (4.24b) for d = 1 km

E_{inf} : 106.9 – 20 log (d_{inf})

E_{sup} : Field strength given by steps1 to 13 for d = 1 km.

4.2.15 Equivalent Basic Transmission Loss

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

$$L_b = 139.3 - E + 20\log(f) \qquad dB \tag{4.28}$$

Where,

L_b: basic transmission loss (dB)

E : field strength (dB(μV/m)) for 1 kW e.r.p.

f: frequency (MHz).

4.2.16 Adjustment for Different Climate Conditions

The curves given in Figure 4.1 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 Five
Frequency Planning in Digital Terrestrial Television Broadcasting

5.1 Introduction

The increasing popularity of, and demand for wireless communications is placing greater pressure on the radio frequency spectrum. In light of these circumstances, broadcasters, along with other stakeholders, may need to review how they currently make use of the frequency bands they have been allocated and whether or not they may be able to do so more effectively.

DTV is the world's most advanced digital terrestrial transmission system offering highest efficiency, robustness and flexibility. It introduces the latest modulation and coding techniques to enable highly efficient use of valuable terrestrial spectrum for the delivery of audio, video and data services to fixed, portable and mobile devices [10].

Over-the-air television channels are divided into two bands: the VHF band which comprises channels 2 through 13 and occupies frequencies between 54 and 216 MHz, and the UHF band, which comprises channels 14 through 83 and occupies frequencies between 470 and 890 MHz. These bands are different enough in frequency that they often require separate antennas to receive (although many antennas cover both VHF and UHF), and separate tuning controls on the television set. The VHF band is further divided into two frequency ranges: VHF low band (Band I) between 54 and 88 MHz, containing channels 2 through 6, and VHF high band (Band III) between 174 and 216 MHz, containing channels 7 through 13. The wide spacing between these frequency bands is

responsible for the complicated design of rooftop TV antennas. The UHF band has higher noise and greater attenuation, so higher gain antennas are often required for UHF.

There is no real physical boundary between Bands IV and V and it is thus not necessary to quote any internal boundary frequency here. In the UHF bands, it was decided at the Stockholm Conference to have a uniform channel width and spacing of 8 MHz, the channels not being completely filled in the case of systems using 7 MHz bandwidth.

The CEPT decided that digital television should take place in Band III and IV/V only. This means that television in Band I will cease to exist in future. Most countries use Band IV/V for the implementation of digital television [21]. Because UHF is better to plan outdoors but around buildings, as it do a better job penetrating wood, steel, and concrete, giving you better range and performance in urban environments and around buildings. Most country use Band III for T-DAB as these frequencies have traditionally been reserved exclusively for broadcasters. However, the demand for access to these frequency bands has been strong from other service providers including telecom operators and technology firms [22].

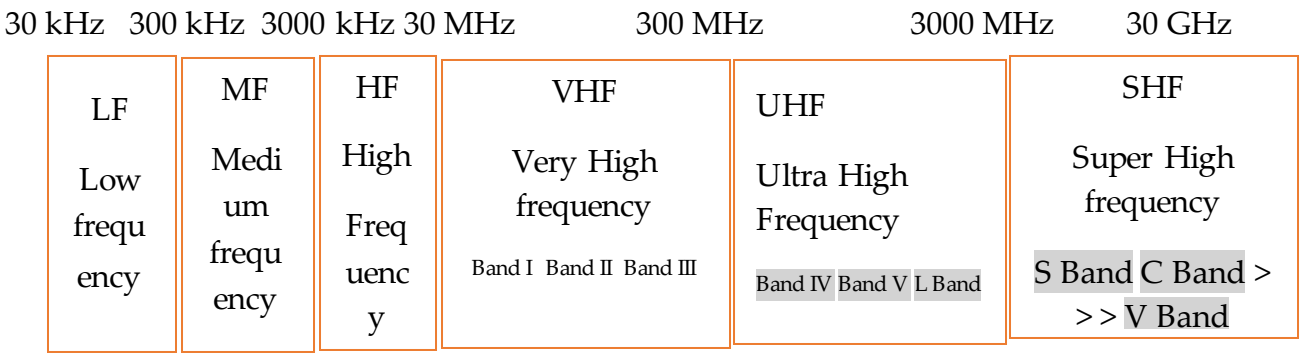


Figure 5.1: Frequency bands and sub-bands [13]

The basic parameters to be consider in television broadcasting is frequency and transmitter out power.

Planning criteria for digital terrestrial television include fixed and portable reception [21].

- Fixed antenna reception; that is a directional roof top antenna
- Portable antenna reception; this can be a simple movable antenna on or near a television-set or a built in antenna on a transportable television set.
- Mobile reception; here reception takes place while moving in a car, train or boat

For fixed reception, "Good" reception has been defined for reception at 95% of locations and "acceptable" reception for 70% locations [7].

5.2 Frequency Planning Options

There are basically three options for achieving an all-digital plan for terrestrial television

a) The conversion of existing analogue assignments into digital assignments. The analogue assignments may either be currently unused or in use for analogue television broadcasting;
b) A plan based on current digital television assignments (new frequencies not/ previously used or reserved for analogue television);
c) A completely new plan.

In this thesis work uses the first option that means the analog television is also in use .The first two options are both based on the current analogue television plan. This has some important advantages and disadvantages such as:

- New frequency assignments are likely to be compatible with analogue services
- Administrations retain their rights
- Smooth transition by means of bilateral agreements is possible

However there are equally important disadvantages, such as:

- The new plan may not lead to equitable access
- The new plan may not be optimized for spectrum efficiency
- The assignments may not result in adequate coverage

The third option, a complete new digital plan, could be designed to solve these disadvantages. It is however difficult to implement because the required change of frequencies and associated technical characteristics and the need to synchronize between countries.

DTT is the implementation of digital technology for the broadcasting of digital television signals via a network of terrestrial transmitters. The basic sound and video signals are converted, modulated and coded into digital form and transmitted as such; Digital terrestrial television allows a greater number of channels, better image, and sound. An internal or external antenna is required for the reception of digital signal. The coverage of a wider area requires a network which can work as a single frequency network (SFN) or a multiple-frequency network (MFN).

5.3 Frequency Planning Networks

The analog terrestrial broadcasting utilizes Multi Frequency Network (MFN), a transmission scheme that uses a different transmitting frequency in each service area. Hundreds of stations are established for national broadcasting service, therefore much frequencies are used [23]. Frequency is one of the scarce resources in the world. Currently in our country there no limitation in frequency but for the future as the technology is growing new services are increased frequency scarcity happen, interference increased. To overcome this, selecting better frequency planning network for efficient use of spectrum is necessary.

There are two basic digital terrestrial television broadcasting network structures [24]:

- Multi Frequency Network(MFN) and
- Single Frequency Network (SFN).

5.3.1 Multi Frequency Network

In a multi frequency network (MFN), each transmitter operates independently (using a different channel) and has its own coverage area. The same channel is re-used only in regions separated by a sufficient distance, to avoid harmful co-channel interference.

MFNs can provide for large coverage where the individual transmitters carry different multiplexes and can thus allow for regional or local programming. In addition, MFNs can be designed to reproduce, approximately, the coverage of the existing analogue networks and this may be of importance when it is considered necessary to maintain an existing coverage pattern for political or commercial reasons.

5.3.2 Single Frequency Network

In a SFN, all transmitters of a network use the same channel. They possess a common coverage area and cannot operate independently. They require a high degree of synchronicity (in time, frequency and data stream): the emitted signal from different transmitters must be identical in content, signal emissions must take place at the same time (or with precisely controlled delays) and the RF carriers must comply with stringent frequency precision requirements. In such SFNs large diversity gain (or network gain) is obtained yielding better coverage and frequency economy than in analog broadcasting networks that uses MFNs [25].r

The main advantages of implementing SFN compared to the conventional multi frequency network are the following [25]:

- High spectrum efficiency is regarded as a major advantage of the SFN concept compared to the MFN approach. Spectrum efficiency is very important in a scarce spectrum environment both in the introductory phase of digital services when the spectrum is occupied by analog services and also in long term when a large number of offered programs will make the broadcasting services more attractive for customers.

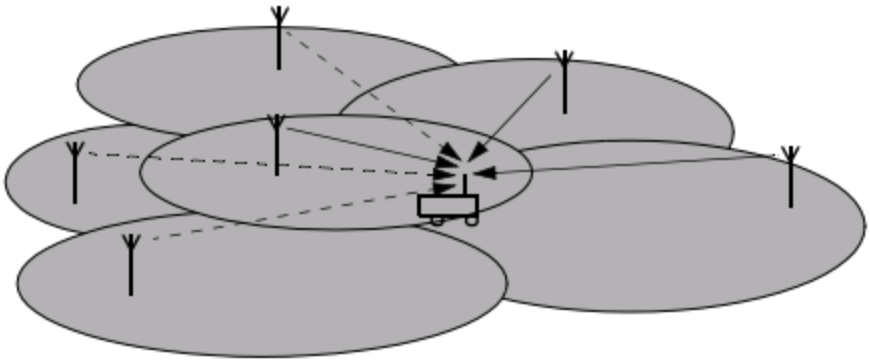


Figure 5.2: Single Frequency Network used in Digital Audio/Video Broadcasting **[26].**

- In SFN all transmitters operate in the same frequency block. The useful signals come from the nearest transmitters, whereas transmitters located far from the receiver contribute to the interfering signal [25].
- In SFN the received signal is a superposition of signals coming from several transmitters. The variation of the total field strength is lower, since one of the transmitters is shadowed, whereas the others are still receivable. This results in a higher location probability compared to the single transmitter case. This phenomenon is usually referred network gain or diversity gain.
- As a result of the network gain, SFN can operate at lower power and the field strength distribution over the total service area is more homogeneous compared to MFNs.

- SFN allows the easy setup of gap-filling transmitters where bad reception quality is observed, i.e., without using extra frequencies.
- Increased robustness is ensured using dense SFNs in which the failure of a single transmitter does not result in coverage outage for the whole network.

The aim of SFNs is efficient utilization of the radio spectrum, allowing a higher number of radio and TV programs in comparison to traditional multi-frequency network (MFN) transmission. An SFN may also increase the coverage area and decrease the outage probability in comparison to an MFN, since the total received signal strength may increase to positions midway between the transmitters.

TABLE 5.1: Advantages and disadvantages of SFN and MFN **[27].**

	SFN	MFN
Advantage	• Excellent spectral efficiency • low bandwidth consumption • Good power efficiency • lower electric energy consumption	• No change in user antenna systems required • Easy coexistence with analog channels

	• More homogeneous filed strength distribution for portable and mobile reception (DVB-H) • Suitable for indoor reception	• Can re-use existing infrastructure of analog TV transmitters and antennae • Network splitting is easy • Different multiplexes in different regions
Disadvantage	• Network splitting for local content is difficult • Excellent synchronization required • Extra cost • Costly infrastructure of dense grid of transmitters needed to avoid self-interference • New aerials often required on the user's side	• Not effective in spectral occupancy (though much better than analog) • Not so good for DVB H • Cannot assure indoor reception • Lower power efficiency

In multiple frequency network, it has been possible to increase coverage only by a combination of increased antenna height, increased transmitter output power, and/or a different antenna pattern. In cases where the maximum allowable ERP already has been reached, it is often prohibitively expensive or altogether impossible to proceed. SFNs can offer an attractive option, easily extending coverage with the simple addition of lower-power transmitters at various sites throughout the desired coverage area. Among their

many benefits, SFNs are more flexible in terms of coverage area; more interference-resistant (and also cause less interference); and inherently more fault-resistant than MFN systems used in analog television broadcasting systems. They also can lower installation costs [28].

Within a Single Frequency Network, all the transmitters from one SFN cell will broadcast over the same frequency, enabling spectrum & bandwidth optimization. The picture below perfectly illustrates the problematic: in MFN, three different broadcast frequencies are in use, with 24 MHz bandwidth occupied. In SFN, only one frequency, with bandwidth optimization: only 8 MHz [29]. SFNs are not generally compatible with analog television transmission, since the SFN results in ghosting due to echoes of the same signal.

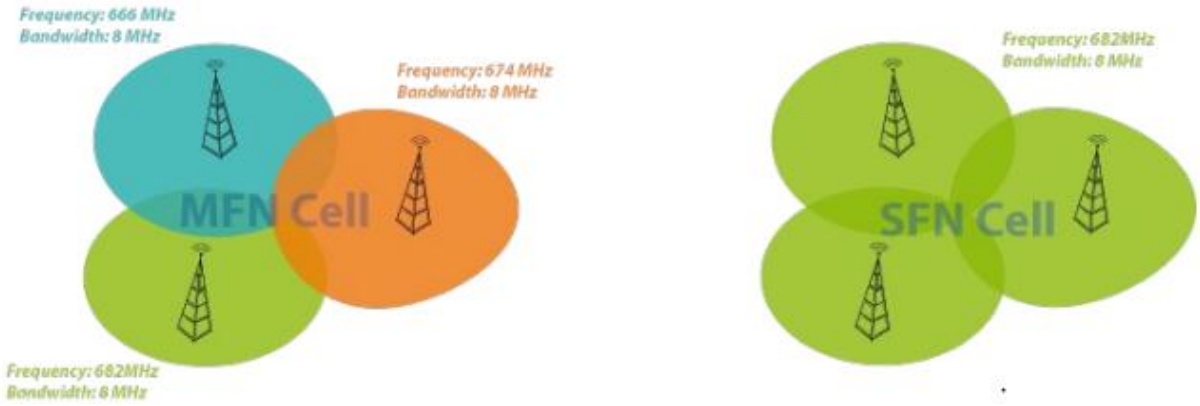


Figure 5.3: Comparison between MFN and SFN topology [29].

5.3.2.1 Principle of the SFN

The signal coverage of a certain area can be provided by a number of transmitters, transmitting the multiplex of digital television or radio signals in the identical frequency channel. Their partial signal contributions in the reception point not only do not interfere, under certain circumstances then even improve the reception. It is thus obvious that

single frequency networks of digital transmitters may considerably improve the utilization of frequency bands and channels as well as energy balance of digital transmitters.

Digital transmitters in SFN might be considerably lesser power for the signal coverage of the given area sufficient for quality reception. Methods of SFN cannot be used with the terrestrial analogue television broadcasting, where in fact all the present day world's television standards use amplitude vestigial sideband modulation and operate in MFN [30].

Single frequency networks can be built only in a limited area, not over a whole country. Let us assume that in the analyzed SFN area [30]:

- All transmitters operate at the same frequency with the same program content to be broadcast,
- These transmitters operate with the same and exact time synchronous digital data multiplex,
- The level of received signals anywhere in the SFN area reaches leastwise the threshold limit value (the level, which DVB-T receiver needs to able to demodulate and decode the signal properly).

5.3.2.1.1 COFDM in SFN

In digital terrestrial television broadcasting, the effects of multipath reception were largely suppressed by choosing of sophisticated modulation methods. Modulation COFDM is characterized by high robustness against inter-symbol interference (ISI), which would threaten the received signal and increase their error rates due to the multipath reception [30]. The first symbol C in the abbreviation means, that the data stream is protected by the error correcting encoding Forward Error Correction (FEC) to detect and correct errors that occur during the transmission.

Reception of more delayed signals from several transmitters working in the single frequency network can be utilized even for improvement of the power efficiency of transmitters. The application of COFDM modulation is an effective, most frequently used, but only possible tool to eliminate the impacts of multipath reception [30].

A SFN is a network of transmitting stations that use the same frequency to transmit the same information. A Single Frequency Network is a means to extend the coverage area without the use of additional frequencies. This transmitter diversity structure makes SFNs very efficient in fading channels with an excellent spectrum saving and very good power utilization. In a SFN multiple copies of the signals arrive at the receiver antenna with different delays. The time dispersion is caused by two main mechanisms [25]. The natural dispersion is caused by wave components reflected by obstacles in the vicinity of the receiver and the artificial dispersion derives from the reception of signals from several transmitters placed at different distances from the receiver as in the Figure 5.5 Thus, the inter-symbol interference is caused mainly by the artificial delay spread.

In OFDM systems the extreme delay spread is controlled by using a longer transmitted symbol than the actual interval observed by the receiver. If the delay spread of the signal is smaller than the guard interval, no inter-symbol interference occurs and the signal contributes totally to the wanted signal. Therefore, in SFNs not only noise but also delayed signals outside the guard interval have an important impact on the achievable coverage.

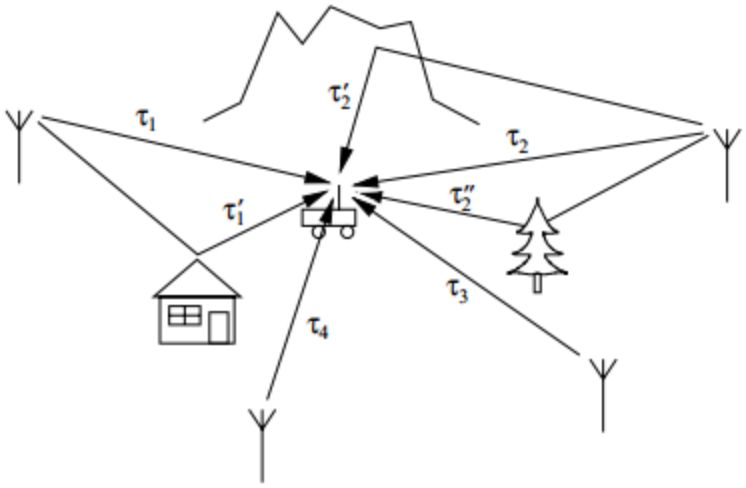


Figure 5.4 : Multi-path propagation due to simulcasting [25].

The SFN is based on the use of Coded Orthogonal Frequency Division Multiplexing (COFDM). COFDM has the advantage that it is very robust against reception of a signal together with echoes of the same signal or multipath reception. This robustness against multipath reception is obtained through the use of a guard interval. This is a proportion of the time there is no data transmitted between the symbols. This guard interval reduces the transmission capacity.

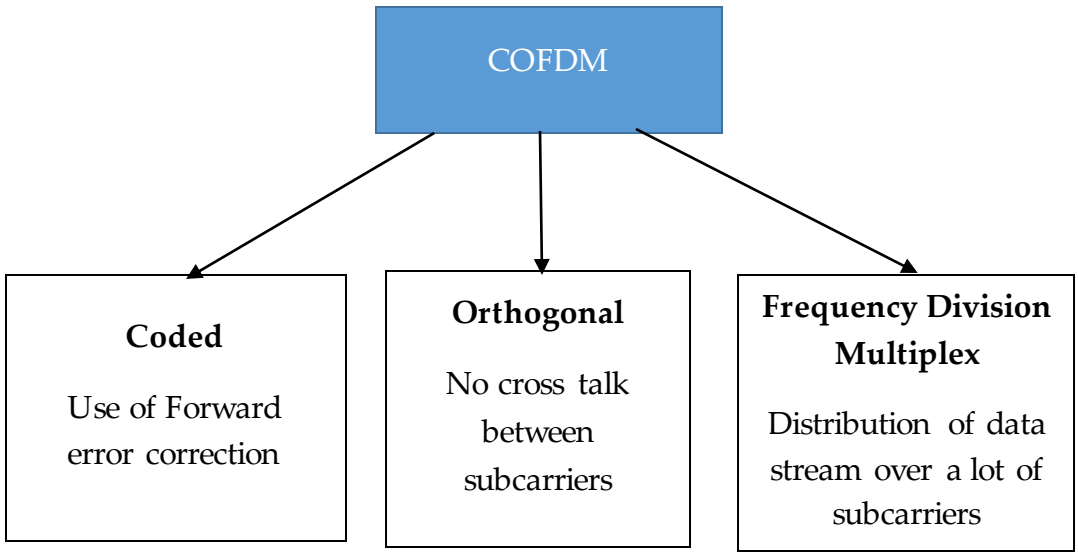


Figure 5.5: Block diagram to explain COFDM **[24]**

The majority of digital terrestrial technologies use multiple carrier OFDM techniques. Adding forward error correction (FEC) produces coded OFDM (COFDM) to improve the robustness of transmission [31]. The OFDM concept is based on spreading the data to be transmitted over a large number of carriers, each being modulated at a low bit rate [24].

The carrier spacing is uniform and deliberately chosen so that it is the inverse of each symbol duration. This choice of carrier spacing ensures orthogonality of the carriers which means that the influence of adjacent carriers (in fact all other carriers) on the demodulation of a particular carrier is zero. It ensures there is no crosstalk between carriers, even though there is no explicit filtering and their spectra overlap.

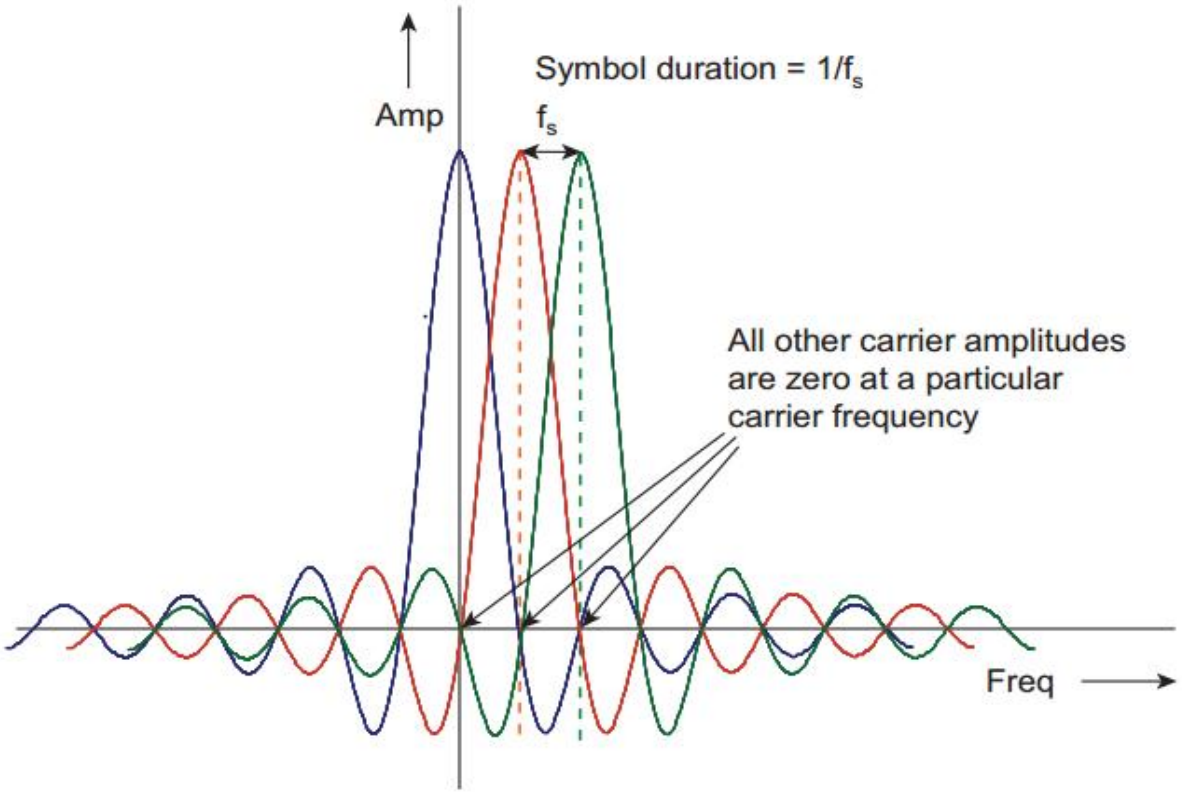


Figure 5.6: Orthogonally **[31].**

5.3.2.1.2 Guard Interval (GI)

In order to overcome the inter-symbol interference problem in DVB-T and T-DAB, part of the symbol is copied from the beginning of the symbol to the end, increasing its duration by a certain amount of time called the guard interval [24]. The basic parameter that defines the size of the SFN area is the guard interval TG. To understand this term, we will to need at least basic explanation to fundamentals of OFDM modulation method. Its great robustness against inter-symbol interference as an effect of multipath reception (an impact of time delayed signals – echoes) consists in largely extending the very short bit time interval Tb in the serial original data stream. The symbol time extension is done by first mapping the original data stream $Sb(t)$ into n parallel data (symbol) streams $S0$ to 1 . The parallel streams are then modulated using a discrete digital method (e.g. m-QAM or QPSK) onto a number of n simultaneously transmitted orthogonal sub-carrier

signals. Orthogonality of this system is ensured by keeping the maxima (minima) spacing of the respective sub-carrier waves and integer multiple of the inverted symbol time value.

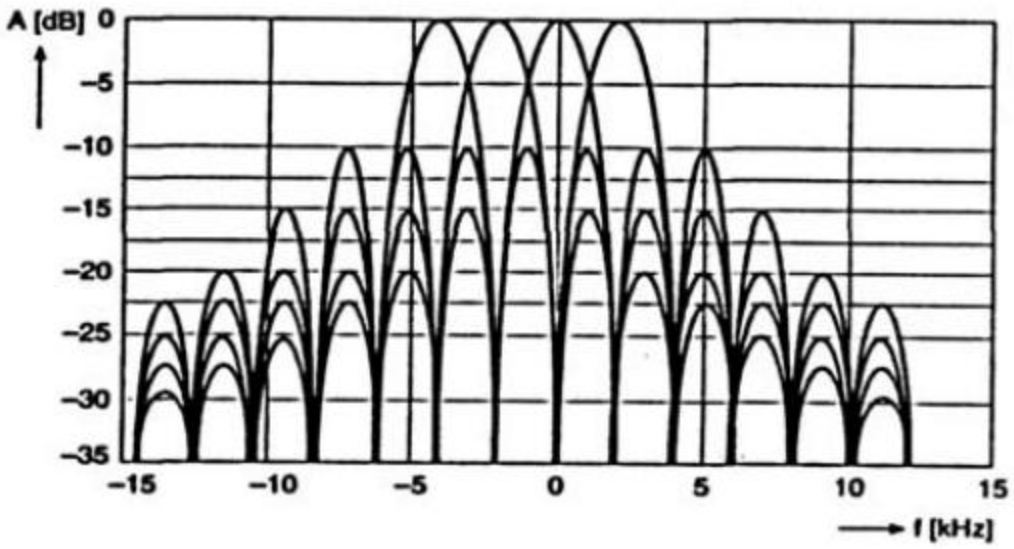


Figure 5.7 :Power spectrum of an orthogonal system for the simplified case of 4 sub-carriers[30].

The number n of orthogonal sub-carrier waves in DVB-T standard is n = 2048 (for 2k mode), n = 8192 (for 8k mode), eventually for DVB-H also n = 3408 (for 4k mode). For the actual transmission of the information data, not all the sub-carriers are used – in 2k mode, the number of active sub-carriers is n = 1075 and in 8k mode, there are n = 6817 active sub-carriers. The remaining sub-carrier waves are used as pilot signals, and some of them carry information about the parameters of the modulation used. The frequency gap Δf between them must conform to the bandwidth Bk of the assigned frequency channel (for video broadcasting 8, 7, 6 MHz) and represents, in fact, the symbol rate Rs of OFDM modulation.

For 8 MHz bandwidth channels, used in frequency raster of terrestrial as well as cable distribution, the spacing of sub-carrier frequencies Δf, which also represents the symbol rate Rs, can be written as

$$\Delta f = Rs = \frac{Bk}{n} = 7.61\frac{.10^6}{6817} = 1.116kHz$$

The corresponding time extended symbol Ts is then

$$Ts = (Rs)^{-1} = (1.116)^{-1} = 896\ \mu s$$

This time is then further extended by the so-called guard interval TG, which is often defined as a part (k_T) of symbol time, i.e.

$$k_T = \frac{T_G}{T_S} = \frac{1}{4}, \frac{1}{8}, \frac{1}{16}, \frac{1}{32}$$

For instance, in 8k mode transmitted in a channel of 8 MHz bandwidth, the longest guard interval of

$$T_G = k_T . T_S = \frac{1}{4} .896\ \mu s = 224\ \mu s$$

Total length of the extended symbol becomes

$$T_N = T_S + T_G \tag{5.1}$$

Table 5.2: Time properties within the COFDM signal in 6, 7, 8 MHz [30]

Channel bandwidth [MHz]	Mode 2k (k_T =1/4)			Mode 8k (k_T = 1/4)		
	T_s [µs]	T_G [µs]	$T_s + T_G$ [µs]	T_s [µs]	T_G [µs]	$T_s + T_G$ [µs]
8	224	56	280	896	224	1120
7	256	64	320	1024	256	1280
6	298	75	373	1197	296	1493

In the guard interval TG, no useful information is transmitted. It is used to eliminate reception of delayed signals and thus influences the possible choice of transmitter

distances in the single frequency network. From the table above the longest guard interval can be obtained at channel bandwidth 8 MHz and 8k mode i.e. T_G=224 μs.

Maximum possible distance between the transmitters working in single frequency network described by a formula expressing the distance of an air propagated electromagnetic wave delayed by TG

$$l_{max} \leq c.T_G$$

$c = 3.10^8$ Speed of light

For example for 8 MHz and 8k mode the maximum distance between the transmitters is

$$l_{max} \leq c.T_G = 3.10^8.224.10^{-6} \cong 67km$$

The length of GI determines the maximum delay spread the system can manage, the longer the GI, the longer the allowed distance among the transmitters, but the lower the transmission efficiency.

Chapter Six

Simulation Analysis and Results

6.1 Introduction

Simulation is a practical and scientific approach to analyze a complex system. In this thesis, simulation is used to investigate the coverage planning of DTB as it is done using MATLAB simulation environment. In the first case the analysis of simulation results of comparison of different propagation models is done. From this analysis, one model is selected for the calculation of coverage distance of 53dBm transmitter from the total pathloss. The total pathloss is calculated using radio link budget calculation.

Once, coverage distance is calculated the number of transmitter that require to cover Addis Ababa city is estimated. Then the optimum site for the transmitter is selected using the digital terrain map of Addis Ababa using MATLAB. In this thesis MATLAB-2016a was chosen as simulation environment for its in-depth input analysis, flexible working environment.

6.2 Simulation flow

Simulation flow is a block diagram that includes the whole process of this paper to achieve its objective. The description of each step is described below.

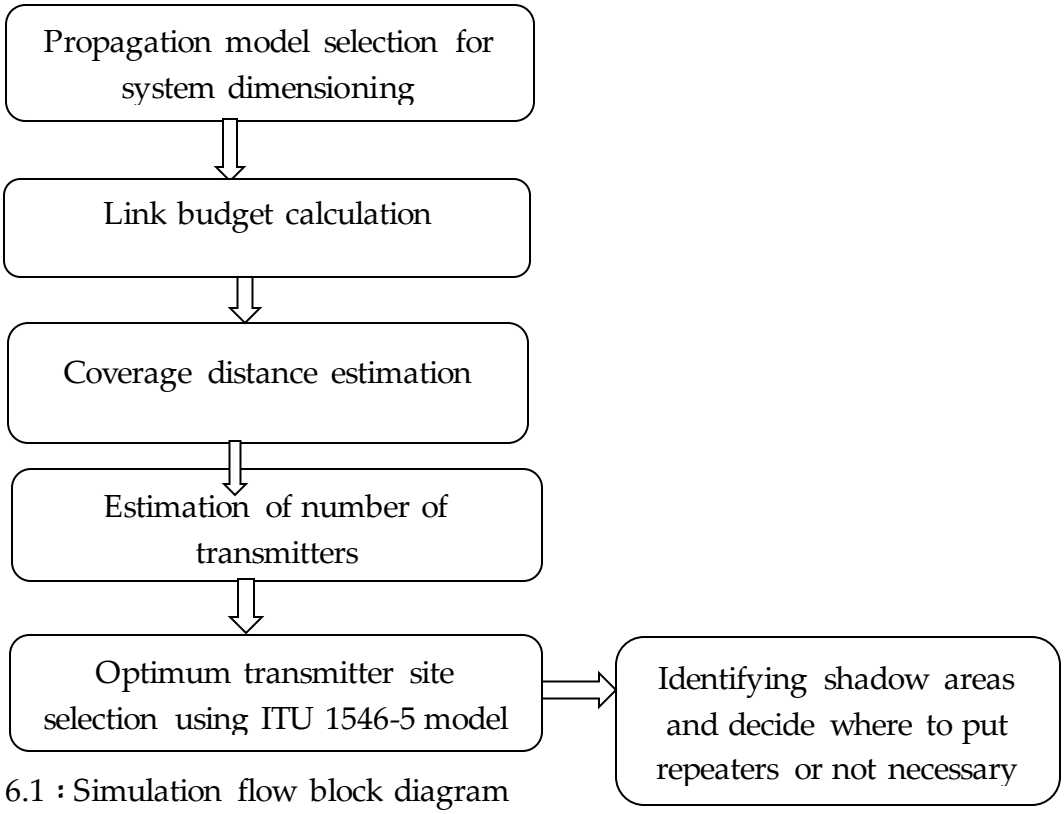


Figure 6.1 : Simulation flow block diagram

6.3 Propagation Model Selection

Radio propagation models are an empirical mathematical formulation for the characterization of radio wave propagation as a function of distance between transmitter and receiver antenna, function of frequency and function of other condition. A propagation models are usually developed to predict the behavior of radio propagation in different environment and different condition. Radio propagation models are empirical in nature and models are developed based on large collection of data collected for the specific scenario [32]. In this thesis work one model is selected for system dimensioning based on path loss simulation result using MATLAB 2016a. COST-231 Hata model is selected from city models in Section 3.2.1.2 by comparing the path loss simulation result with ITU-R 1546-5 model.

From the Figure 6.2 below FSPL has lower pathloss, if we considers only LOS propagation FSPL if selected for system dimensioning but in this thesis work we are not considering

only LOS but also NLOS conditions. Based on this one even if FSPL have lowest path loss result, it is not recommended for this planning. As it can be seen from the result, ECC-33 model have lower path loss result next to FSPL but this model's result may be exaggerated because it is recommended for higher frequency up to 3.5 GHz. Therefore from this simulation result COST-231 Hata model is selected for system dimensioning. Based on this model the coverage distance of 53 dBm output power transmitter is calculated.

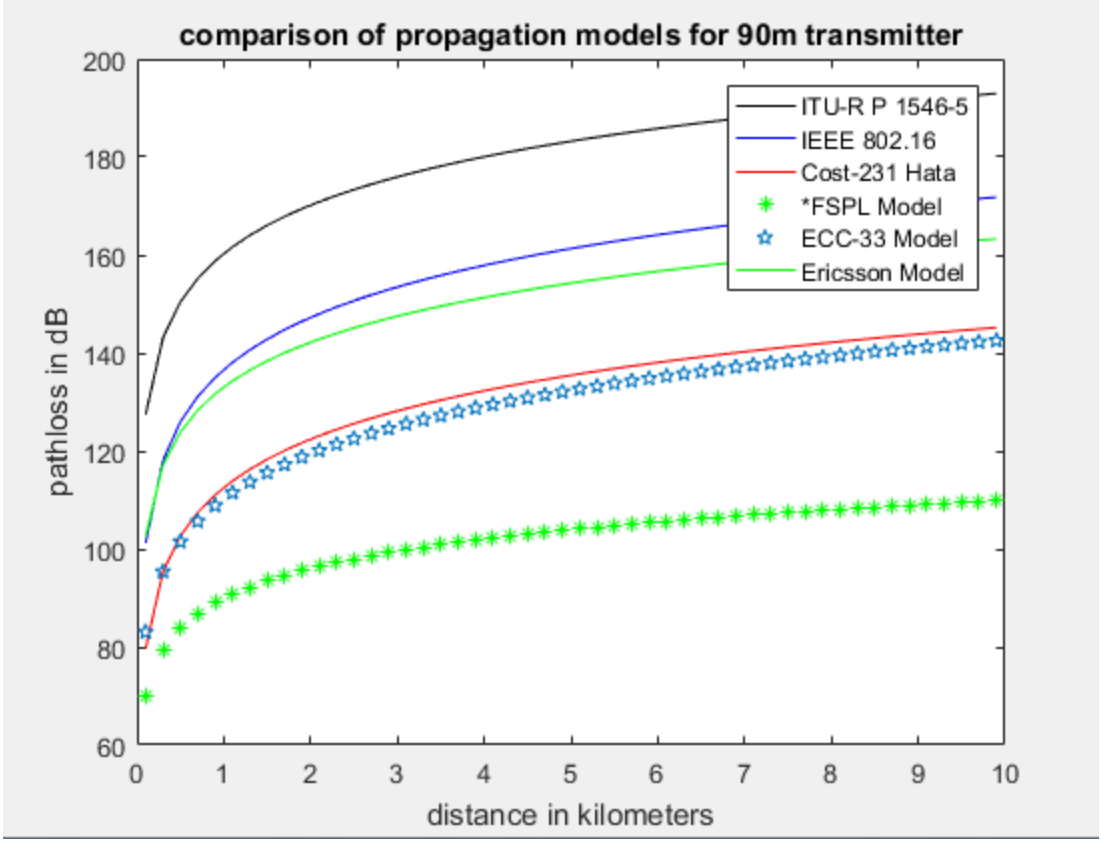


Figure 6.2 : Comparison of propagation models

6.4. Link Budget Calculation

As the name implies, a link budget is an accounting of all the gains and losses in a transmission system. The link budget looks at the elements that will determine the signal strength arriving at the receiver.

Parameters that determine link budget may the following items and can discussed below:

- Transmitter power.
- Antenna gains (receiver and transmitter).
- Antenna feeder losses (receiver and transmitter).
- Receiver sensitivity

Received Power (dB) = Transmitted Power (dB) + Gains (dB) − Losses (dB)

$\frac{C}{N} = ERP - path\ loss + Rx\ antenna\ gain - Rx\ feeder\ losses - LNB\ noise\ figure +$
$noise\ floo$r.

6.3.1 Effective Radiated Power (ERP)

The Effective radiated power (ERP) of a transmission system depends on the transmitter power, the antenna gain and the losses in the transmission system [15].

$$ERP = Tx\ out\ put\ power - Tx\ feeder\ losses + Tx\ antenna\ gain$$

Where Tx is the transmitter, and the feeder is generally a low loss transmission line feeding the signal to the broadcast antenna.

Then the carrier to noise ratio can be derived from the following.

6.3.2 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. The maximum allowable radiated power is 1,000 kW for UHF channels. The planning this thesis work is done with maximum power of 200 W or 53dBm and then necessary trade-off will be made with transmitter antenna tower height.

6.3.3 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. It is assumed that the transmit antenna will be oriented so that its maximum gain direction is pointed along the path toward the receiver antenna, so the maximum gain value from the manufacturer is used here. By convention, the gain of antennas used in digital TV broadcasting and other fixed broadband wireless systems are usually given in dB relative to an isotropic radiator, denoted as dBi.18 dBi is used for this design [33].

6.3.4 Transmitter Feeder Losses

For the top-roof antenna, the feeder loss is assumed to be 4 dB meanwhile for the indoor antenna, the feeder loss is assumed to be 1 dB [11]. Hence for this work the feeder losses are assumed to be 4 dB.

Pathloss: The total path loss is the free space path loss, *Lf*, calculated using the Friis space loss formula below [15].

$$\text{pathloss} = 20\log(4\pi\text{d}/\lambda)$$
$$= 32.44 + 20\log f\,(MHz) + 20\log d\,(km)\;dB$$

6.3.5 Receiver Antenna Gain

See the discussion for the transmitter antenna gain mentioned earlier.20dBi is taken for this work.

6.3.6 Noise Figure

Maximum acceptable loss is given from the manufacturer. The FCC has recommended 7dB for the UHF band(470-862 MHz) and 10 dB for the VHF band [34].7dB is used for this design.

6.3.7 Noise Floor

The noise floor is the measure of the signal created from the sum of all the noise sources and unwanted signals within a measurement system, where noise is defined as any signal other than the one being monitored. These are different losses such as fading margin, body loss, polarization mismatch, and other losses 15 dB is used for this design.

6.3.8 Carrier to Noise Ratio

In broadcasting system carrier-to-noise ratio, often written CNR or C/N, is the signal-to-noise ratio (SNR) of a modulated signal. Therefore, the term carrier-to-noise-ratio (CNR), instead of signal-to-noise-ratio (SNR) is preferred to express the signal quality when the signal has been digitally modulated. The required CNR value is the CNR value needed at the input of the receiver to achieve a specific signal quality at the output of the receiver [35].

6.3.9 Frequency (f)

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 pathloss so it is not necessary to specify it with a great deal of precision. We take for this 630 MHz.

$$\frac{C}{N} = ERP - path\ loss + Rx\ antenna\ gain - Rx\ feeder\ losses - LNB\ noise\ figure + noise\ floor$$

$$\frac{C}{N} = Tx\ power - Tx\ \&\ Rx\ feeder\ losses + Tx\ antenna\ gain - path\ loss + Rx\ antenna\ gain - LNB\ noise\ figure + noise\ floor \quad (6.1)$$

From the above link budget formula, the coverage distance can be found from the path loss formula given below.

$$path\ loss = 53dBm + 18\ dBi + 65\ dBm + 20\ dBi - 7dB - 8\ dB + 15\ dB$$

$$X\ watt\ power = X\ watt\ power\ in\ dB + 30\ dBm \qquad in\ dBm$$

$$path\ loss = 195\ dBm$$

Where, Tx is for transmitter and Rx is for receiver

From the above calculation the coverage distance of 53 dBm transmitter with center frequency of 630 MHz is 23km.

6.4 Coverage Distance Estimation

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.

As the basic work of this thesis work is coverage planning and frequency planning, that means estimating the coverage radius of single transmitter then after calculating the number of transmitters to cover the whole Addis Ababa city and as DTTB is used SFN, it uses repeater to extend coverage with using additional bandwidth. Coverage distance is estimating from link budget calculation using one selected propagation model. For this thesis work COST-231 Hata model is used to estimate the coverage distance of 53dBm transmitter**.** The total path loss obtained from link budget calculation is 195dBm. Then using this path loss value the coverage distance is estimated using COST-231 Hata model in Section 3.2.1.2.4.

The value of distance, d, that can produce this much loss according to COST-231 Hata model with 90m transmitter and 10m receiver antenna height is calculated to be 23 km. With this value at hand, the next step is to determine the number of transmitters and dimension the entire area of Addis Ababa into the 'territory' of each transmitter.

6.5 Estimation of Number of Transmitters

The number of transmitters that can cover a certain area depends on the radius distance value of coverage as discussed in the above 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 km^2 because of irregularity in shape.

The total coverage area for the radius of coverage distance calculated in the above section is $1.661x10^3\ km^2$, which is far larger than the area we estimated for the city. Therefore, one transmitter was found to be enough for the entire Addis Ababa city.

6.5.1.1 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 $5197X6277$ matrix or 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.

For digital television transmitter site selection for the case of Addis Ababa city, six sites were selected in order to select the optimal site for best coverage. The selection is based on the topography. The city lies at the foot of Mountain Entoto and forms part of the watershed for the Awash. From its lowest point, around Bole International Airport, at 2,326 meters (7,631 ft) above sea level in the southern periphery, Addis Ababa rises to over 3,000 meters (9,800 ft) in the Entoto Mountains to the north. There is about 1000m maximum altitude difference between the highest and lowest point in the city.

Location A is selected as it represents the center of the first high altitude topographic region. It is located on Entoto Mountain around Kuskam Mariam. Location B, located around the mountain around Yeka sub city in front of Enque Lideta Mariam Church. These sites found on the highest altitude. Site E and D represent the central part of Addis

Ababa city and around Asco progress academy respectively. F and G are from the lower latitude around Jommo and Hana Mariam respectively.

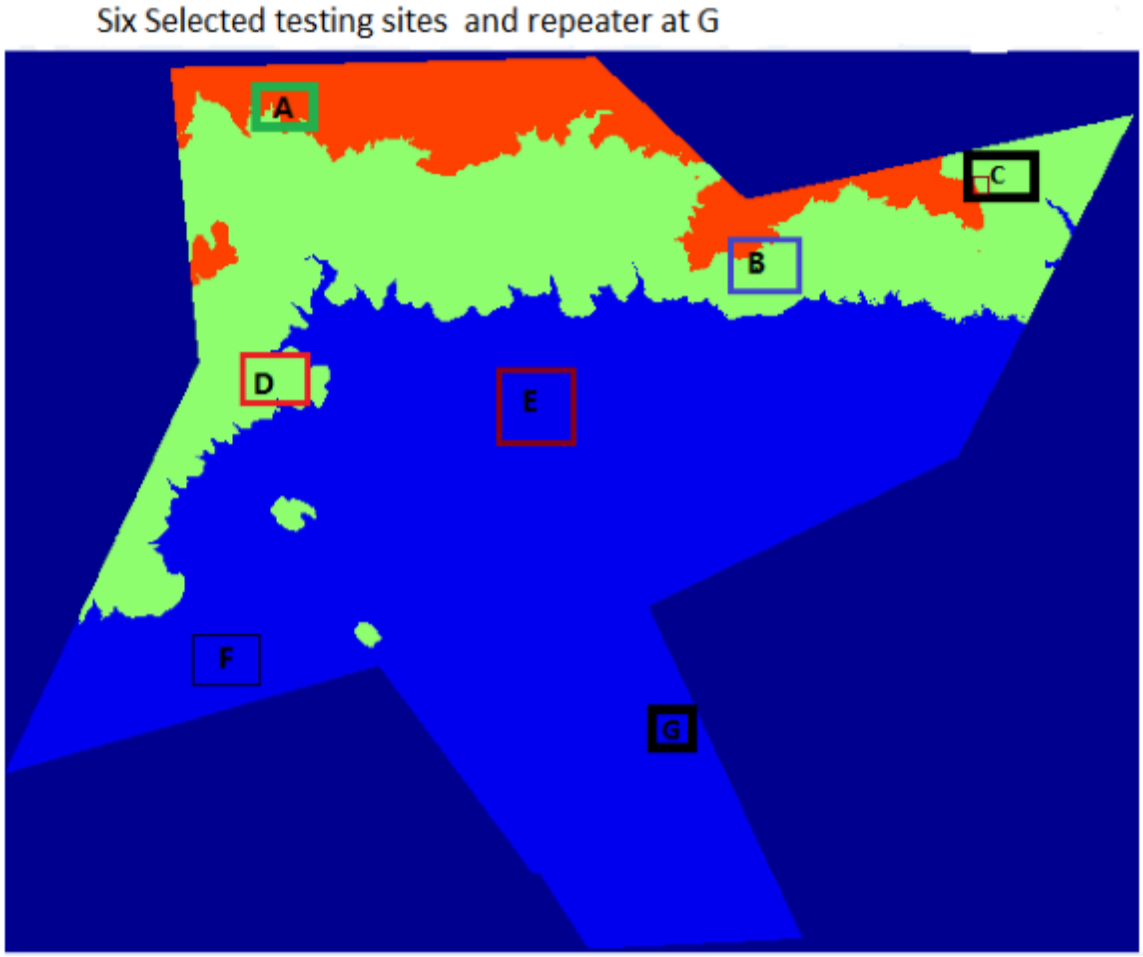
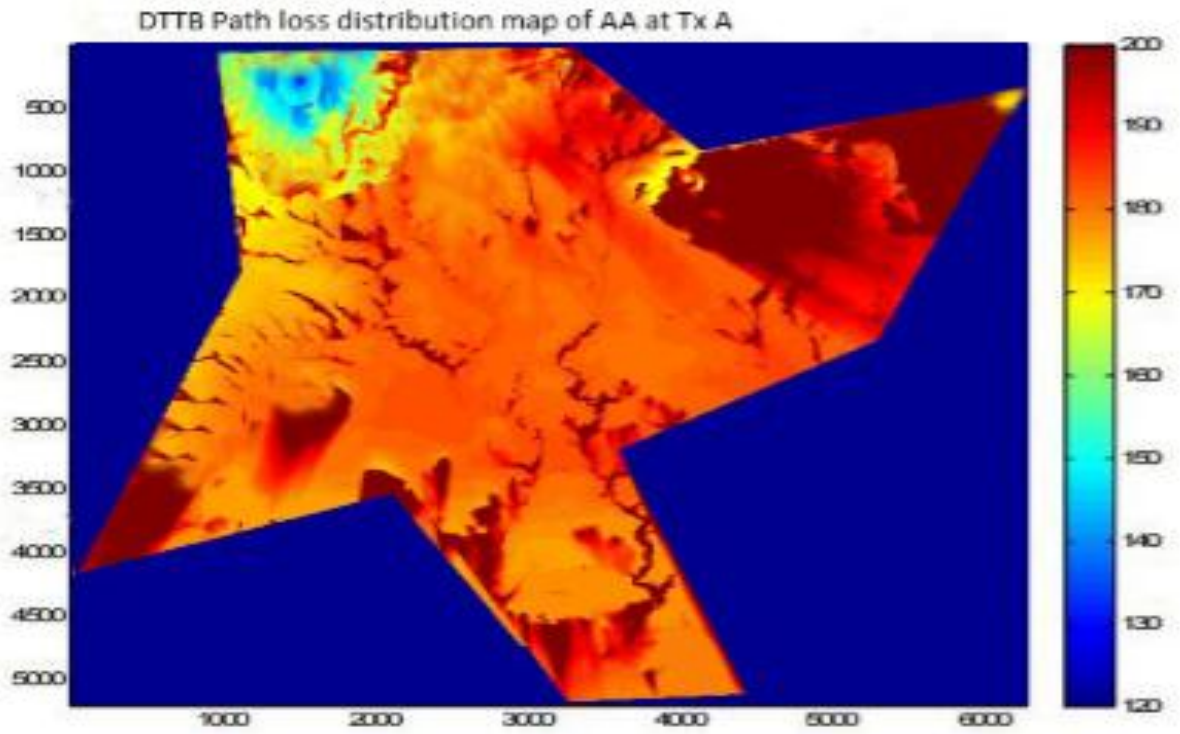


Figure 6.3 Selected candidate sites for transmitter tower position

Figure 6.3 represents different six selected transmitter sites that simulate independently. Then after by comparing their pathloss coverage area one transmitter site is selected. The details of each site is given below.


DTTB Path loss distribution map of AA at Tx A
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
1000
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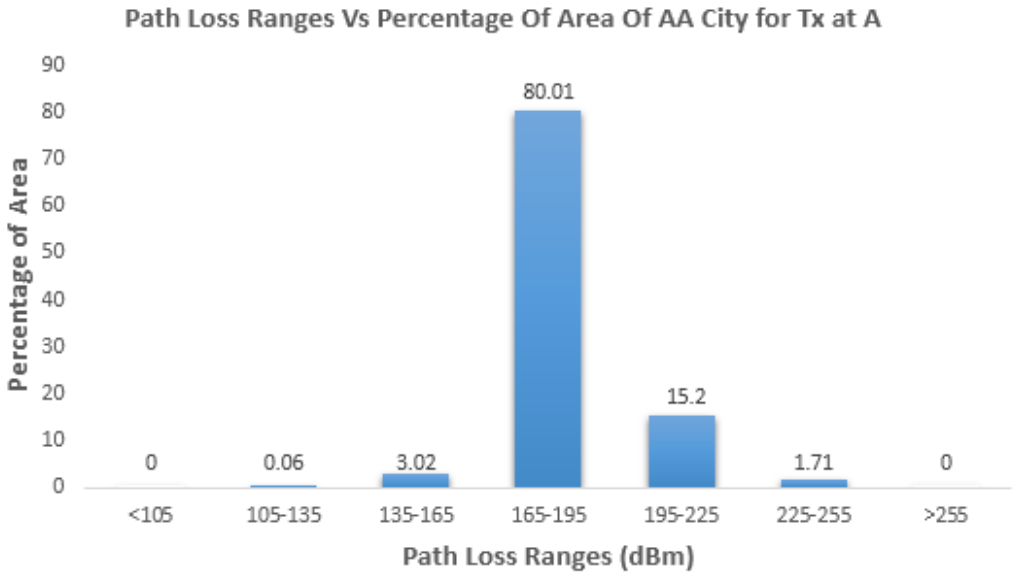
5000
6000
200
190
180
170
160
150
140
130
120

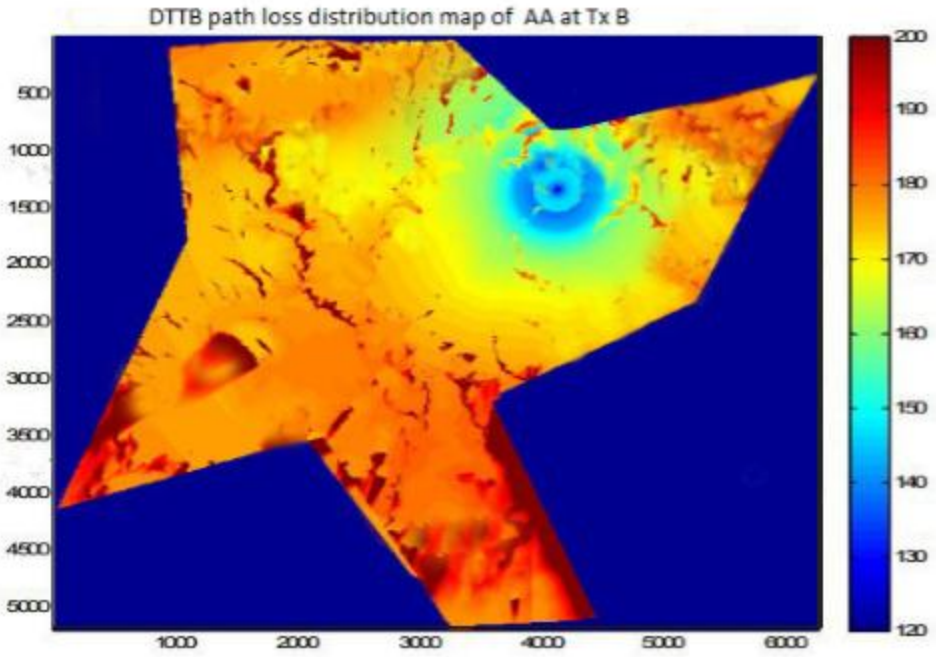
a)



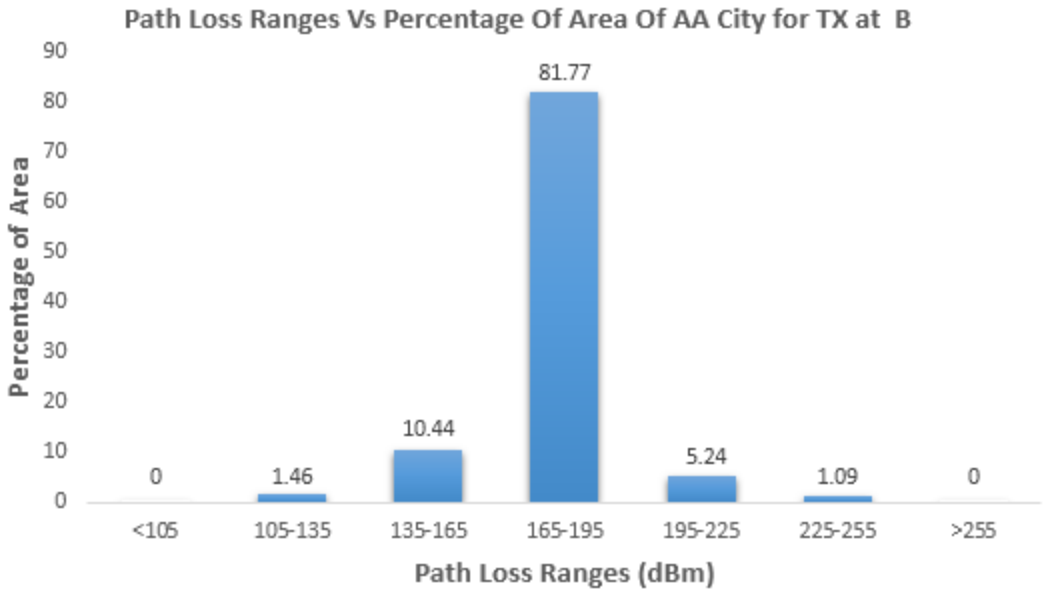
b)

Figure 6.4: Path Loss Map of Addis Ababa city with the transmitter located at Position A (around Entoto Mountain); (b) The percentage of the city covered with different path loss ranges.

The above Figure 6.4 represents the transmitter site position A (Entoto mountain) covers 83.9% of the area of Addis Ababa city.



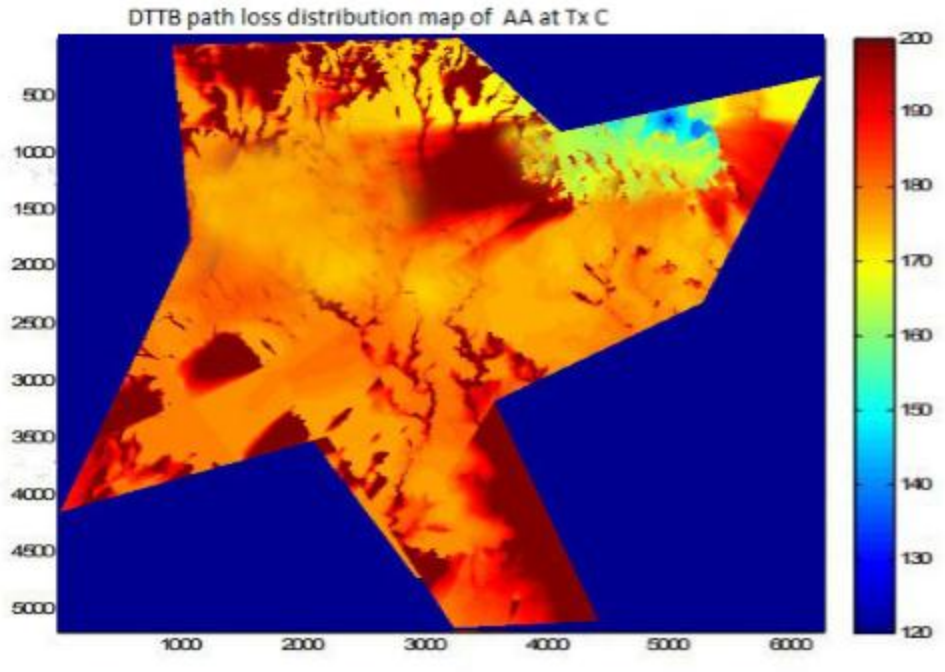
a)



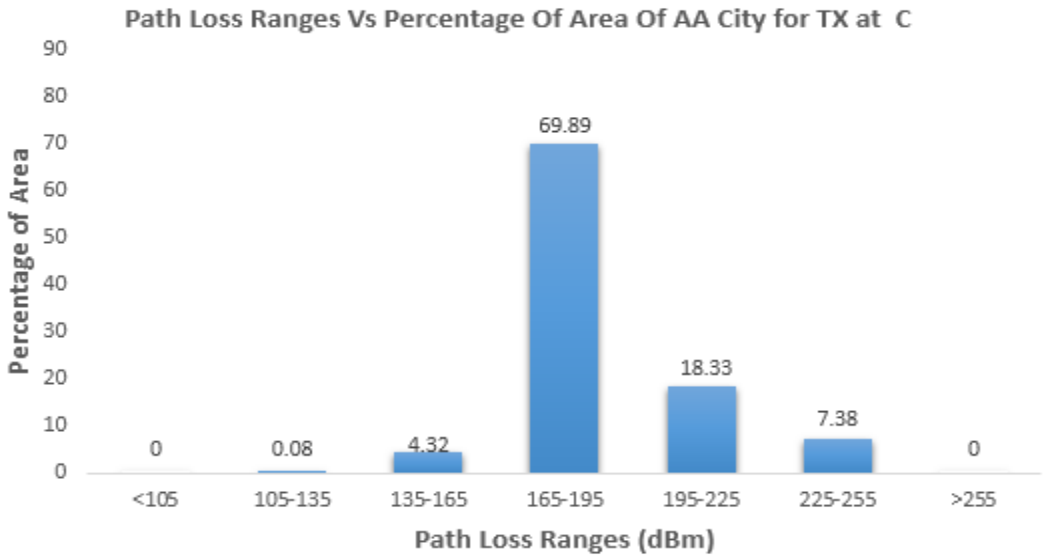
b)

Figure **6.5**: Path Loss Map of Addis Ababa city with the transmitter located at Position B(around Yeka Mountain); (b) The percentage of the city covered with different path loss ranges.

The above Figure 6.5 represents the transmitter site at position B (Yeka Mountain) covers 93.67% of the area of Addis Ababa city.



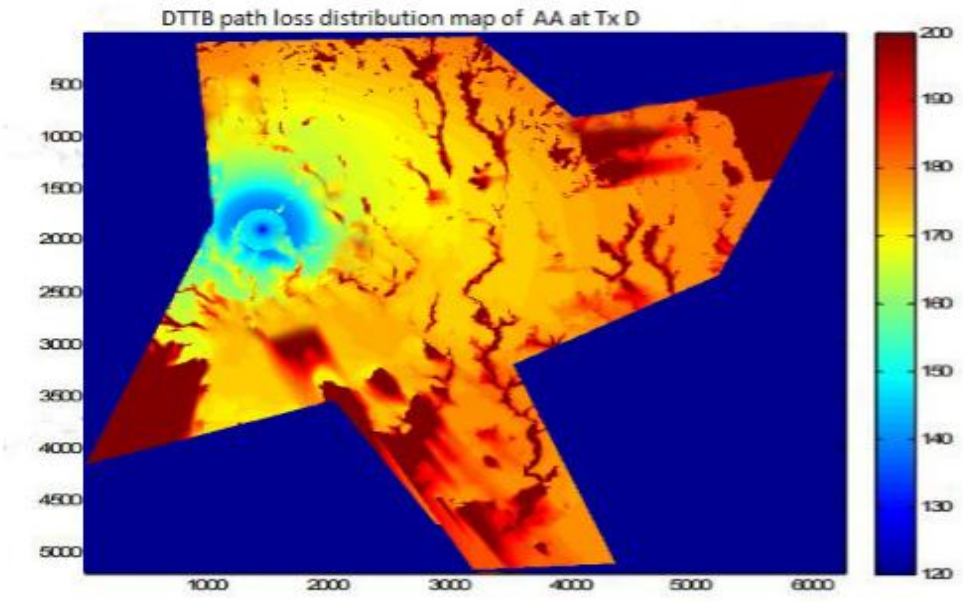
a)



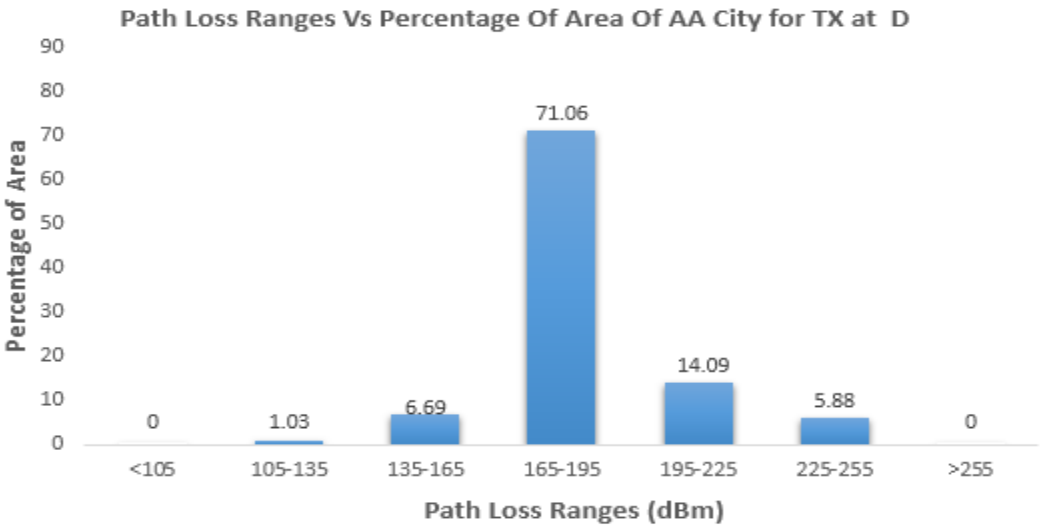
b)

Figure 6.6: Path Loss Map of Addis Ababa city with the transmitter located at Position C (around Kotebe); (b) The percentage of the city covered with different path loss ranges.

The above Figure 6.6 represents the transmitter site at position C (around Kotebe) covers 74.29% of the area of Addis Ababa city.



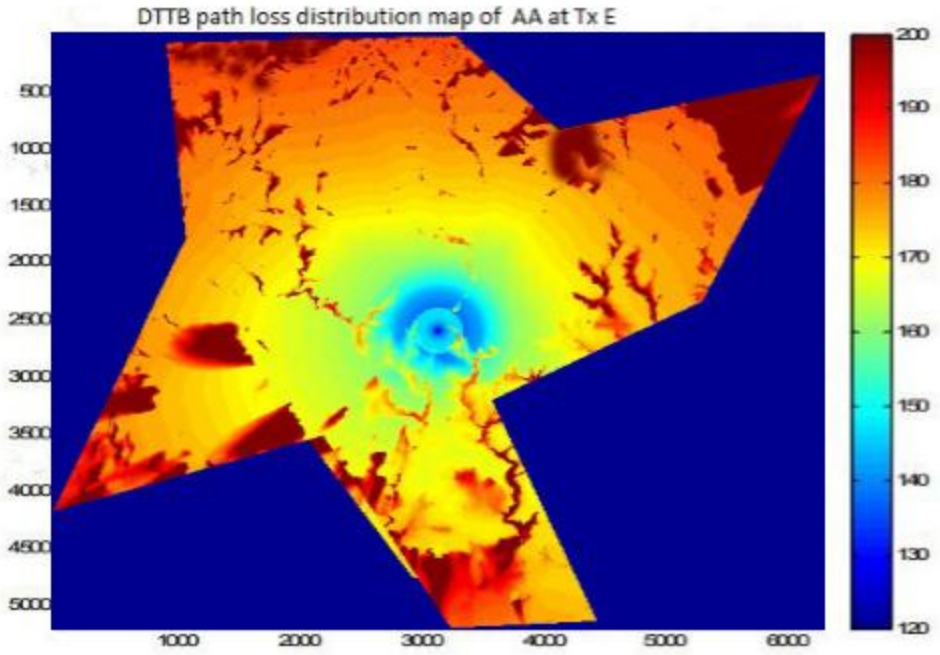
a)



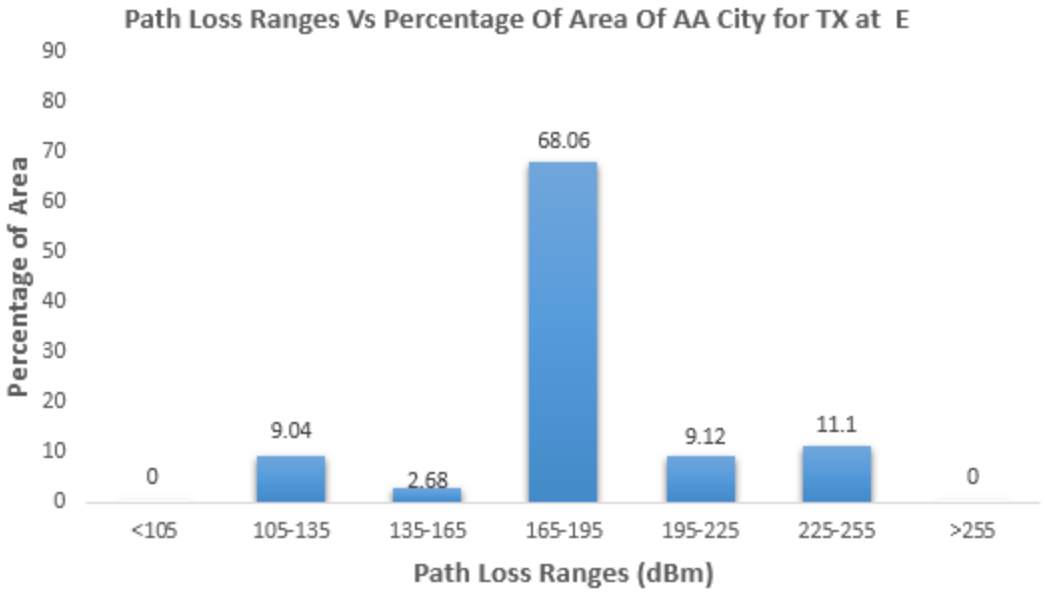
b)

Figure 6.7: Path Loss Map of Addis Ababa city with the transmitter located at Position D (around Asco Progress Academy); (b) The percentage of the city covered with different path loss ranges.

The above Figure 6.7 represents the transmitter site at position D (around Asco Progress Academy) covers 78.78% of the area of Addis Ababa city.



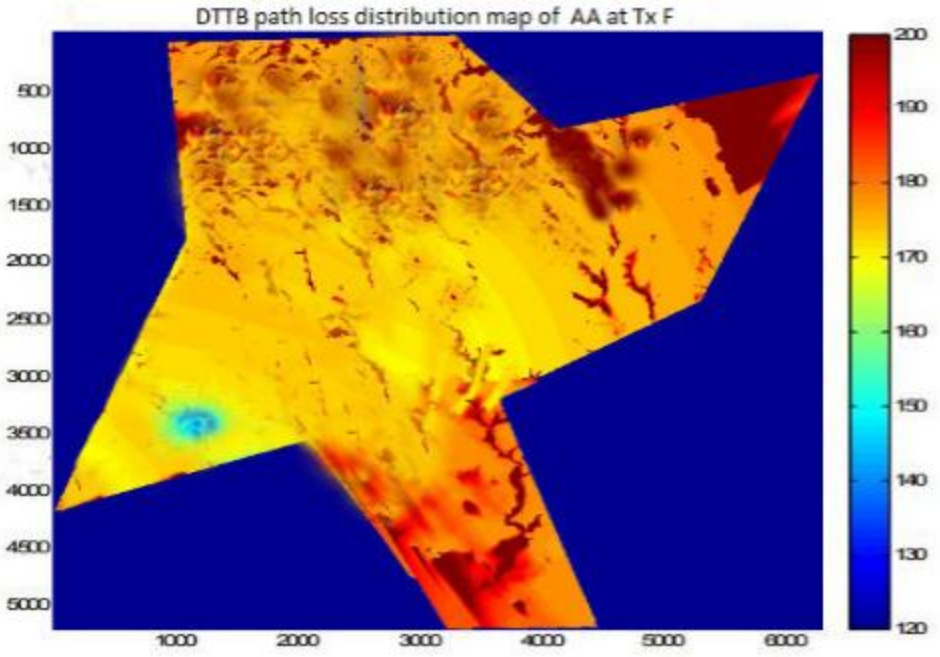
a)



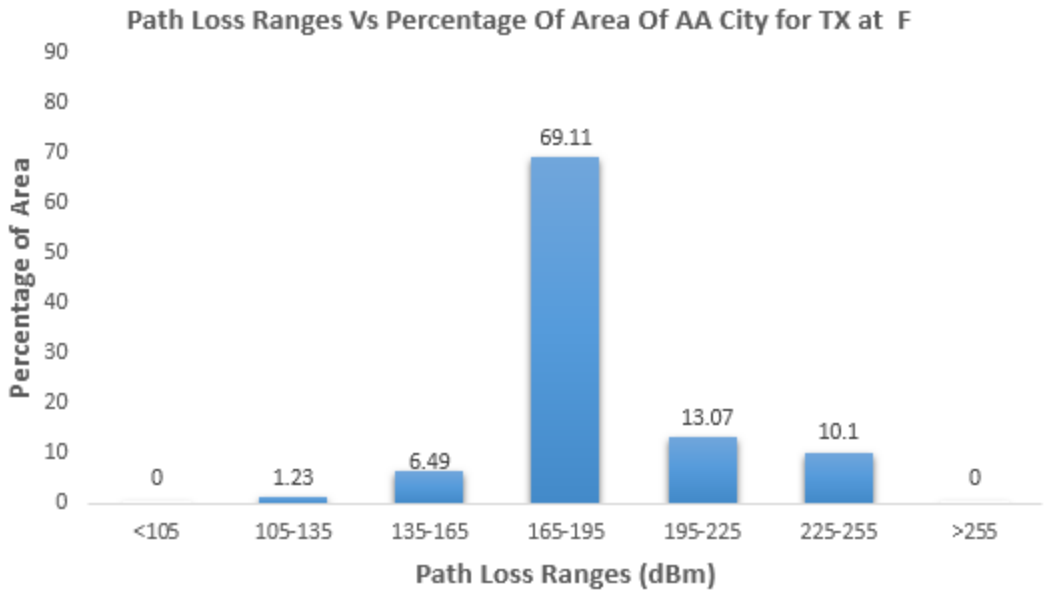
b)

Figure 6.8: Path Loss Map of Addis Ababa city with the transmitter located at Position E (around Ethiopian broadcasting agency); (b)The percentage of the city covered with different path loss ranges.

The above Figure 6.8 represents the transmitter site at position E (around Ethiopian broadcasting Agency) covers 79.78% of the area of Addis Ababa city.



a)

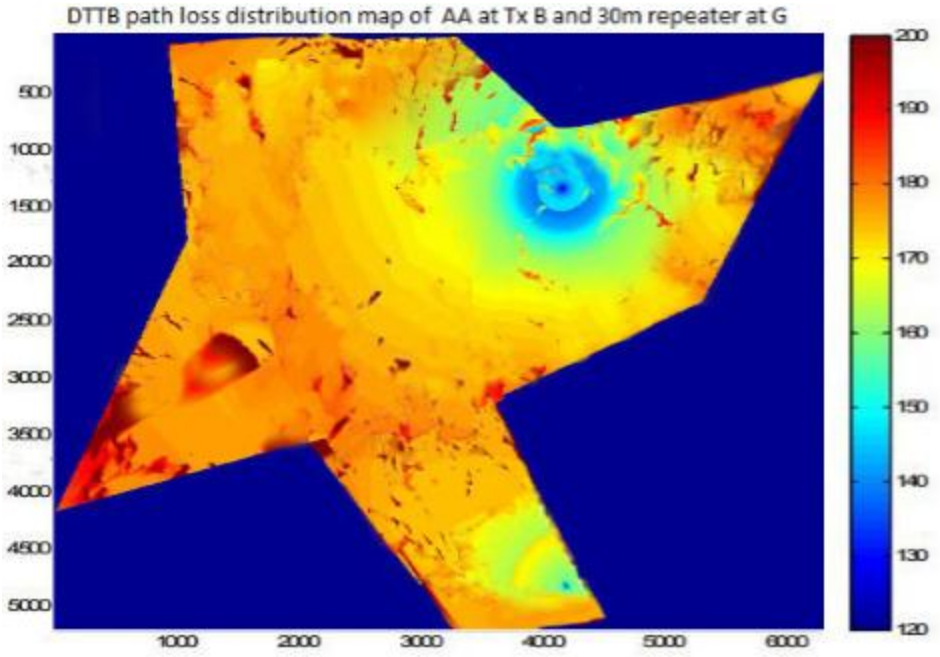


b)

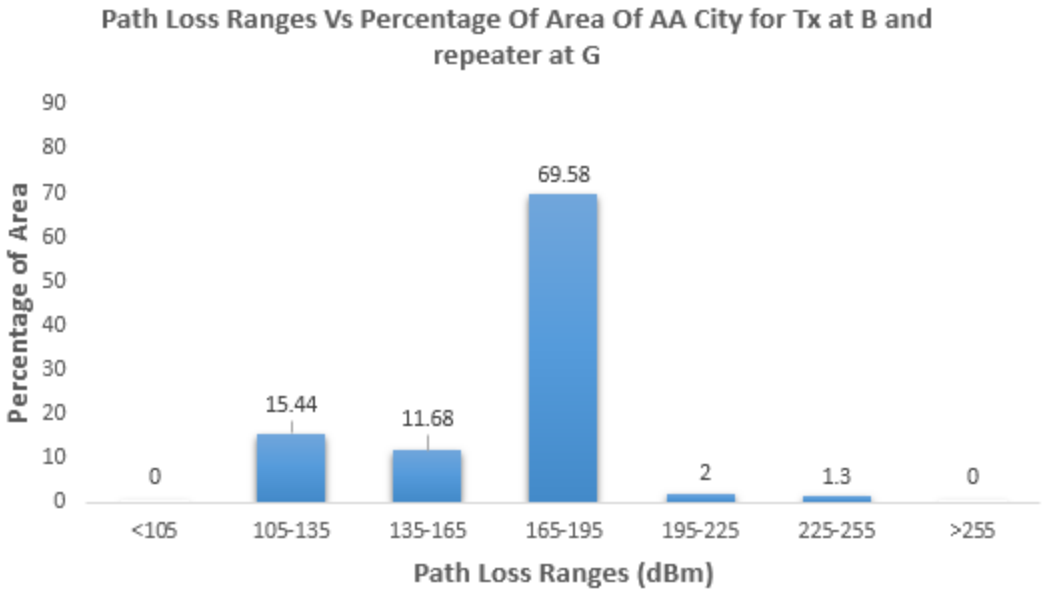
Figure 6.9: Path Loss Map of Addis Ababa city with the transmitter located at position F (around Jommo Mountain); (b) The percentage of the city covered with different path loss ranges.

The above Figure 6.9 represents the transmitter site at position F (around Ethiopian broadcasting Agency) covers 76.83% of the area of Addis Ababa city.

From the above simulation path loss maps and their respective bar graphs that show percentage coverage area of Addis Ababa city, it was seen that a transmitter located at Position B had shown best coverage of 93.67% of the area of the city below the threshold path loss value. So the planning work with a transmitter at Position B was taken as the final result. It can be seen from the path loss map of Position B (Figure 6.5 above) that, a portion of the area with no coverage was shadowed. In such cases, the planning solution is to extend the coverage by using repeaters in the same band. A 30 meter repeater was added shown in Figure 6.10 below. It was found out that the repeater needs to cover 6 km radius on the side of the uncovered area. It was calculated from the cost-231 Hata model and link budget calculation (Equation 6.1) that the output power to cover this radius is 30dBm.



a)



b)

Figure 6.10: Path Loss Map of Addis Ababa city with the transmitter located at position B(around yeka mountain) and repeater G around Hana Mariam; (b) The percentage of the city covered with different path loss ranges.

Chapter Seven

Conclusions and Recommendations

7.1 Conclusions

In general, Analogue broadcasting entails that each broadcaster is allocated its own frequency. This means, the more the broadcasters, the more frequency bands that are used up, leaving no space for other services. Digital TV broadcasting system provides efficient use of spectrum as multiple channels can transmit in a single bandwidth occupied by a single channel of analog television. Where one frequency carries up to 20 channels, thereby freeing more spectrum band for the other services.

This thesis focuses on coverage planning of digital terrestrial television broadcasting as these are the basic parameters system implementation. Two propagation models are used this work, like cost-231 Hata model for system dimensioning and ITU-R P.1546-5 model for detailed planning. During the system dimension a single transmitter with 53 dBm output power and 90m transmitter antenna is enough to cover area of Addis Ababa. Optimum site for the transmiter is selected using ITU-R P 1546-5 around Yeka Mountain.

This thesis work concludes that whole Addis Ababa is covered 96.7% coverage is achieved by adding a repeater with 30 dBm output power and 30 m antenna height around Hana Mariam. There is not adjacent channel interference and power limitation because it uses single frequency network. The uncovered areas are gorgeous areas. It can be concluded the coverage is good, since coverage is described as good if at least 95 % of the sub-area is served for 99 % of the time and as acceptable if at least 70 % of the sub-area is served for 99 % of the time [7].

7.2 Recommendations

In this thesis work, to select the optimum site of transmitter it uses ITU-R P 1546-5. In future works, other propagation models can be compared to determine if better results could be obtained from the other models that were not discussed in this thesis. Measurements need to be done before going to extensive implementation some can going through this.

This thesis work can be done in future with another high performance computer in order to optimize each planning parameter by taking many testing points. 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.

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