



ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL AND COMPUTER
ENGINEERING

PLANING EFFICIENT MICROWAVE LINK
FOR EBC (main studio)

By

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A thesis submitted to the School of Electrical and Computer Engineering in Partial Fulfillment of the requirements for the Degree of Masters of Science in Communication Engineering.

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ABSTRACT

Microwave links play an important role in the broadcasting industry by linking main radio and television studios with remote transmitter stations. With the currently increasing number of locally and internationally broadcasted television and radio stations the need for such links is expected to increase significantly. Furthermore, the expected links are also required to overcome the dynamic nature of the country's main cities. To emphasize on the matter, the country's main broadcasting corporation, i.e., Ethiopian broadcasting corporation (EBC), can be taken as an example. The corporation currently utilizes microwave links for transmission of programs from production studios to transmitter station and also from the temporary outside broadcast (OB) studios to main head office studios. But due to topological nature of Addis Ababa and intensive constructions of new tall buildings microwave links have become one of the many reasons for most live television broadcasting failures.

Overcoming the stated problem on locally existing microwave links requires a careful planning and analysis that are in phase with the dynamics of the cities. This thesis thus provides a solution for improving the quality of microwave links that are currently utilized by Ethiopian Broadcasting Corporation (EBC). To accomplish the task, three frequently utilized microwave link sites, located at Addis Ababa stadium, Janmeda, and Millennium hall, are selected. Afterwards, planning and antenna height selection for repeater stations were performed. Based on the planning ten repeater sites are found to be in line of sight to the temporary stations. Finally, the quality of established link between the repeaters and temporary studios were analyzed using a simulation software namely Radio Mobile. The analysis has shown that, as compared to existing microwave links the proposed solution improved field strength by 61.66% and fading margin by 64.44%. Furthermore, out of selected repeater sites Gomakuteba is found to be the best links for Janmeda & Milinim Hall whereas Legehar for Stadium. In general, the thesis has set preliminary results that are found to be promising.

Keywords: *Microwave link, Radio Mobile software tools, Field strength, Total Propagation loss, fade margin.*

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Acronyms and abbreviations

2D	Two-Dimensional Space
BS	Base Station
DC	Direct Current
DBM	Decibel Mill Watt
DBW	Decibel Watt
DBI	Decibel Isotropic
EBC	Ethiopia Broadcasting Corporation
ECC	Electronic Communication Committee
EIRP	Effective Isotropic Radiation Power
EM field	Electromagnetic Field
EMW	Electromagnetic Wave
FCC	Federal Communication Commission
FEW	Fixed Wireless Access
FM	Fade Margin
FSL	Free Space Loss
GPS	Global Position System
GSM	Global System for Mobile Communication
HPA	Hecopascals
HF	High Frequency
ITU-R	International Telecommunication Union –Radio communication (Recommendation)
IEEE	Institute of Electrical and Electronics Engineering
IRL	Isotropic Receiver Level
IDU	Indoor Unit
LATT	Latitude
LONG	Longitude
LUF	Lowest Usable Frequency
LOS	Line of sight
LMDS	Local Multiple Distribution Service

MOS	Minimum Output Signal
MIS	Minimum Input Signal
MUF	Maximum Usable Frequency
MS	Mobile Station
MW	Microwave
NLOS	Non Line of Sight
ODU	Outdoor Unit
PL	Path Loss
RCS	Radar Cross Section
RF	Radio Frequency
RMD	Removable Memory Device
RX	Receiver
RMP	Radio Mobile Path
RSI	Receiver Signal Indication
RSSI	Receiver Signal Strength Indication
SWR	Standing Wave Ratio
SOM	System Operating Margin
T-R	Transmitter-Receiver
TX	Transmitter
UHF	Ultra High Frequency
VHF	Very High Frequency

CHAPTER ONE

1.1. Introduction

A microwave link is a communications system that uses a beam of the radio wave in the microwave frequency range to transmit information between two fixed locations on the earth. They are crucial to many forms of communication and impact a broad range of industries. Broadcasters use microwave links to send programs from the studio to the transmitter location, which might be miles away. Microwave links carry cellular telephone calls between cell sites. Wireless Internet service providers use microwave links to provide their clients with high-speed Internet access without the need for cable connections. Telephone companies transmit calls between switching centers over microwave links, although fairly recently they have been largely supplanted by fiber-optic cables. Companies and government agencies use them to provide communications networks between nearby facilities within an organization, such as a company with several buildings within a city.

One of the reasons microwave links are so adaptable is that they are broadband. That means they can move large amounts of information at high speeds. Another important quality of microwave links is that they require no equipment or facilities between the two terminal points, so installing a microwave link is often faster and less costly than a cable connection. Finally, they can be used almost anywhere, as long as the distance to be spanned is within the operating range of the equipment and there is clear path (that is, no solid obstacles) between the locations. Microwaves are also able to penetrate rain, fog, and snow, which means bad weather doesn't disrupt transmission.

In a microwave link, the transmitter produces a microwave signal that carries the information to be communicated. That information the input can be anything capable of being sent by electronic means, such as a telephone call, television or radio programs, text, moving or still images, web pages, or a combination of those media.

Microwave, in general, denotes the technology of transmitting information by the use of the radio waves whose wavelengths are conveniently measured in small centimeters. In the context of this thesis, microwave refers to terrestrial point-to-point digital radio communications usually employing highly directional antennas in clear line-of-sight (LOS) and operating in licensed frequency bands from 0.3GHz to 300GHz.

A microwave radio system is a system of radio equipment used for microwave data transmission. A modern microwave radio based on a split-mount mode consists of three basic components: the *indoor unit (IDU)* which performs all digital processing operations containing the baseband, digital modem circuitry and optionally a network processing unit that provides advanced networking capabilities such as routing and load balancing; the *outdoor unit (ODU)* which houses all the radio frequency (RF) modules for converting a carrier signal from the modem to a microwave signal and the *antenna* used to transmit and receive the signal into/from free space, which is typically located at the top of a communication tower, as illustrated in Figure 1-1. Antennas used in microwave links are highly directional, which means they tightly focus the transmitted and received energy mainly into/from one specific direction. To avoid waveguide losses, the antenna is directly attached to the ODU which in turn is connected to the IDU by means of a single coaxial cable, the distance between the single coaxial cable. The distance between the (usually operating in duplex mode³) between two locations that can be several kilometers apart. It should be noted that a single IDU can support multiple ODUs in the same site and thus, multiple microwave links between different locations.

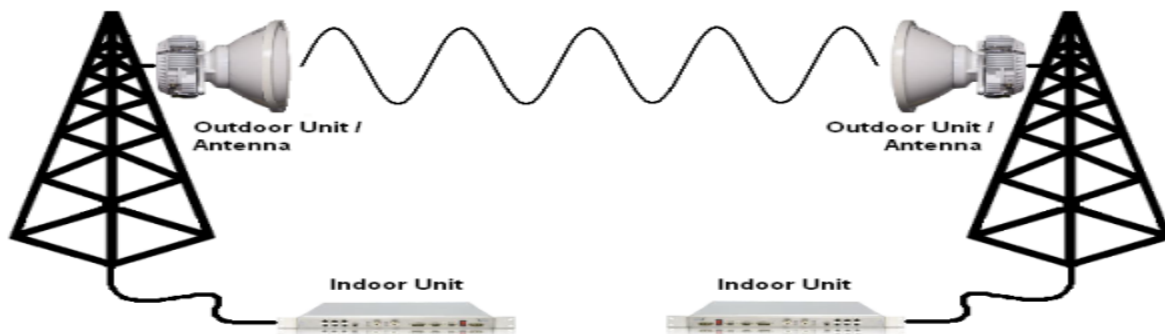


Figure 1-1 A schematic illustration of a microwave link [21].

In a microwave radio system, communication starts with an information source that can be audio, video or data in many forms. The IDU accesses a service signal, prompting baseband processing,

multiplexing, and intermediate frequency modulation. The signal is then sent to the ODU via coaxial cable for RF processing before being finally transmitted. The energy radiated by the RF transmitter is amplified by the transmitting antenna before propagating in the form of radio waves in the directions determined by the design and orientation of the antenna.

Antennas used in microwave links are highly directional, which means they tightly focus the transmitted energy, and receive energy mainly from one specific direction. This contrasts with antennas used in many other communications systems, such as broadcasting. By directing the transmitter's energy where it's needed toward the receiver and by concentrating the received signal, this characteristic of microwave antennas allows communication over long distances using small amounts of power. As a radio wave travels through the atmosphere, it experiences different propagation phenomena, for example, free-space loss, reflection, diffraction, and scattering. Which negatively impact the perceived energy at the receiving antenna? Besides the transmitted signal the electromagnetic fields from the interference and noise sources are also converted to power at the RF receiver likely leading to the imprecise interpretation of the transmitted signal. Finally, the RF receiver processes this power in an effort to recover exactly the source information that was originally transmitted.

1.2 Statement of the Problem

Ethiopian Broadcasting Corporation (EBC) uses microwave link for two purposes. The first microwave link is used to create a link between main studio and the transmitter station (Furi). Second to transmit program signal from temporary studio to main head office studio. The common temporary studio places where an event of public and government festival and the game takes places at Addis Ababa stadium, Janmeda and Millennium hall the program of an event from each place transmitted to the main EBC head office studio is with the help of microwave link. However, with the emergence of new and tall buildings in Addis Ababa, it becomes challenging to find proper Line of sight, The microwave link with poor line of site can result in periodic system outages, resulting in increased system latency, decreased throughput, or worst case a complete failure of the system.

1.3 Motivation of the thesis

Radio link operating at microwave frequencies on line-of-sight paths are fixed, dependable and cost-effective means of providing point-to-point communications. They are heavily employed in carrying large numbers of voice, video, wideband data transmissions, high definition television (TV) channels, and high quality audio among others but the problem is a new and tall buildings are challenge in addition to this topography of Addis Ababa is difficult to get LOS .this problem getting from working experience microwave (MW) link for live program in EBC to get MW sustainable transmission we learn from another big city how to communicate the main studio to temporary studios and searched literature review concerned to this issue. Finally, by considering of Masters Class of communication engineering, we do this thesis in order to solve the problem.

1.4 Objective

1.4.1. General objective

EBC is currently utilizing three temporary studios to cover live events. But the microwave link between the sites and main studio is being blocked by intensive constructions. Thus, this thesis aims at mitigating the mentioned problem and improve link quality between the temporary and the main studio.

1.4.2. Specific Objective

The specific objectives of this thesis are,

- ✓ Improving the line of sight between main and temporary studios.
- ✓ Selection of appropriate repeater stations.
- ✓ Selection of appropriate antenna height for repeater stations.
- ✓ Analysis of Link between repeater stations and temporary studio.
- ✓ Analysis of overall system.
- ✓ Identification of best repeater links.
- ✓ Providing solution for worst case scenario.

1.5. Literature Review

Literature Review carried out to enhance and develop the core idea of this thesis paper from the beginning with the help of former technical research papers, international research journals, articles, different textbooks written and the previous EBC works on MW link.

[1] A.Thakur and S.Kamboj Has predicted path loss and Link budget using Hata and Lee free space propagation models before the real links were established. As it is well known path loss is a reduction in the signal's power, which is a direct result of the distance between the transmitter and the receiver. The free space models utilized in [1] can be seen as the best-case scenario, they underestimate the path loss actually experienced for mobile communication. Thus, they were practically used for predicting point to point, fixed path loss.

[2] On the contrary took into consideration site survey which is the basic mechanisms to take into account the influence of site location on the propagation of electromagnetic waves. In the paper three empirical models namely, COST231-Hata, Okumura-Hata and Egli were utilized which were suitable for path loss prediction of selected areas. By using these propagation models the broadcast signal strength were predicted for the hilly mountains of Nigeria. Finally, physical measurements of UHF signals from Indanre Town of ondo state Nigeria were obtained and compared with the results predicted by the propagation model for the same location.

In [3] Radio propagation affected by location of the site, atmospheric effects, frequency operation and other dynamic factor were discussed. Also characterization of radio channel through key parameters and a mathematical model is important for: Predicting signal coverage, achievable data rates, network planning, Quality of service, and hand over performance studied. Finally, path loss can be determined by measured strength of signal through site specific field measurements.

In [4] general analysis in microwave communication took place theoretically and the actual link was analyzed to check the expected results. In Fresnel zones and free space losses calculations, there was no any significant issue other than slight variations in decimal points, but there were several effects on other parameters such as fade margin, fading probability, path reliability, link

budget, transmit power and receive level due to arithmetic errors in design. Process and test results not satisfying the expected results under real environment and climate conditions.

In [5] the design of wireless communication links between two sites, issues of range, that is, how far the transmitted signal would go given certain transmission parameters, and the throughput of such link, are of great concern to the radio engineer such that several loss factors militating against the strength of the transmitted signal as it travels through the medium to the receiver were given holistic consideration in this work. Major loss *factors* like antenna feeder loss, antenna mismatch loss, propagation path loss, signal polarization loss, multipath propagation loss, obstruction loss and diffraction loss were discussed. Efforts at reducing the Presence and effects of these losses on transmitted signal in a radio link would greatly enhance the efficiency of the transmission system

In [6] propagation link analysis of fixed terrestrial point-to-point microwave LOS/NLOS radio systems for rural environment is studied. The performance analysis in terms of both total received power and link availability of fixed terrestrial microwave LOS/NLOS radio links have been simulated and evaluated. The worst month link availability is investigated for fixed terrestrial microwave LOS/NLOS radio links operating in NATO Band 3+ (1350-2690 MHz) and NATO Band 4 (4400-5000 MHz) frequency bands.

In [7] the large-scale propagation performance of Okumura, Hata, and Lee models has been Compared varying Mobile Station (MS) antenna height, Transmitter-Receiver (T-R) distance and Base Station (BS) antenna height, considering the system to operate at 900 MHz. Through the MATLAB simulation it is turned out that the Okumura model shows the better performance than that of the other large-scale propagation models.

[8] Compares the performance of propagation path loss models which may give different results if they are used in different environment other than in which they were designed. Thus, the paper compares the results of different path loss propagation models with measured field data. For comparative analysis the paper utilized, Stanford University Interim (SUI) Model, Hata model, Okumura's Model, COST231 Extension to Hata Model and ECC-33 model along with the field measured data. The field measurement data is taken in urban (high density region), sub urban (medium density region) and rural (low density region) environments in INDIA at 900 MHz

&1800 MHz frequency with the help of spectrum analyzer. After analyzing the results COST-231 and SUI Model shows the better results in all the three environments particularly in urban and sub urban environments.

In [9] Different models are used to calculate path loss in three types of environment urban, sub-urban and rural areas with the help of the received the received. The Okumura –Hata model used in urban area due to buildings consider. Hata model is suited for large cell mobile system, but not good for personal communication having cells of 1 Km radius. The Longley- Rice model gives accurate result and has applications over very tough terrain.

In [10] survey of the basic mechanisms which influence the propagation of electromagnetic waves at most was made. It also deals with features of empirical models often used in a process of fixed wireless access network planning and implementation. Four empirical models, SUI, COST 231-Hata, Macro and Ericsson, which are most suitable for path loss prediction for such a system, are presented. By using these propagation models the receiving signal levels are predicted for different types of environment for a WiMAX (Worldwide Interoperability for Microwave Access) system installed in the city Osijek, Croatia. Measurement results of receiving WiMAX power at 3.5 GHz are also presented and compared with the results predicted by using the propagation models.

This thesis aims at mitigating the problems associated with the degrading quality of Microwave links between the main studio and temporary studios of Ethiopian Broadcasting Corporation (EBC) located in Addis Ababa. The problem arises due to intensive undergoing constructions around and inside the city. To mitigate the problem the thesis utilizes routing of Microwave links via repeater stations which have better line of site with temporary studios of the corporation. To achieve this objective the thesis performs repeater site survey and analysis of link quality between selected reaper sites, temporary studio and main studio.

1.6 Methodology

Achieving the seated objects requires dividing the tasks into two main parts namely Site planning and Analysis.

Site planning

This phase requires four critical tasks

- ✓ Selecting sites based on topographical maps.
- ✓ Physical site seeing and altitude measurement.
- ✓ Checking Line of sights with targeted studios.
- ✓ Antenna height estimation.

Analysis

- ✓ Selection of performance criteria.
- ✓ Selection of suitable simulation tools.
- ✓ Analysis of Links from repeater to temporary studios.
- ✓ Analysis of overall system.
- ✓ Analysis of improvement.

CHAPTER TWO

2.1. Radio Link Planning

Microwave transmission is a very attractive transmission alternative for applications ranging from the coverage of the rural, sparsely populated areas of developing countries that have ineffective or minimal infrastructures to the well-developed industrial countries that require rapid expansion of their telecommunications networks. Most of the commercially used terrestrial microwave point-to-point (also called *radio-relay*) systems use frequencies from approximately 2 to 60 GHz (and lately up to 90 GHz) with maximum hop lengths of around 200 km (125 mi). According to the IEEE, electromagnetic waves between 30 and 300 GHz is called *millimeter waves (MMW)* instead of *MW* because the wavelengths for these frequencies are about 1 to 10 mm. Millimeter-wave propagation has its own peculiarities, but the spectrum from 30 to 300 GHz is of increasing interest to service providers and systems designers because of the wide bandwidths available for carrying communications at this frequency range. Such wide bandwidths are valuable in supporting applications such as high-speed data transmission and video distribution. Planning for millimeter-wave spectrum use must take into account the propagation characteristics of radio signals at this frequency range. While signals in lower frequency bands can propagate for many miles and penetrate more easily through buildings, millimeter-wave signals can travel only a few miles or less and do not penetrate solid materials very well. However, these characteristics of millimeter-wave propagation are not necessarily disadvantageous. Millimeter waves can permit more densely packed communications links, thus providing very efficient spectrum utilization, and they can increase the security of communication transmissions. The radio frequency propagation mechanisms for microwave and millimeter-wave frequencies include diffraction, refraction, reflection, and scattering.

2.1.1. Planning Brief

Planning brief has been specified that clearly defines what the customer is trying to achieve. The next step is to determine the initial network topology. First, the site location of the customer end sites must be determined; then an initial diagram with the circuit connections and traffic capacity can be worked out. In practice, this will always be an iterative process since the end sites may change depending on the final position of a new building, a power station, or the area coverage

of a GSM repeater. Site availability of planned repeaters is also a major variable. Switch (telephone exchange) sites.

2.1.2. Path profile

The first step in microwave path design is positioning microwave antennas to form a line-of-site connection between two stations. The Curvature of the earth, terrain elevation, buildings, and trees must all be taken into consideration when planning the microwave link. Intrusions into the signal path by terrain, trees, buildings, or other obstacles can degrade the signal quality by causing signal attenuation and reflection or refraction of the signal. A path profile provides information on where interference might occur and aids in selecting an appropriate path and antenna height.

2.1.3. Site Selection

It is very important to check and verify information on site locations. Microwave radio links allow very little inaccuracy of the site coordinates because the clearance of the beam is critical. This will be covered in great detail later in the book. In most cases site coordinates need to be accurate to within a few meters. The modern tendency is to specify site coordinates from Global Positioning System (GPS) readings. While this is a very useful and necessary tool, serious planning errors can be made if the limitations of this terminology are not clearly understood. The GPS is a satellite-based system owned by the Department of Defense in the United States. In many cases, GPS systems are very useful in that qualified surveyors with expensive equipment are not required. However, it must be recognized for microwave radio applications that the more expensive site location methods will be required. These include using GPS systems in differential mode or using surveyed coordinates with survey beacons and a theodolite. Accurate differential carrier phase GPS systems can achieve an accuracy of 1 mm; however, they tend to be very expensive.

Another important consideration is to obtain the coordinates of the actual position of the antenna mounting and not just the position of the overall site. An accurate location of a building, power station or hill top is useless if the actual position of the antenna location is some distance from this reference point. Building new repeater sites on a major transmission route can cost hundreds

of thousands of dollars. Therefore, it is the very important point to realize is that a detailed analysis of a path profile only makes sense if the site location data is accurate [10].

2.1.4. Antenna height

An outdoor wireless network system antenna should be installed at its optimal height. An antenna mounted on a tower has to be up high enough to "see" over the curvature of the Earth and over any intervening obstructions (trees, hills, buildings, and other obstructions.) If an antenna is mounted above the height where it can "see" over the Earth curvature and obstructions then performance begins to degrade. If it's too low then it won't be able to properly 'see' its partner and the connection will suffer. If it's too high then it's going to 'see' out over the horizon to a greater distance and pick up more environmental background noise and interference. The higher the antenna is mounted, the further over the horizon it can "see" and, hence, the more environmental and atmospheric noise and interference it receives. Remember: "Higher" is not "better". There are times when equipment specifications for wireless radios indicate that the combination of power output and antenna type provide coverage for many miles outdoors. Outdoor signal coverage is, however, dependent on more than the equipment installed at either end of a point-to-point link. To create an outdoor point-to-point or point-to-multipoint link requires no obstructions exist between the antennas that would cause degradation of the signal. The biggest obstruction is the Earth itself. Since the Earth is curved, the further apart two radios are the more the curve of the Earth becomes an issue. Outdoor antennas must often be installed on towers to raise them high enough to avoid the natural curvature of the Earth

2.2. Radio Wave Propagation

Electromagnetic waves propagate through environments where they are reflected, scattered, and diffracted by walls, terrain, buildings, and other objects. The ultimate details of this propagation can be obtained by solving Maxwell's equations with boundary conditions that express the physical characteristics of these obstructing objects. This requires the calculation of the Radar Cross Section (RCS) of large and complex structures. Since these calculations are difficult, and many times the necessary parameters are not available, approximations have been developed to characterize signal propagation without resorting to Maxwell's equations.

The most common approximations use ray-tracing techniques. These techniques approximate the propagation representing the wave front as simple particles determining the reflection and refraction effects on the wave front but ignoring the more complex scattering phenomenon predicted by Maxwell's equations. Many propagation environments are not accurately reflected with ray tracing models. In these cases, it is common to develop analytical models based on empirical measurements and it will be discussed below several of these most common empirical models.

2.2.1. Propagation of mechanism

The propagation mechanisms are examined to help the development of propagation prediction models and to enhance the understanding of electromagnetic wave propagation phenomena. Propagation models are more efficient when only the most dominant phenomena are taken into account. Which radio propagation phenomena need to be taken into account and in how much detail does it need to be considered will also differ depending on if it is liked modeling the average signal strength, the fading statistic, the delay spread or any other characteristics.

The mobile radio environment causes some special difficulties to the investigation of propagation phenomena:

- 1) The distances between a TX and an RX range from some meters to several kilometers.
- 2) Man-made structures and natural features have the size ranging from smaller to much larger than a wavelength and affect the propagation of radio waves.
- 3) The description of the environment is usually not at our disposal in very much detail. Two complementary approaches can be identified to deal with these difficulties.
- 4) Experimental investigations (i.e. live measurements) which are closer to the reality but at the expense of weaker control on the adaption to the environment.
- 5) Theoretical investigations which consider the only simplified model of the reality but give an excellent control of the adaptation to the environment.

The main propagation mechanisms are explained below. As smaller wavelengths, the wave propagation becomes similar to the propagation of light rays. A radio ray is assumed to propagate along a straight line bent mainly by refraction, diffraction or scattering.

2.2.2 Reflection

When the electromagnetic waves falling on the object some of the signal power may be reflected back to its origin rather than signal is carried out by all the way is known as Reflection is as shown in figure 2-1 The transmitted radio wave nearly travels in one path to the receiving antenna, which means that there is no LOS between transmitting antenna to the receiving antenna. Thus, the signal received by the antenna is the total of all the signal components transmitted by the antenna meant for transmission. For example, the surface of the Earth, buildings, and walls etc. causes the reflection of signals.

2.2.3 Diffraction

When the Radio waves strike on the surface and change its direction. The Radio path between the transmitter and the receivers obstructed by the surface with sharp irregular edges As the wave bends around the obstacle, even though when LOS does not exist. In practice, the height of the mobile antenna is lower than the base station antenna as there may be high rise buildings or hills in the region.

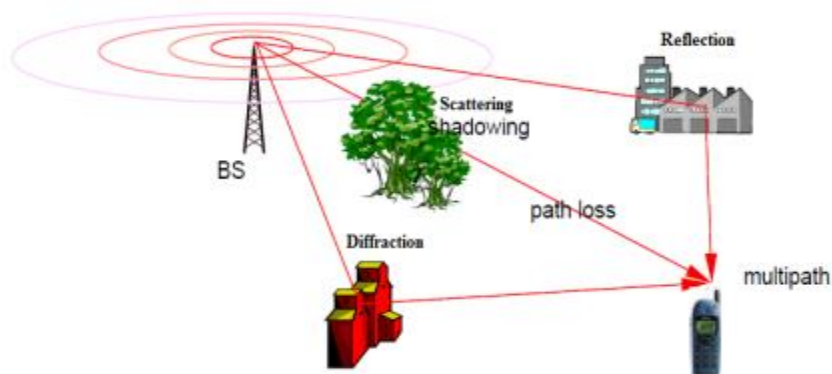


Figure 2-1 Basic propagation mechanism of mobile communication (courtesy – Google.com).

2.2.4 Scattering

Scattering occurs when the medium through which the wave travels consists of objects with dimensions that are smaller compared to the wavelength, or the number of obstacles per unit volume is quite large. This phenomenon occurs when the propagating radio wave meets objects in the transmission medium equal or smaller than its wavelength. This causes the radio wave to be reflected in different directions. As the frequency increases, the wavelength becomes shorter,

and the reflecting objects seem rougher resulting in diffused reflections. Small imperfections in the atmosphere as a result of the inhomogeneous refractive structure, also causes the energy to scatter. This mechanism is called troposcatter and is very useful in communications where high power transmitters and high gain transmitter and receiver antenna can be used to reduce attenuation due to this mechanism, more so in satellite systems.

2.2.5 Radio Wave Propagation Modeling

Propagation models are fundamental tools for designing any fixed broadband wireless communication system. A propagation model basically predicts what will happen to the transmitted signal while in transit to the receiver. In general, the signal is weakened and distorted in particular ways and the receiver must be able to accommodate the changes if the transmitted information is to be successfully delivered to the recipient. The design of the transmitting and receiving equipment and the type of communication service that is being provided will be affected by these signal impairments and distortions. The role of propagation modeling is to predict the system performance with these distortions and to determine whether it will successfully meet its performance goals and service objectives. If the performance is inadequate, the system design can be modified accordingly before the system is built [25].

Propagation and channel modeling is a very pragmatic endeavor. A model is developed so that it adequately provides the information necessary for the system performance prediction task at hand. A model is chosen by a system designer to be appropriate to the design problem being addressed. For example, for the preliminary step of dimensioning a Local Multipoint Distribution Service (LMDS) system at 28 GHz, a simple model that predicts the service radius of a hub is all that is required to estimate the number of hubs needed to cover the intended service area. However, when detailed system design is undertaken, a comprehensive point-to-point model, which can determine whether a path is line-of-sight, is needed. Such models make use of detailed terrain and building databases and the best available methods for predicting the availability of the links with multipath and rain fading conditions.

System designers sometimes make inappropriate propagation model choices. In the early days of cellular system deployment, the Hata–Okumura model was very widely used for

predicting the coverage of cell sites. Unfortunately, this model was developed in relatively flat areas so it did not explicitly take into account the mountains or tall structures that can create low signal levels, a process commonly called *shadowing*. Because the Hata–Okumura model could not predict shadowing, it failed rather badly in predicting system performance in hilly or mountainous areas. The result was poor coverage, impaired system performance, and dissatisfied customers. While much more advanced and sophisticated models are now available, to some extent this type of problem still afflicts modern cellular system design. Choosing and applying the appropriate propagation model is an important aspect of wireless system design.

2.2.6 Classification of propagation model

Anderson has summarized the classification of propagation models in his highly descriptive book [17]. In this section, we briefly review representative examples of this work as a means of creating a context for the propagation models that are used for fixed broadband link design according to Anderson’s classification. The classification outline in the figure below defines channel models in terms of how they work and the information they provide, rather than the bandwidth of the signal that can successfully be used with them. The significance of propagation and channel models in designing and building successful communication systems, a considerable amount of effort has been devoted by the industry to developing such models. In this portion, propagation and channel models will be divided into three basic classifications: Theoretical, empirical and physical, with non-time dispersive and time-dispersive models as the primary subcategories. A time-dispersive model is one designed to provide information about the time delay experienced by a transmitted signal and its multipath replicas in reaching the receiver. Each of the categories in Figure below is briefly described below along with citations of representative published examples of the model. Empirical models are based on observations and measurements alone. These models are mainly used to predict the path loss, but models that predict rain-fade and multipath have also been proposed [26]. The deterministic models make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. Deterministic models often require the complete 3-D map of the propagation environment. An example of a deterministic model is ray tracing model. Stochastic models, on the other hand, model the environment as a series of random variables. These models are least accurate but require the least information about the environment and use much less

processing power to generate predictions. Empirical models can be split into two subcategories namely, time dispersive and non-time dispersive [17].

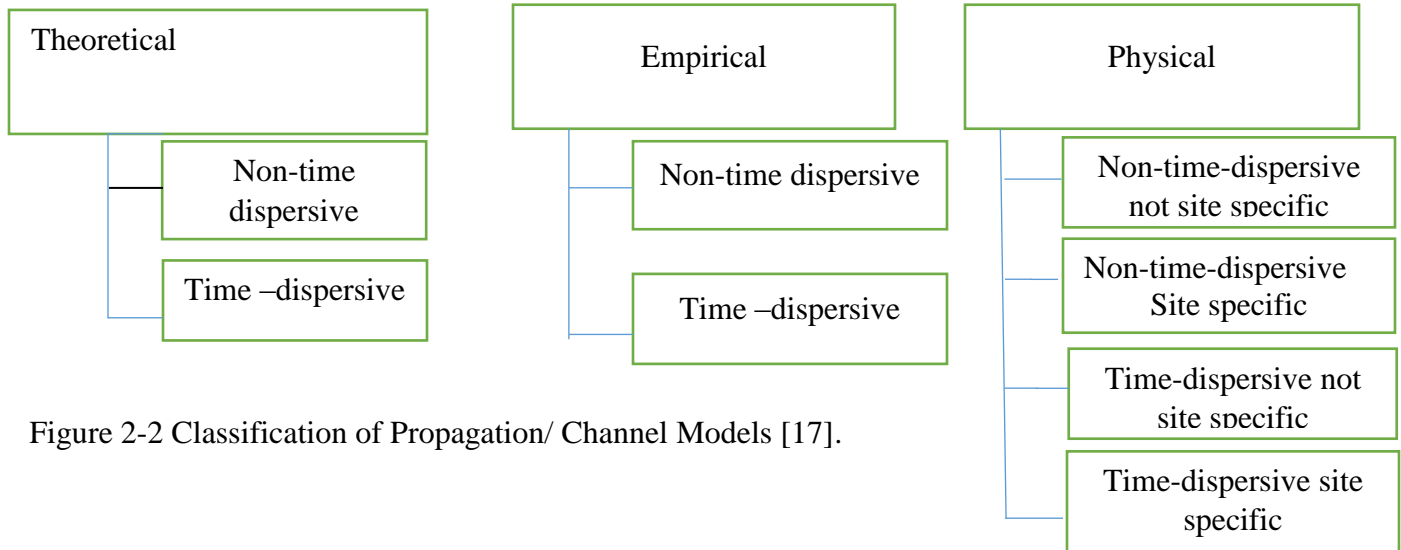


Figure 2-2 Classification of Propagation/ Channel Models [17].

Measurements are typically done in the field to measure path loss, delay spread, or other channel characteristics. Their use for dimensioning non-line-of-sight (NLOS) point-to-multipoint systems is becoming more widespread.

2.2.6.1 Empirical models

Empirical models use what are known as predictors or specify in general statistical modeling theory. Predictors are parameters, which have been found through statistical analysis, to bear a relationship to (are correlated with) the quantity that is to be predicted. The accuracy and usefulness of such empirical models also depend on the environment in which the original data for the model were taken and how universally applicable that environment is. A common problem is trying to use empirical models in areas where the propagation environment is widely different from the environment in which the data were gathered. An example is the Hata model, based on the work of Okumura, in which propagation path loss is defined for urban, suburban, and open environments. These correction factors in Okumura’s work are an effort to mitigate their limitations. In spite of their limitations, empirical models such as the FCC, ITU-R, and Hata models are still widely used because they are simple and allow rapid computer calculation. They also have a certain ‘comfort’ factor in that people using them in certain circumstances over time

have come to know what to expect and make their own localized ‘corrections’ to the predicted values provided by the model.

With the growing interest in fixed broadband systems for business and residential use, empirical propagation models have taken on new importance since they can offer simple predictions for these environments without the need for detailed propagation environment databases as required by site-specific physical models. Their simplicity also limits empirical models to system dimensioning (an approximate count of the cell sites or hubs needed to serve an area). They cannot be used for detailed system planning where specific site information, shadowing effects, and so on must be considered.

Empirical models fundamentally use experimental measurement data to deduce a relationship between the propagation circumstances and expected field strength or time dispersion results. Because they use statistical specifics that have no direct physical relationship to the quantity being predicted, they are inherently non-causal. They are also inherently not site-specific since they do not explicitly take into account the unique features of a given propagation environment along a path from a transmitter to a receiver. The FCC, ITU-R, and Hata models are examples of empirical propagation models among many others. Models developed by the Institute of Electrical and Electronic Engineers (IEEE) 802.16 Working Group, for use in planning fixed broadband systems in the 2 to 11 GHz frequency range are examples of empirical time dispersive models [18].

2.2.6.2 Physical or Deterministic Model

Physical models rely on the basic principles of physics rather than statistical outcomes from experiments to find the EM field at a point. Physical models are causal by design. Depending on whether they consider the particular elements of the propagation environment between a transmitter and receiver, physical models may or may not be site-specific. Also, they may or may not provide time dispersion information. One aspect that affects the capabilities and success of a physical model is the kind of information about the propagation environment it can use and what it does with it. This is an important point about physical propagation modeling. The quality of the model’s predictions is a direct consequence of how the model maps the real propagation environment into the model propagation environment. For a channel model to be a physical, site-

specific model it not only must use the physical laws of EM wave propagation but it must also have a systematic technique for mapping the real propagation environment into the model propagation environment [17].

Deterministic models make use of the laws governing electromagnetic wave propagation in order to determine the received signal power in a particular location [19]. These models rely on the basic principle of physics rather than statistical outcomes from the experiments. Deterministic models are also known as physical channel models; they are either site-specific or not site specific. A physical not specific model uses physical principles of electromagnetic waves propagation to predict signal levels in a generic environment in order to develop a simple relationship between the characteristics of that environment and propagation.

A physical, the not time-dispersive model is one in which the EM field at the receiver is predicted using physical laws governing wave propagation, but no signal time delay information is available from the model. Models in this category include a collection of propagation algorithms to predict signal attenuation over the terrain. Examples of physical models specifically useful for fixed broadband wireless systems are the Bollington, Longley–Rice, TIREM, Free Space+RMD, and the Anderson 2D models [26]. Physical site-specific, time-dispersive models use physical laws along with one-to-one mappings from the real environment to the model environment. These models are basically known as ray tracing, a high-frequency approximation method that tracks the trajectory of EM waves leaving the transmitter as they interact with objects in the propagation environment. Since a ray tracing model tracks ray trajectories, it not only provides time dispersion information but also angle-of-arrival information that is of great interest in assessing the operation of adaptive or ‘smart’ antennas. Perhaps the earliest example of ray-tracing models comes from broadcasting rather than from the mobile radio [17].

2.2.6.3 Theoretical Channel Model

Models in this category are based on some theoretical assumptions about the propagation environment. They do not directly use information about any specific environment, although the assumptions may be based on measurement data or physical laws. Theoretical models are useful for analytical studies of the behavior of communication systems under a wide variety of channel

response circumstances, but because they do not deal with any specific propagation information, they are not suitable for planning communication. Systems to serve a particular area. With this objective, they usually rely on assumptions that lead to mathematically tractable formulations. Theoretical models have relatively little application to fixed broadband wireless systems except as they may be applied to predict rain attenuation [17].

2.2.7 Propagation Path Loss Models

Electromagnetic waves are used for transmitting information between transmitter and receiver. The Strength of signal reduces due to an interaction between electromagnetic waves and environment. Path loss models use set of mathematical equations and algorithms for prediction of path loss values. Such models are categorized into three categories i.e. deterministic (uses physical law leading to propagation of waves), Empirical (based on measurements and observations) and stochastic (uses series of random variables) models. A propagation model describes the average signal propagation and it provides the maximum cell range with respect to the maximum propagation loss. It depends on the following Environments (such as urban, sea, rural, forest, dense) etc., Distance, Frequency, Atmospheric conditions, and Indoor /Outdoor [20, 21].

2.2.7.1 Free-Space Path Loss Model

The free space path loss, FSPL, is used in many areas for predicting radio signal strengths that may be expected in a radio system. Although the free space path loss does not hold for most terrestrial situations because of other effects from the ground, objects in the path and the like, there are still very many situations in which it can be used. It is also useful as the basis for understanding many real-life radio propagation situations. Accordingly, the free space path loss, FSPL, is an essential basic parameter for many RF calculations. It can often be used as a first approximation for many short-range calculations. Alternatively, it can be used as a first approximation for a number of areas where there are few obstructions. As such it is a valuable tool for many people dealing with radio communications systems.

Free space path loss basic, the free space path loss, also known as FSPL is the loss in signal strength that occurs when an electromagnetic wave travels over a line of sight path in free space.

In these circumstances, there are no obstacles that might cause the signal to be reflected refracted, or that might cause additional attenuation.

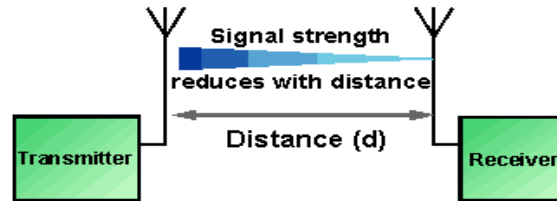


Figure 2-3 free space path loss [22].

The free space path loss calculations only look at the loss of the path itself and do not contain any factors relating to the transmitter power, antenna gains or the receiver sensitivity levels. These factors are normally addressed when calculating a link budget and these will also be used within radio and wireless survey tools and software.

To understand the reasons for the free space path loss, it is possible to imagine a signal spreading out from a transmitter. It will move away from the source spreading out in the form of a sphere. As it does so, the surface area of the sphere increases. As this will follow the law of the conservation of energy, as the surface area of the sphere increases, so the intensity of the signal must decrease.

As a result of this, it is found that the signal decreases in a way that is inversely proportional to the square of the distance from the source of the radio signal in free space.

$$\text{Signal} = \frac{1}{\text{distance}^2} \tag{2.1}$$

The free space path loss formula or free space path loss equation is quite simple to use. Not only is the path loss proportional to the square of the distance between the transmitter and receiver, but the signal level is also proportional to the square of the frequency.

$$\text{FSP} = \left(\frac{4\pi df}{c}\right)^2 \tag{2.2}$$

Where FSP is the free space path loss, d is the distance of the receiver from the transmitter (meters) and f is the signal frequency (Hertz) and c is the speed of light in a vacuum (meters per second). Although the free space loss equation to indicate that the loss is frequency dependent. The attenuation provided by the distance traveled in space is not dependent upon the frequency. The reason for the frequency dependence is that the equation contains two effects:

1. The first results from the spreading out of the energy as the sphere over which the energy is spread increases in the area. This is described by the inverse square law.
2. The second effect results from the antenna aperture change. This affects the way in which an antenna can pick up signals and this term is frequency dependent.

As one constituent of the path loss equation is frequency dependent, this means that there is a frequency dependency within the complete equation. Most RF comparisons and measurements are performed in decibels. This gives an easy and consistent method to compare the signal levels present at various points. Accordingly, it is very convenient to express the free space path loss formula, FSPL, in terms of decibels. It is easy to take the basic free space path loss equation and manipulate into a form that can be expressed in a logarithmic format.

$$\text{FSP}=32.45+20\log_{10}(d)+20\log_{10}(f) \quad (2.3)$$

Where f is frequency in MHz is the distance between transmitter and receiver in the kilometer. This model can be used in a clear line-of-sight microwave link and also in satellite communication.

2.2.7.2 Cost 231 walfisch-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. It distinguishes different terrain with different proposed parameters. The equation of the proposed model is expressed in [31].

For line-of-sight (LOS) condition

$$\text{PLOS}=42.6+26\log_{10}(d)+20\log_{10}(f) \quad (2.4)$$

And for non-line-of-sight (NLOS) condition

$$\text{PNLOS}=\text{LFSL}+\text{Lrst}+\text{Lmsd} \quad \text{for urban and suburban} \quad (2.5)$$

$$\text{PNLOS}=\text{LFSL} \quad \text{if } \text{Lrst}+\text{Lmsd}>0 \quad (2.6)$$

Where LFSL is free space loss, Lrst is roof top to street diffraction and Lmsd is multi-screen diffraction loss.

Free space loss:

$$\text{LFSL}=32.45+20\log_{10}(d)+20\log_{10}(f) \quad (2.7)$$

Roof top to street diffraction: H mobile

$$\begin{aligned} \text{Lrst} &= -16.9 - 10 \log_{10}(w) + 10 \log_{10}(f) + 20 \log_{10}(\text{Hmobile}) + \text{Lori} & (2.8) \\ &= 0 \quad \text{for } h_{\text{roof}} > h_{\text{mobile}} \end{aligned}$$

$$\begin{aligned} \text{Lori} &= -10 + 0.345\Phi \quad \text{for } 0 < \Phi < 35 \\ &= 2.5 + 0.075(\Phi - 55) \quad \text{for } 35 < \Phi < 55 & (2.9) \\ &= 4 - 0.114(\Phi - 55) \quad \text{for } 55 < \Phi < 90 \end{aligned}$$

Note that

$$\Delta h_{\text{mobile}} = h_{\text{roof}} - h_{\text{mobile}} \quad (2.10)$$

$$\Delta h_{\text{base}} = h_{\text{base}} - h_{\text{roof}} \quad (2.11)$$

The multi-screen diffraction loss is:

$$\begin{aligned} \text{Lmsd} &= \text{Lbsh} + \text{Ka} + \text{kd} \log_{10}(d) + \text{Kf} \log_{10}(f) - 9 \log_{10}(f) - 9 \log_{10}(B) \quad \text{for } \text{Lmsd} > 0 & (2.12) \\ &= 0 \quad \text{for } \text{Lmsd} < 0 \end{aligned}$$

Where

$$\text{Lbsh} = -18 \log_{10}(1 + \Delta h_{\text{base}}) \quad \text{for } h_{\text{base}} > h_{\text{roof}} \quad (2.13)$$

$$= 0 \quad \text{for } h_{\text{base}} < h_{\text{roof}}$$

$$\text{Ka} = 54 \quad \text{for } h_{\text{base}} > h_{\text{roof}} \quad (2.14)$$

$$= 54 - 0.8 \Delta h_{\text{base}} \quad \text{for } d > 0.5 \text{ Km and } h_{\text{base}} < h_{\text{roof}}$$

$$\text{Kd} = 18 \quad \text{for } h_{\text{base}} > h_{\text{roof}} \quad (2.15)$$

$$= 18 - 15 \left(\frac{h_{\text{base}}}{h_{\text{roof}}} \right) \quad \text{for } h_{\text{base}} < h_{\text{roof}}$$

$$\text{Kf} = -4 + 0.7 \left(\left(\frac{f}{925} \right) - 1 \right) \quad (2.16)$$

For suburban or medium size cities with moderate tree density.

$$\text{Kf} = -4 + 1.5 \left(\left(\frac{f}{925} \right) - 1 \right) \quad \text{for metropolitan or urban area}$$

Where d is the distance between transmitter and receiver antenna in meter, f is frequency in GHz, B is building to building distance in meter, w is street width in meter, and Φ is street orientation angle w.r.t. direct radio path in degree.

2.2.7.3 ECC Model

The ECC-33 path loss model, which is developed by Electronic Communication Committee (ECC), is extrapolated from original measurements by Okumura and modified its assumptions so that it more closely represents a fixed wireless access (FWA) system [27]. In this model path loss is given by [26].

$$\text{PL} = \text{Afs} + \text{Abm} - \text{Gt} - \text{Gr} \quad (2.17)$$

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

$$A_{fs}=92.4+20\log_{10}(d)+20\log_{10}(f) \tag{2.18}$$

$$A_{bm}=20.41+9.83\log_{10}(d)+7.894\log_{10}(f)+9.56(\log_{10}(f))^2 \tag{2.19}$$

$$G_t=\log_{10}(hb/200)[13.98+5.8(\log_{10}(d))^2] \tag{2.20}$$

For medium city environments (27)

$$G_r=[42.57+13.7\log_{10}(f)][\log_{10}(hm)]-0.585 \tag{2.21}$$

ECC-33 model is one of the most extensively used empirical models, which is based on Okumura model. This model is widely used for urban environments especially in large and medium-size cities. This model was formed in Tokyo city having crowded and tallest buildings.

2.2.7.4 Ericsson Model

To predict path loss, network planning engineers used software provided by Ericsson Company based on a model called Ericsson model. This model also stands on the modified Hata-Okumura model to allow room for changing in parameters according to the propagation environments [13].

Path loss according to this model is given by [26]

$$PL=a_0+a_1\log_{10}(d)+a_2\log_{10}(h)+a_3\log_{10}(hb)\log_{10}(d)-3.2(\log_{10}(11.75hr))^2+g(f) \tag{2.22}$$

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

$$g(f)=44.49\log_{10}(f)-4.78(\log_{10}(f))^2 \tag{2.23}$$

Where, f is the frequency in GHz, hb is transmitter antenna height and hr is receiver antenna height in meter. The default values of these parameters (a_0 , a_1 , a_2 and a_3)

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

Table 2-1 Values of parameter for Ericsson model [25].

The values of parameters a_0 and a_1 in suburban and rural areas are based on the Least Square (LS) method [26].

2.2.7.5 Long Rice Model

In January 1, 1967, the American National Bureau of Standards published Technical Note 101, [10] on propagation treatise that is being referred to as the “Longley-Rice Model”. The Longley-

Rice Model considers atmospheric absorption including atmospheric absorption by water vapor and oxygen, loss due to sky-noise temperature and attenuation caused by rain and clouds. It considers terrain roughness, ground reflections, knife-edge, and loss due to isolated obstacles, diffraction, forward scatter and long-term power fading in its pre-defined signal level representations. It is usually used for calculating coverage areas and interference for broadcasting stations. The model predicts long-term median transmission loss. The model was designed for frequencies between 20 MHz to 40 GHz. The Longley-Rice Model requires the input of certain general parameters so as to set-up the program for propagation calculations. These parameters include: Frequency; Effective Radiated Power; Antenna Direction; Heights; Polarization; Refractivity; Permittivity; Conductivity; Variability and Climate [32].

	Relative permittivity	Conductivity (Siemens per meter)
Average ground	15	0.005
Poor ground	4	0.001
Good ground	25	0.020
Fresh water	81	0.010
Sea water	81	5.00

Table 2-2 Longley Rice Parameters [32].

CHAPTER THREE

3.1. Link Budget

The Link budget is the accounting of all gains and losses from the transmitter (TX) through the medium (free space) to the receiver (RX) in a wireless communication system. Link budget considers the parameters that decide the signal strength reaching the receiver. The factors such as antenna gain levels, radio TX power levels, and receiver sensitivity must be determined to analyze, and estimate the link budget. The following parameters are considered to perform the basic link budget:

- ✓ Transmitter power.
- ✓ Antenna gains (related to TX and RX).
- ✓ Antenna feed losses (related to TX and RX).
- ✓ Antenna type and sizes.
- ✓ Path losses several secondary factors which are directly or indirectly responsible for link budget.
- ✓ Receiver sensitivity (this is not part of the actual link budget, but this threshold is necessary to decide the received signal capability).
- ✓ Required range.
- ✓ Available bandwidth.

The definition of different terminologies with regard to the different power parameters that can be measured or described at different points of transmission along the radio path is critical for understanding the power budget and what can be measured at what point along the link. Some of the power parameters are defined below.

A) Effective isotropic radiated power (EIRP) this refers to the algebraic sum of the transmit power output, transmit antenna gain and the transmission losses pertaining to the different connection elements at the transmit antenna. it is given by [34,36]

$$\text{EIRP}(\text{dbw}) = P_{\text{tx}} + G_{\text{tx}} - L_{\text{tx}} \quad (3.1)$$

Where P_{tx} is the transmit power.

G_{tx} is the transmit antenna gain.

L_{tx} is the total sum of the losses at the transmit antenna.

B) Isotropic receive level (IRL) this refers to the power that impacts on the receiver. This would specifically be the power measured at the isotropic receiver base. It is the algebraic sum of the free-space loss and other absorption losses. It is given by [35, 36]:

$$\text{IRL}(\text{dbw}) = \text{EIRP} + \text{FSL} - \text{La} \quad (3.2)$$

Where La is the absorption loss.

FSL is the free space loss.

The Link budget is prepared that accounts for the transmitter effective isotropically radiated power (EIRP) and all of the losses in the link prior to the receiver [47]. Depending upon the application, the designer may also have to compute the noise floor at the receiver to determine the signal level required for signal detection. The link budget is computed in decibels (dB) so that all of the factors become terms to be added or subtracted. Very often the power levels are expressed in dBm rather than dBW due to the power levels involved. It is important that consistency of units be maintained throughout a link budget analysis.

3.1.1 Path Loss

A fundamental concept in planning any type of radio communications link is the concept of Path Loss. Path Loss describes the amount of signal loss (attenuation) between a receiver and a transmitter. It is possible to compute the path loss in a theoretically ideal situation, where transmitter and receiver are in empty space, with no surfaces anywhere nearby causing reflections, and with no objects or materials in between them. This is generally called the Free Space Path Loss. Estimating the path loss within a given real-world terrain/geography is a hard problem, and there are no easy solutions. It is impacted, among other things, by

- ✓ The height of the transmitter and receiver antennas.
- ✓ Whether there is line-of-sight (LOS) or non-line-of-sight (NLOS).
- ✓ The geography/terrain in terms of hills, mountains, etc.
- ✓ Any type of construction, and if so, the type of materials used in that construction, the height of the buildings, their distance, etc.
- ✓ The frequency (band) used. Lower frequencies generally expose better NLOS characteristics than higher frequencies.

The above factors determine on the one hand side the actual attenuation of the radio wave between transmitter and receiver. On the other hand, they also determine how many reflections there are on this path, causing so-called Multipath Fading of the signal.

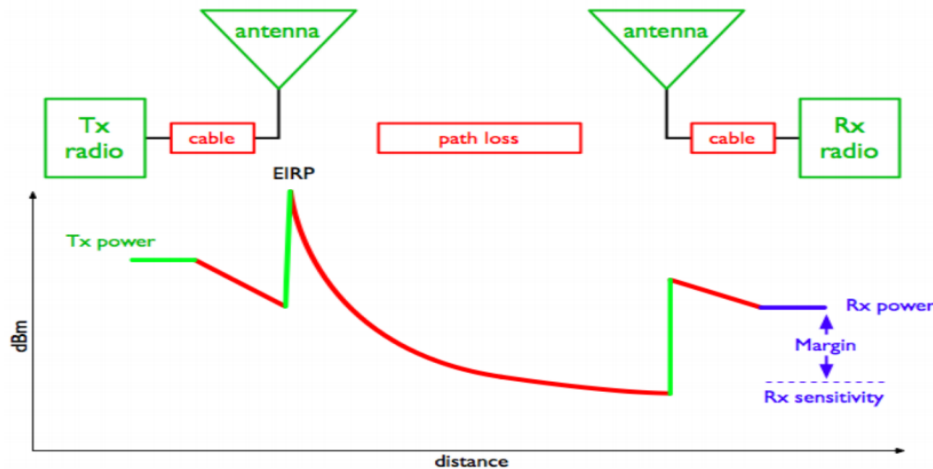


Figure 3-1 path losses [36].

Filters used in the transmission equipment control spectral spreading but in turn create additional insertion losses since some modulation schemes are less efficient due to transmit carrier components. Sometimes, the gain of the antenna is reduced and its noise level increases if there is a random covering it. The problem is even escalated further if the random is wet or dirty. Therefore, it is of paramount importance that the waveguides are firmly fixed and the proper choice of coaxial cables for the particular frequency of operation be made. In most point-to-point radio links, directional antennas are normally used so as to increase the amount of energy directed at the receiver. This could in effect lead to increase in transmit range or a *reduction in transmit power close to the link*. *Poor alignment of directional antennas leads to pointing losses*. Also depending on the orientation of the transmitter and the receiver polarization vectors and the axial ratio, varying degrees of polarization losses will occur. Transfer of power is usually affected by polarization vector mismatches. At high frequencies, rain, water vapor as well as oxygen absorption losses are very significant attenuation components. In the most basic form, the path loss can be computed from the following expression [35, 36,37].

$$PL = FSL + F_m + L_{misc} \tag{3.3}$$

Where PL is the path loss.

F_m is budgeted fade margin.

L_{misc} is miscellaneous losses (fade margin, body loss, polarization mismatch, other loss) (db).

3.1.2 Receiver Sensitivity

Sensitivity in a receiver is normally taken as the minimum input signal (S_{min}) required producing a specified output signal having a specified signal-to-noise (S/N) ratio and is defined as the minimum signal-to-noise ratio times the mean noise power, see equation (3.4). For a signal impinging on the antenna (system level) sensitivity is known as minimum operational sensitivity (MOS), see equation (3.5). Since MOS includes antenna gain, it may be expressed in dBi (dB referenced to a linear isotropic antenna). When specifying the sensitivity of receivers intended to intercept and process pulse signals, the minimum pulse width at which the specified sensitivity applies must also be stated.

$S_{min} = (S/N)_{min} K T_o B (NF)$ receiver sensitivity ("black box" performance parameter) (3.4)

$MOS = (S/N)_{min} K T_o B (NF) / G$ system sensitivity i.e. the receiver is connected to an antenna (transmission line loss included with antenna gain). (3.5)

Where S/N_{min} = Minimum signal-to-noise ratio needed to process (vice just detect) a signal.

NF = Noise figure/factor.

K = Boltzmann's Constant = 1.38×10^{-23} Joule/°K.

T_o = Absolute temperature of the receiver input (°Kelvin) = 290°K.

B is Receiver Bandwidth (Hz).

G is Antenna/system gain.

We have a lower MOS if temperature, bandwidth, NF, or S/N_{min} decreases, or if antenna gain increases. For radar, missile, and EMW receivers, sensitivity is usually stated in dBm. For communications and commercial broadcasting receivers, sensitivity is usually stated in microvolts or dB μ v.

3.1.3 Receiver Signal Level

Receive signal level is the actually received signal level (usually measured in negative dBm) presented to the antenna port of a radio receiver from a remote transmitter. It is the algebraic sum of the receiver gain and the receiver line losses. It is also referred to as the nominal receive power. It is given by [38, 39, and 14]:

$$RSL(\text{db}) = IRL + G_{rx} - L_{rx} \quad (3.6)$$

Where G_{rx} is the receiver gain.

L_{rx} is receiver loss.

Therefore the RSI can be directly computed from individual gains and losses and transmit power from [31].

$$RSL(\text{dbw}) = P_{tx} + G_{tx} + G_{rx} + FSL - (L_g + L_R + L_w + L_{tx} + L_{rx}) \quad (3.7)$$

Where L_g is the gaseous absorption loss.

L_R is loss induced by rain.

L_w is the loss arising from antenna wetness or dirtiness. All in all, this is calculated depending on the information on the information available and the environmental conditions.

3.1.4 Fade Margin

Fade margin is the difference between the unfaded Receiver signal level and the Receiver sensitivity Threshold. Each link must have sufficient Fade margin to protect against path fading that weakens the radio signal. Fade margin is the insurance against unexpected system outages. Fade margin directly related to link availability, which is the percentage of time that the link is functional. The percentage of time that the link is available to increase as the fade margin increase. A link will experience fewer system outages with a greater fade margin. A link with little or no fade margin may experience periodic outages due to path fading phenomena. The link margin is obtained by comparing the expected received signal strength to the receiver sensitivity or threshold. The link margin is a measure of how much margin there is in the communications link between the operating point and the point where the link can no longer be closed. The link margin can be found using

$$\text{Link margin} = EIRP - L_{path} + G_{rx} - THR_x \quad (3.8)$$

Where $EIRP$ is the effective isotropic radiated power in dbw or dbm.

L_{path} is the total path loss, including miscellaneous losses, reflections and fade margins in db.

G_{rx} is the receive gain in db.

THR_x is the receiver threshold or minimum received signal level that will provide reliable operation (such as the desired bit error rate performance) in dBW or dbm.

The available link margin depends upon many factors, including the type of modulation used, the transmitted power, the net antenna gain, any waveguide or cable loss between transmitter and antenna, random loss, and most significantly the path loss. The modulation affects the link margin by changing the required E_b/N_0^* or SNR. The antenna gains, transmission losses, and transmitted power all directly affect the link budget.

3.1.5 System Operating Margin

System operating margin (SOM) is the difference (measured in dB) between the nominal signal level received at one end of a radio link and the signal level required by that radio to assure that a packet of data is decoded without error (see Figure 3-2). In other words, SOM is the difference between the signal received and the radio's specified receiver's sensitivity. SOM is also referred to as link margin or fade margin.

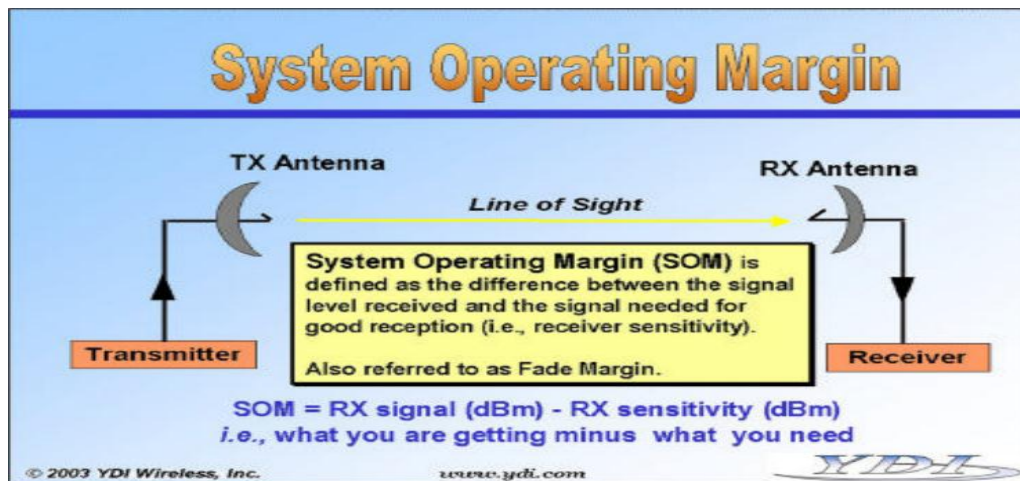


Figure 3-2 system operating margin [40].

3.2 Fundamental Parameter of MW Link

3.2.1 Line of Sight

Microwave radio systems are regarded as the line of sight when the waves transmitted between the two stations do not meet any obstacle most of the time. It is very important to find out a visible path between sites before establishing those links. Now a day, LOS and other parameters are designed in special RF virtual instruments. Moreover only seeing a visible path does not

always Confirm that LOS will give a sufficient level of the signal, it should satisfy another parameter such as the terrain for wave propagation.

3.2.2 Non LOS Propagation

There are several means of electromagnetic wave propagation beyond LOS propagation. The mechanisms of non-LOS propagation vary considerably, based on the operating frequency. At VHF and UHF frequencies, indirect propagation is often used. Examples of indirect propagation are cell phones, pagers, and some military communications. An LOS may or may not exist for these systems. In the absence of an LOS path, diffraction, refraction, and/or multipath reflections are the dominant propagation modes. Diffraction is the phenomenon of electromagnetic waves bending at the edge of a blockage, resulting in the shadow of the blockage being partially filled-in. Refraction is the bending of electromagnetic waves due to inhomogeneity in the medium. Multipath is the effect of reflections from multiple objects in the field of view, which can result in many different copies of the wave arriving at the receiver.

3.2.3 Fresnel Zone

Radio frequency waves travel along a straight line. When they get away from the transmitting antenna, they spread out the farther. Fresnel zone is the area that the microwave signal spreads out or cylindrical ellipse drawn between transmitter and receiver. The size of the ellipse is determined by the frequency of operation and the distance between the two sites. When there is an obstacle in the Fresnel zone, part of the microwave radio signal will be diffracted away from the straight-line path. The practical effect is that on a microwave radio link, is reduce the amount of energy that reaching the receive antenna [46].

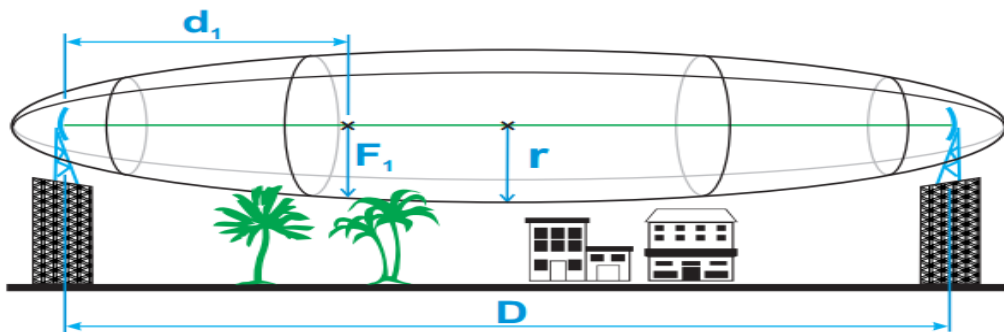


Figure 3-3 Fresnel zone [36].

The general equation for calculating the first Fresnel zone radius at any point P in between the endpoints of the link is the following:

$$F1=17.32\sqrt{\frac{d1(D-d1)}{fD}} \quad (3.9)$$

Where F1 is Radius of first Fresnel zone, m.

d1 distance from one point to radius point, Km.

D distance between antennas, Km.

f is frequency, GHz.

Fresnel zones are used by propagation theory to calculate reflections and diffraction loss between a transmitter and receiver. Fresnel zones are numbered and are called 'F1', 'F2', and 'F3' etc. There is an infinite number of Fresnel zones, however, only the first 3 have any real effect on radio propagation. In Radio Mobile software tools Fresnel zones over a radio path can be analyzed in 'Radio Link' and 'RMpath'.

When a radio signal travels between transmitter and receiver, it can travel in several ways. It can go directly between transmitter and receiver (main signal). The Signal can reflect off the ground and then carry on to the distant receiver (reflected signal). It can go left or right and be reflected back by a hill (another reflected signal). When a signal is reflected two things happen:

- ✓ The phase of the signal reverses and the signal changes in phase by 180°.
- ✓ Since the signal is being reflected and not going in a direct line, it travels slightly further to the reflection point and then on to the receiver. Therefore, the signal is shifted further in phase, by the difference in path length.

They are both on the same frequency. It receives both main and reflected signals. It also receives any other signals within its designed frequency range.

When an antenna receives the main signal and a reflected signal, the two signals will combine and add together at the antenna. If they are 360° shifted (in phase), there is no issue. However, if the signals are 180° apart (opposite phase), they will cancel and the receiver will receive nothing. Fresnel zone Radius and Earth clearance: The diameter of the Fresnel Zone (half the diameter is the radius) of the elliptical cylinder can be calculated. The important component of Fresnel Zone

Radius is the clearance between the Fresnel zone cylinder and the surface of the earth. As shown in Figure 5-6 the Fresnel zone radius and Fresnel zone earth clearance are shown.

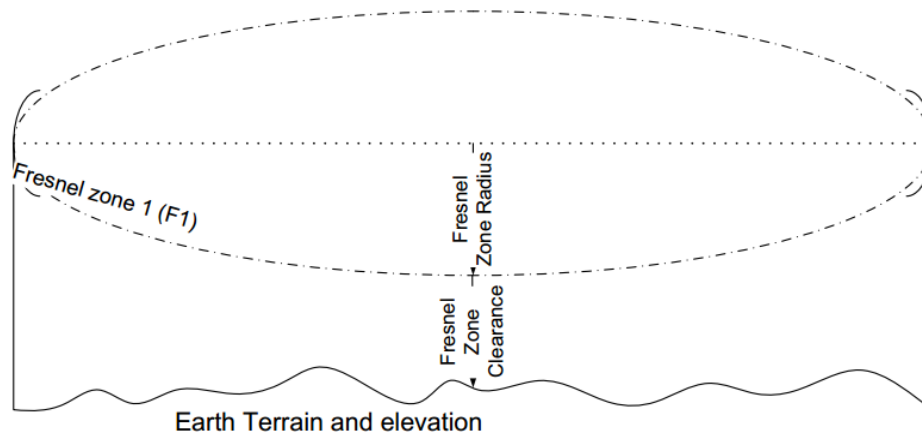


Figure 3-4 Fresnel Zone Radius and Earth Clearance [42].

If the ratio of:

Fresnel zone earth clearance / Fresnel zone radius

Is greater than 60%, the radio path is considered “clear, the line of sight” and incurs no diffraction loss.

3.3. Microwave Antenna

There are several shapes of antenna available for transmitting microwaves. Microwave telecommunication systems almost always use the parabolic type, and sometimes the horn type. These antennas are highly directional. The microwave energy is focused into a very narrow beam by the transmitting antenna and aimed at the receiving antenna, which concentrates the received power by a mechanism analogous to the telescope. Figure 6.1 shows how the microwave energy is transmitted by a parabolic antenna, by placing the microwave guide opening at the focus of the parabola. For the simplest style of antenna feed, the waveguide opens in the form of an enlarging taper, which is designed to match the impedance of the waveguide to that of free space. This system is analogous to the searchlight or flashlight beam at optical frequencies. Both light and microwaves are electromagnetic waves, so they have similar qualities. Because we can see light (or light allows us to see), it is often helpful to use the analogous optical mechanism for the purpose of shedding some light on the subject of

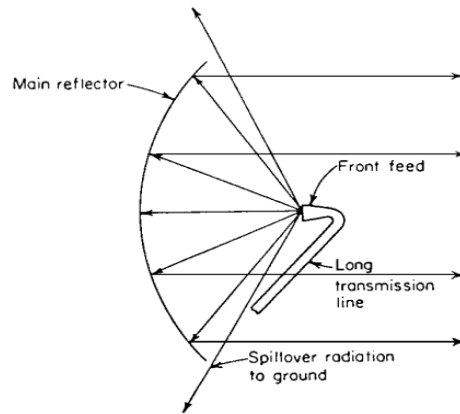


Figure 3-5 Front-feed parabolic antenna [43].

Microwaves Parabolic antennas are available in sizes ranging from about 0.5 to 36 m in diameter [48].

3.3.1 Parameters of Antenna

There are various considerable vital parameters that influence an antenna's performance and it can be synchronization during the designing procedure [48].

Following are the main considerable parameters for antenna:

1. Input Impedance
2. Power flux density
3. Gain
4. Radiation pattern and angular beam width
5. Directivity
6. Polarization
7. Polarization loss factor
8. Pointing loss

3.3.1.1 Input impedance

Input impedance is the most important parameter that's related to the antenna and its transmission line. It is used to determine the transferring power from the antenna to transmission line and vice versa. Between antenna and transmission line the Impedance match is expressed by the term Standing wave ration (SWR) or reflection coefficient and is expressed in decibels [50].

3.3.1.2 Power flux density

The Concept of power flux density is easier to understand by considering a theoretical source which radiates the same power, watts, in all directions. In practice, this isotropic radiator does not exist but let suppose that is located at the center of a sphere whose radiometers. Power flux density is defined as the power radiated by the source outward per unit surface, given in Watts/m² as follow.

$$F = \frac{P_t}{4\pi r^2} \quad (3.10)$$

3.1.1.3 Gain

The most important characteristic of an antenna is its gain. This is a measure of an antenna's ability to transmit waves in a specific direction instead of all directions. It is a measure of directionality. An antenna radiating energy equally in all directions is called an omnidirectional, or isotropic, antenna. For a point-to-point system, as in microwave communication systems, it is desirable to have a high degree of directionality. In other words, the isotropic antenna is not efficient because energy is wasted. The gain of an antenna describes the extent to which an amount of isotropically radiated energy can be directed into a beam, the narrower the beam, the more highly directional the antenna and therefore the higher the gain. Mathematically,

$$\text{Gain (G)} = 10 \log_{10} \left(\frac{4\pi A_e}{\lambda^2} \right) \quad (3.11)$$

Where A is effective area of the antenna aperture (m^2).

e is efficiency.

λ is wavelength (m).

An isotropic antenna, by definition, has a gain of 1 (or 0 dB). For a parabolic antenna, the efficiency is not 100 percent, because some power is lost by “spillover” at the edges of the antenna when it is illuminated by the waveguide fixed at the focus. Also, the antenna dish is not fabricated in a perfectly parabolic shape. The waveguide feed at the focus causes some reduction of the transmitted or received power because it is a partial blockage to the microwaves. Commercially available parabolic antennas have efficiencies in the region of 50 to 70 percent. For an efficiency of approximately 60 percent, Eq. (3.10) can be rewritten

$$G = 20 \log_{10} (8.1 D f) \quad (3.12)$$

Where D is antenna aperture (diameter) (m).

f is frequency (GHz).

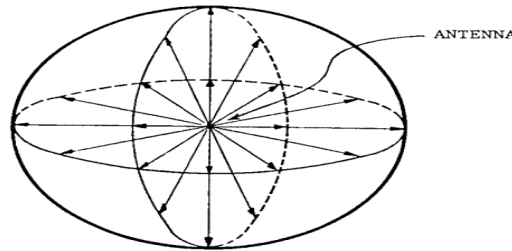


Figure 3-6 Radiation pattern isotropic antenna [35].

3.3.1.4 Radiation pattern and angular beam width

3.3.1.4.1 Radiation pattern:

Variations of gain depending on direction are represented in the radiation pattern. Two ways to depict are common, in polar or Cartesian coordinate form. The maximum radiation corresponds to the main lobe, and side lobes should be as less as possible. In other words, the radiation pattern is equal to the gain normalized respect to the maximum value G_{max} and is expressed as a function of azimuth Θ and elevation Ψ angles.

$$g(\Theta, \Psi) = \frac{G(\Theta, \Psi)}{G_{max}} \tag{3.13}$$

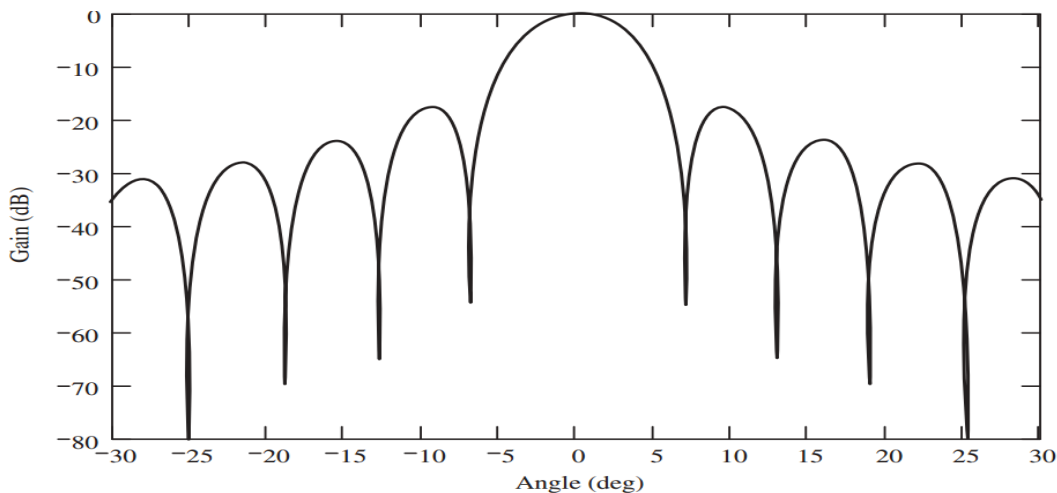


Figure 3-7 typical antenna radiation pattern (normalized gain) in one dimension [35].

The beam width of the antenna is defined as the angle between two directions where the gain falls a certain value respect to the maximum; a fall of the half is denoted as 3 dB beam width.

Another often-quoted specification of directional antennas is the front-to-back ratio. This is the ratio of the antenna gain at 0 and 180 degrees azimuth and provides an indication of how well the antenna will reject interfering signals that arrive from the rear of the antenna. The front-to-back ratio is a very important parameter when planning frequency reuse and interference reduction.

The antenna pattern of an aperture antenna is a function of the illumination taper across the aperture. The relationship between the spatial energy distribution across the aperture and the gain pattern versus angle is an inverse Fourier transform [45]. Thus a uniformly illuminated aperture will produce the narrowest main beam and highest possible gain at the expense of producing side lobes that are only 13dB below the peak. By tapering the illumination using a window function, the gain is slightly reduced (taper loss) and the main lobe is broadened, while the side lobes are reduced in amplitude. Illumination taper functions such as a raised cosine are often used to produce antennas with acceptable side lobes. Whenever an illumination taper is used, the resulting antenna efficiency (and therefore gain) is reduced.

3.3.1.4.2 Angular beam width:

The beam width is another important characteristic of antennas, and for parabolic antennas the beam width is

$$\varphi = \frac{21.3}{fD} \quad (3.14)$$

Where φ is beam width measured at the half-maximum power points (3-dB down points).

f is frequency (GHz).

D is antenna diameter (m).

Figure 6-6 shows the antenna beam width plotted against the parabolic antenna dish diameter for several frequencies. Note that the beam width for a 3-m antenna is very narrow: less than 2° in the 4 to 6 GHz range. If larger antennas are used, the beam width is further reduced. Interference from external sources and adjacent antennas is minimized by using narrow beam antennas. Although large-diameter antennas provide desirably high gain, the decrease in beam width can cause problems. The two antennas in each hop must be aligned very precisely; the narrower the beam width, the higher the alignment precision required. A very small movement in either

antenna will cause degradation of the received signal level. This problem can be serious, particularly when large antennas are used on high towers in very windy regions.

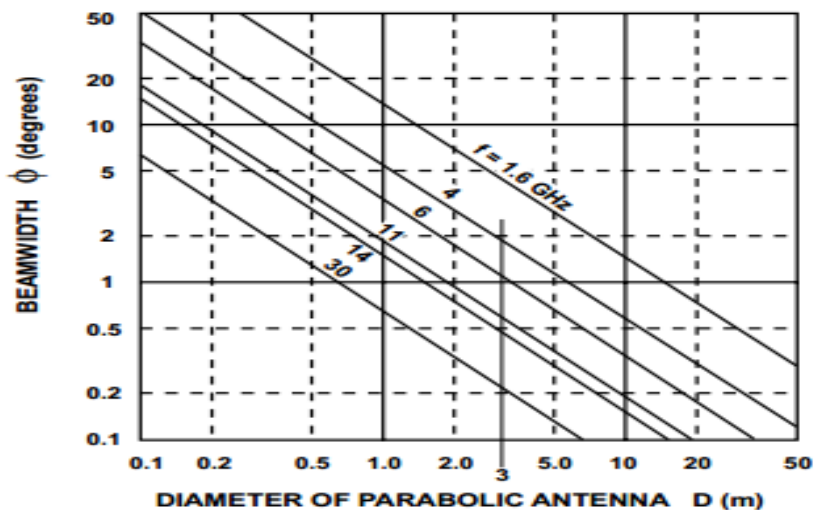


Figure 3-8 Graph of parabolic antenna gain against beam width [44].

3.3.1.5 Directivity

Antenna Directivity means that maximum antenna gain compared with its gain that is averaged in all direction. Directivity go antenna always independent of its radiation efficiency [45].

3.3.1.6 Polarization

Polarization is defined as the orientation of the plane that contains the electric field component of the radiated waveform. In many cases, the polarization of an antenna can be determined by inspection. For instance, a vertical whip antenna generates and receives vertical polarization. Similarly, if the antenna element is horizontal, the wave polarization will be horizontal. Vertical and horizontal polarizations are both considered linear polarizations. Another type of polarization is circular or elliptical polarization. Circular polarization is similar to linear polarization, except that the polarization vector rotates either clockwise or counterclockwise, producing right-hand circular or left-hand circular polarization. Circular polarization is a special case of elliptical polarization, where the vertical and horizontal components of the polarization vector are of equal magnitude. In general, aperture antennas can support vertical, horizontal, or elliptical polarization, depending upon the type of feed that is used.

3.3.1.7 Polarization Loss Factor

Ideally, the receiving antenna is oriented according to the polarization of the received wave, nevertheless, along with the path, the radio wave is affected by atmospheric conditions that change its polarization. Expressing polarization loss as a factor, PLF, it is a term that indicates the portion of the power actually picked up by the receiver antenna. This concept is defined as

$$P_r = \text{PLF} \cdot P_i \quad (3.15)$$

Where P_r is the incident power.

P_i is the power coupled into the receiving antenna. An alternative form to calculate PLF in terms of axial ratio is given in [22]

$$\text{PLF} = \frac{(1 + AR_w^2)(1 + AR_r^2) + 4 AR_w AR_r + (1 - AR_w^2)(1 - AR_r^2) + \cos 2(\tau_w - \tau_r)}{2(1 + AR_w^2)(1 + AR_r^2)} \quad (3.16)$$

Where AR_w and AR_r correspond to the axial ratio of the incident wave polarization vector and receive antenna polarization vector respectively, in the same way, τ corresponds to the angle between the wave polarization and the receive antenna polarization and conversely. Observing the equation one can see that for AR equal to 1 and even if τ is unknown, PLF is founded to be 1. That is the case of circular polarization whose axial relation is equal to unity. In a communication system with circular polarization in one end and linear polarization in the other one, PLF is assumed as 3 dB regardless of the orientation of the linearly polarized wave. This value is for ideal circularized antenna or wave when it is not ideal PLF value can be above or below 3dB according to orientation and the axial ratio. PLF is also calculated as the square of the cosine of the angle between the unit vectors of the incident wave and antenna.

3.3.1.8 Pointing Loss

Pointing losses are the result of the misalignment of angles of transmission and reception due to a not lined-up bore sights between Earth station and satellite antennas, such that the received signal is outside the peak of the antenna beam at the reception. Next figure shows it graphically where angle in the transmitter is named Θ_R and Θ_T is used for the angle in the receiver. The Figure below represents the satellite link at 90° of elevation angle nonetheless Θ_R and Θ_T changes depending on time and orbit [47].

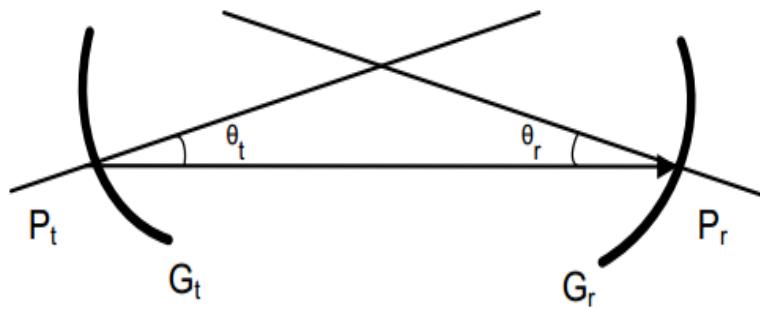


Figure 3-9 Misalignment between receiver and transmitter antennas [47].

Losses can be obtained as a function of the mentioned angles, as follow [47].

$$L_T = 12 \left(\frac{\Theta_T}{\Theta_{3db}} \right) \quad (3.17)$$

$$L_R = 12 \left(\frac{\Theta_R}{\Theta_{3db}} \right) \quad (3.18)$$

Θ_{3db} is the angle where gain falls down half respect its maximum value. The main causes of misalignment on NUTS link are due to inaccuracy on Earth tracking system and ADCS of the satellite.

CHAPTER FOUR

4. Analysis of Results and Discussion

The findings of this thesis are presented in this chapter. In general, the findings are categorized into two main parts,

- ✓ Repeater site survey.
- ✓ Link strength measurements.

4.1. Site Survey

Selection of repeater stations was conducted with the following key points in mind.

- ✓ Distance between antenna pairs.
- ✓ Terrain overview.
- ✓ Possible obstruction on the link path.
- ✓ Availability of existing infrastructures.
- ✓ And minimized antenna height.

To extract the needed information three basic steps were followed in the survey. The first survey required the utilization of topographical maps, such as Google earth, to conduct preliminary selection. Following the preliminary selection physical altitude measurement were taken on selected sites. The physical altitude measurement was necessary since topographical maps might be prone to errors. Finally, clearance for line of sight was checked using binoculars. After taking the stated steps ten existing sites were selected for reasons shown in Table 4-1.

One point to note here is that the selection of sights by itself will not ensure link quality. Ensuring link quality, furthermore, requires selection of appropriate tower height that is in line with the topology of sites. Selection of antenna heights, on the other hand, requires meeting with the rules and regulations of respective authorities and also maximum building height within the city, i.e., Addis Ababa. By contacting the respective authority, i.e., ministry of urban development, it is found that the maximum building height in Addis Ababa is 230m above the ground. Thus, for this thesis Antenna height for each selected site is set to 250m above the ground.

N0.	Site name	Lat/long(DMS)	Reason to select the site
1	Entoto	9°2'17.9"N/38°47'38.9"E	A.A tourism project have planned and height altitude
2	Addisugebeya	9°3'31.9"N/38°44'17.6"E	Altitude and architectural view of the city
3	Hana mariam	8°55'40.7"N/38°44'30.4"E	Altitude
4	Old bus station (leghare)	9°0'41.3"N/ 38°45'3.6"E	Architectural view of the city
5	Yeshidebeli	9°1'8"N/ 38°41'48.2"E	Architectural view of the city and altitude
6	Yeka park	9°2'19.95"N/38°52'7.03"E	Have been planned for transmitter station EBC
7	MW(gomakoteba)	9°1'5"N/ 38°44'50.5"E	Transmitter station on EBC
8	Jemo	8°56'46.3"N/38°43'55.3"E	Altitude
9	Abonepiterose	9°2'8.1"N/38°44'59.7"E	Architectural view of the city and previse radio studio
10	Karakori	8°58'9.4"E/38°41'31.6"N	Fana radio transmitter station/ altitude

Table 4-1 ten repeater sites.

To observe the appropriateness of the selected antenna height worst case scenario is searched and is found to be the link associated with Stadium and Hana Mariam. To overcome this problem the thesis utilized a relay system as discussed in section 4.3.

4.2 Link Analysis and Simulation Studies

While analyzing link quality the thesis took three key performance parameters into account. i.e.

- ✓ Free space loss.
- ✓ Diffraction loss due to obstruction(s) of the path terrain profile.
- ✓ Attenuation due to atmospheric/topography.

A. Total Path Loss, fade margin and field strength associated with repeater stations and temporary studios

One of the key contributors to a weak signal link are path loss and fading. Thus, fading margin and the path loss from the three selected Addis Ababa stations, i.e., Janmeda, Stadium and Milinium hall, to the ten repeater stations were simulated using Radio Mobile. The results are summarized as in Table 4-2.

To have a better understanding of the table two separate examples for total propagation loss and fade margin can be taken as an example. In regard to the total path loss the link between Janmeda and Goma Kuteba can be taken as an example. While calculating the loss, Radio Mobile takes the losses associated with free space, obstruction, static, urban and forest. These losses accounted for 118.4 dB. Furthermore, as demonstration individual losses are plotted on

google earth and are depicted in Figure 4-1. Moreover, the fading margin indicates the difference between the receiver threshold and required statistical threshold, which is associated with the location, situation and time probability of network parameters. These margins are further depicted in Figure 4-2 for the link associated with Janmeda and Goma kuteba, showing 0.5µv for receiver sensitivity and -78db for statistical threshold.

RX	TX Stadium			TX janmeda			TX Milliniume hall		
	E-field (dbµv/m)	Total propagation loss(db)	margin(db)	E-field (dbµv/m)	Total propagation loss(db)	margin(db)	E-field (dbµv/m)	Total propagation loss(db)	margin(db)
Intoto	67.8	117.3	36.10	69	116	37.25	69	115.7	37.4
Addisugebe	67.5	117.6	35.8	61.5	123.7	29.77	35.6	149.5	3.9
Hana mareyame	31.4	153.8	-0.36	55.3	129.8	23.62	59.9	125.2	28.21
Legehare	83.7	101.4	51.98	65.7	119.2	33.95	65.5	119.6	33.79
Yeshidebeli	64.1	121.6	32.36	60.6	124.6	28.86	59	126.2	27.23
Yekaparke	64.6	120.5	32.58	65.6	119.5	33.89	67.3	117.9	35.56
Jemo	35	150.2	3.32	57.6	127.6	28.85	60.7	124.4	28.98
Gomakoteba	78.9	107.1	44.22	66.7	118.4	34.99	64.2	121	32.41
Abonepitrose	75.9	115.3	42.62	71.8	113.4	40.66	58.9	126.3	27.16
Kara kori	58.3	126.3	26.57	56.1	129.1	24.34	57.6	127.5	25.9

Table 4-2 Total path loss, fading margin and field strength associated with selected repeater sites.

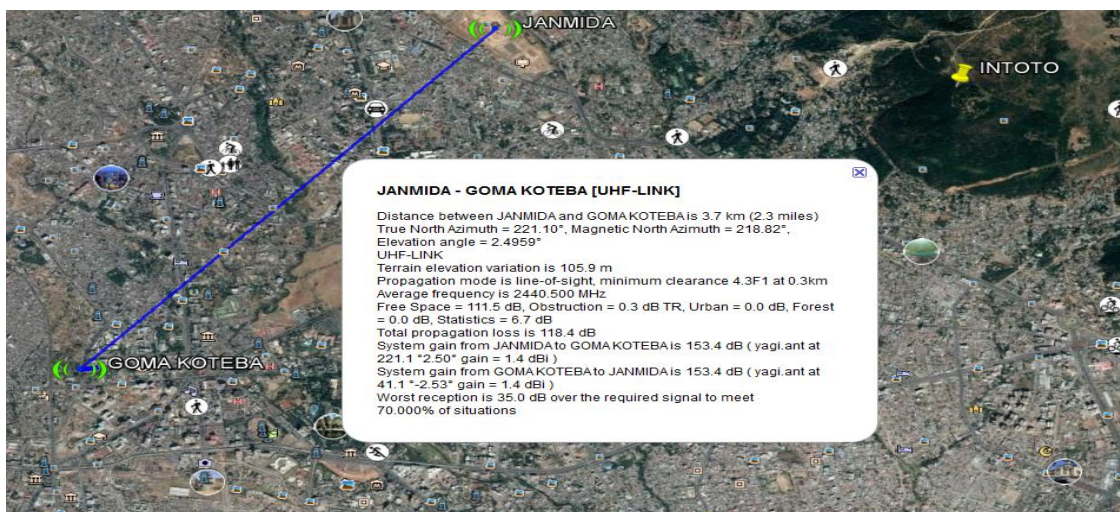


Figure 4-1 exporting RM software results to Google earth (JANMIDA -GOMAKOTEBA).

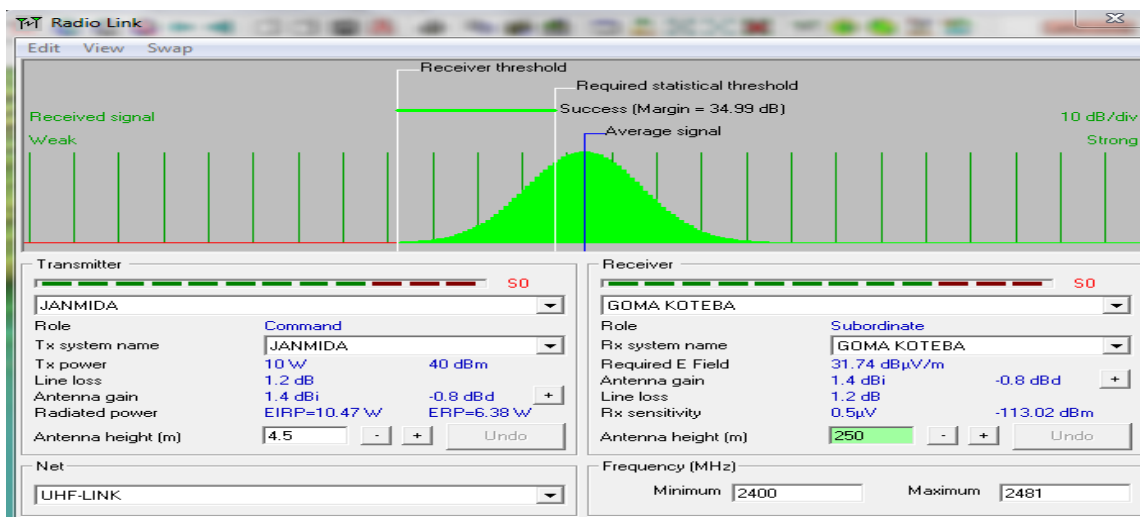


Figure 4-2 the probability that is applicable to the analyses radio link from Janmida to Gomakoteba.

B. Total Path Loss, fade margin and field strength associated with repeater stations and Main Studio

As discussed in previous chapter EBC have temporary studios in Addis Ababa for the purpose of live program transmission; they are commonly utilized for public events such as governmental festivals, and events taking place at Addis Ababa stadium, Janmida and millennium hall. Ensuring the quality of transmission from these temporary sites requires a strong link between the repeater stations and EBC main studio. This is because the links from temporary studios to EBC is currently being challenged by dynamic nature of Addis Ababa. Thus, Table 4-3 summarizes the performance parameters associated with the link between EBC main studio and ten selected repeater stations.

TX	RX EBC		
	E-field (dbμv/m)	Total propagation loss(db)	margin(db)
Intoto	70.1	115.1	38.35
Addisugebeya	57.2	127.9	25.48
Hana mariyame	58.8	126.4	27.07
Legehare	78.9	106.3	47.13
Yeshidebeli	26.2	159	-5.54
Yekaparke	66.6	118.6	34.84
Jemo	60.3	124.9	28.55
Gomakoteba	82.3	102.9	50.42
Abonepitrose	71.8	113.3	39.82
Kara kori	60.5	124.6	28.77

Table 4-3 RMS tools results from TX ten repeater site to EBC (main studio).

4.3 Worst Case Scenario (Link obstruction from Stadium to Hanna Mariam)

Line-of-sight (LOS) is a preferred propagation mechanism in every radio network. Some systems strictly require clear LOS, while others can function without it. The topography of Addis Ababa is very difficult to guarantee point to point (LOS) communication. In this thesis LOS obstruction was observed for selected 250m antenna height for the Stadium to Hanna Mariam Link as shown in Figure 4-3. The figure depicts where the obstacle is at and at what point from the transmitter side have obstacle happen and the distance between the obstacle and transmitter.

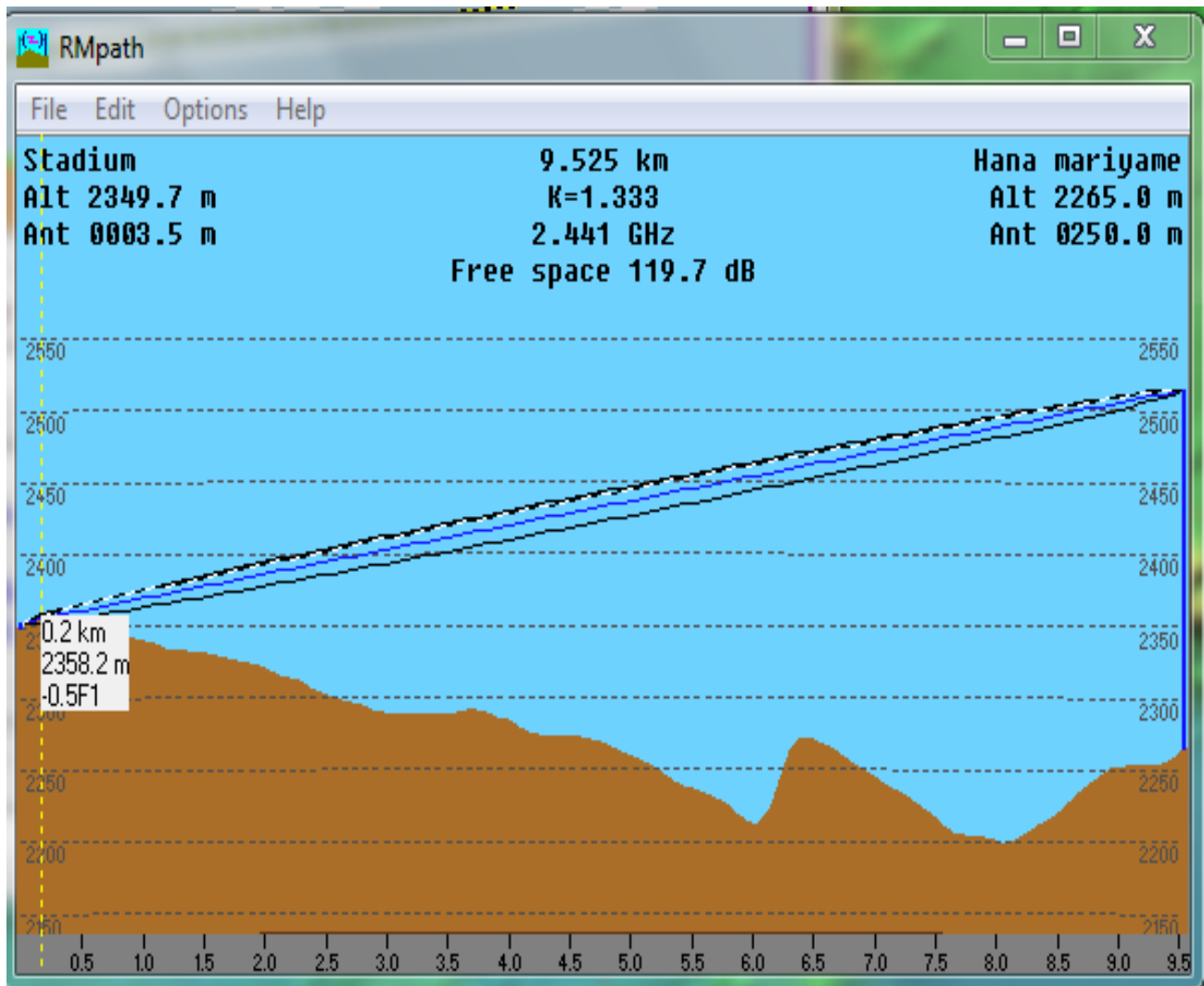


Figure 4-3 RM path TX worst case (stadium) to RX Hana Mariam.

Furthermore, the impact of the obstruction on the fading margin can be seen in Figure 4-4. As the figure shows the statistical threshold is greater than the received resulting a fade margin threshold of -0.36dB. Thus, the link is destined for a failure.

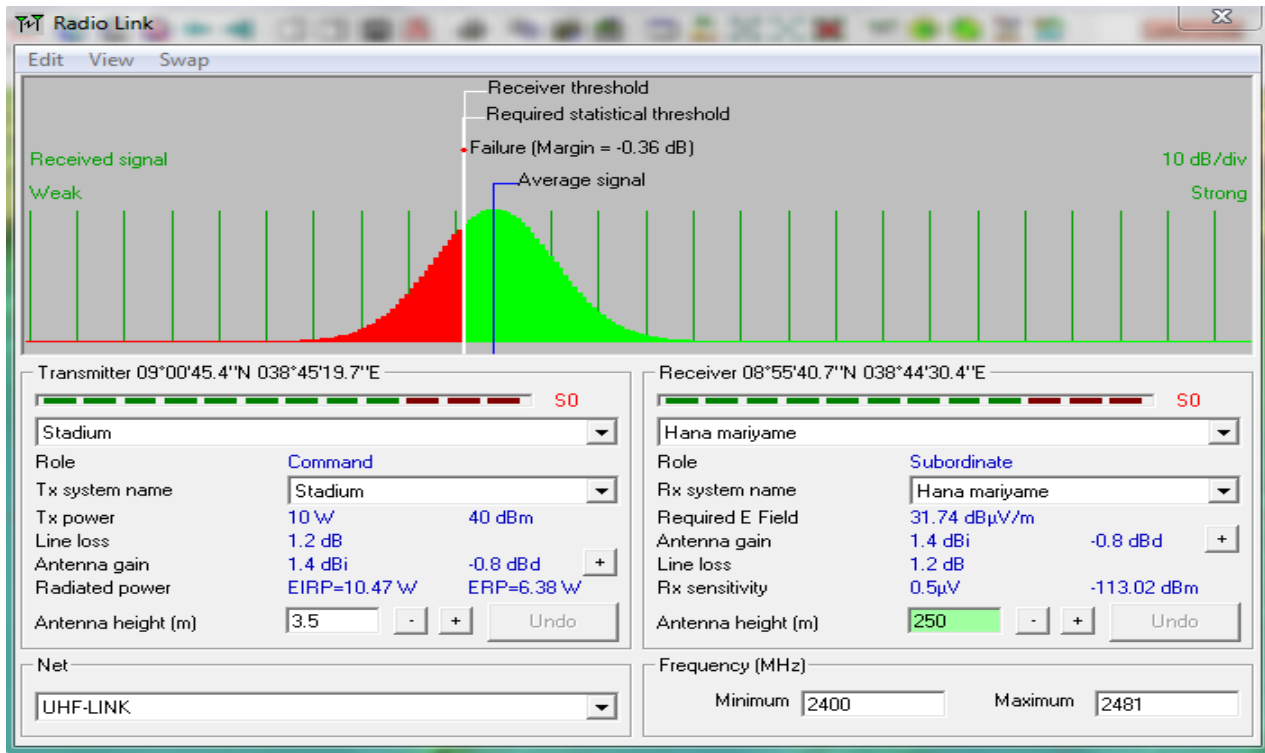


Figure 4-4 link distribution from Tx worst case (stadium) to RX Hana mariame.

To overcome this problem the thesis utilized relay stations (hop method). The method utilizes a relay that is in LOS with the repeater station, in this case Goma kuteba, to avoid the obstruction. By utilizing this method, the thesis was able to achieve an improvement on the fade margin ranging to 25.86 dB as shown in Figure 4-5.

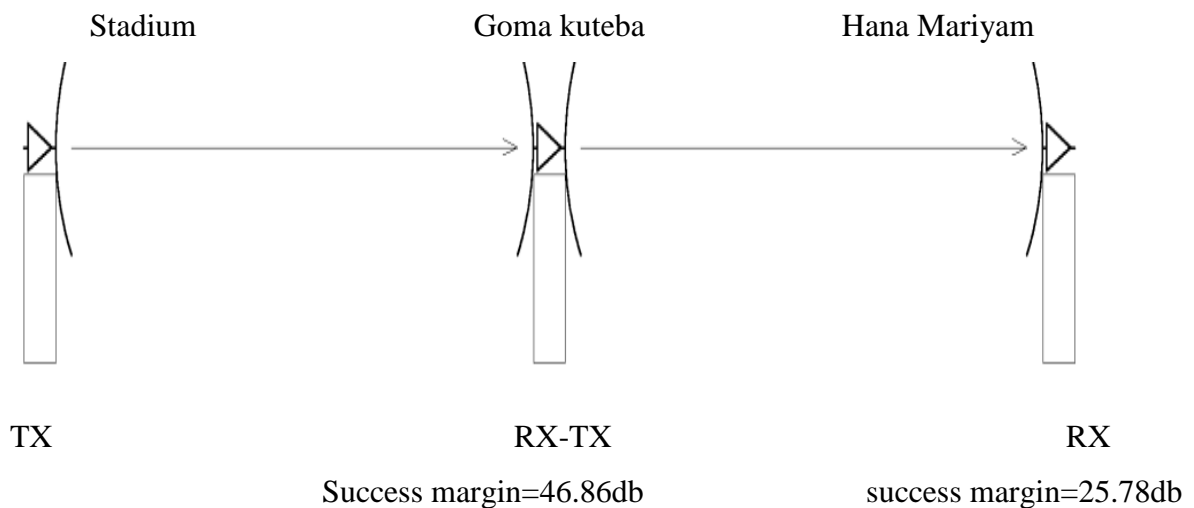


Figure 4-5 using relay system communicate two point.

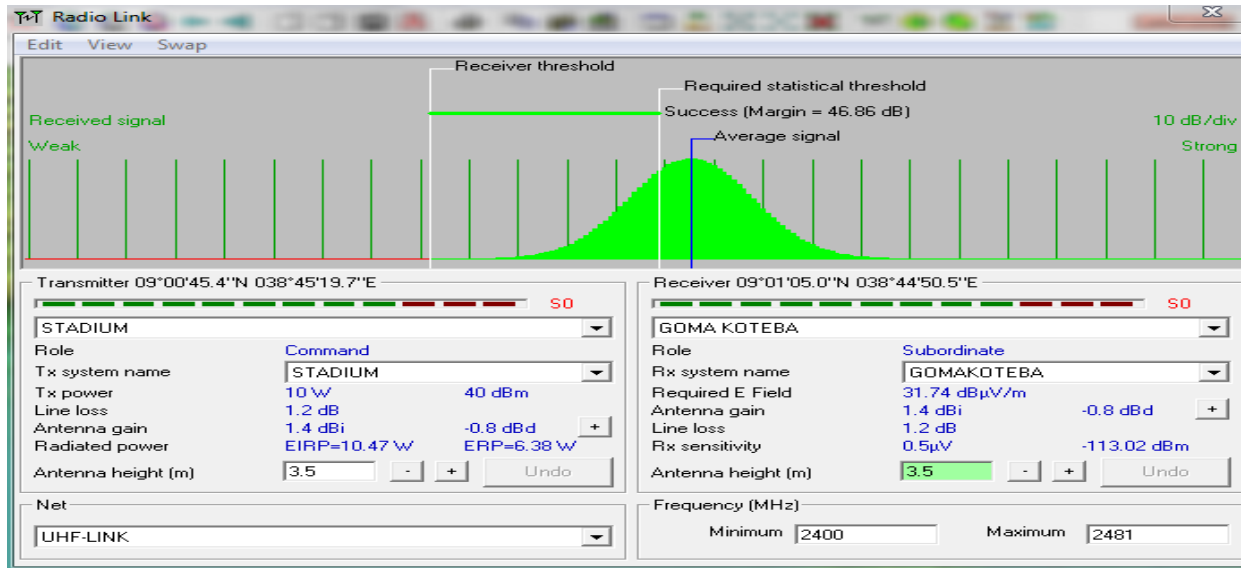


Figure 4-6 distribution of the link b/n Stadium to Goma koteba.

4.4 Full System Simulation Results

The previous section presented the results associated with temporary studios and selected repeater stations. In this section the full system simulation results, i.e., links from temporary studio to repeater stations and finally repeater station to EBC, are presented. Tables 4-4 to 4-6 presents the full link performance via the three selected temporary studios and ten repeater stations.

Name of site	Total system results from stadium-ten repeater station-EBC			
	E-field (dbμv/m)	Total propagation loss(db)	Success margin(db)	Rank
Intoto	137.9	232.4	74.45	4
Addisugebeya	124.7	245.5	61.2	6
Hana mariyame	90.2	280.2	27.07	10
Leghare	162.6	207.7	99.11	1
Yeshidebeli	90.3	280.9	32.36	9
Yekaparke	131.2	239.1	67.42	5
Jemo	95.3	274.9	31.87	8
Gomakoteba	161.2	210	96.73	2
Abonepitrose	147.7	228.6	84.04	3
Kara kori	118.8	250.9	55.34	7

Table 4-4 overall system results transmitted from stadium to ten repeater sites and ten sites to EBC.

Name of site	Total system results from Janmeda-ten repeater station-EBC			
	E-field (db μ v/m)	Total propagation loss(db)	Success margin(db)	Rank
Intoto	139.1	231.3	75.58	4
Addisugebeya	118.7	251.6	55.25	6
Hana mariyame	112.1	256.2	50.69	9
Leghare	144.6	225.5	81.08	2
Yeshidebeli	86.8	283.6	28.86	10
Yekaparke	132.2	238.1	68.73	5
Jemo	117.9	252.5	54.4	7
Gomakoteba	149	221.3	85.41	1
Abonepitrose	143	226.7	80.48	3
Kara kori	116.6	253.7	53.11	8

Table 4-5 overall system results transmitted from Janmida to ten repeater sites and ten sites to EBC.

Name of site	Total system results from Millinium Hall-ten repeater station-EBC			
	E-field (db μ v/m)	Total propagation loss(db)	Success margin(db)	Rank
Intoto	139.6	230.8	76.0	3
Addisugebeya	92	227.4	29.38	9
Hana mariyame	118.7	251.6	55.28	7
Leghare	144.4	225.9	80.92	2
Yeshidebeli	85.2	285.2	27.23	10
Yekaparke	133.9	236.5	70.4	4
Jemo	121	249.3	57.53	6
Gomakoteba	146.5	223.9	82.83	1
Abonepitrose	130.7	239.6	66.98	5
Kara kori	118.1	252.1	54.67	8

Table 4-6 overall system result transmitted from Millennium hall to ten repeater sites and ten sites to EBC.

Based on the archived RMS tools result by compare E (field), margin and total propagation the best sites are selected as follows:

1. Gomakoteba: has the highest link quality for two temporary studios, i.e,Millennium and Janmida.
2. Leghare: has the highest link quality for Addis Ababa Stadium followed by Goma Kuteba.
3. Abonepitrose: has better link quality for A.A stadium and Janmida as compared to the remaining seven repeaters.
4. Intoto: is better than Abonepitrose by for Millennium hall.

Thus, in average Gomakoteba will take the highest link quality followed by Legehar, Abonepitros, and Intoto respectively.

4.5 Comparison of simulation results with Existing systems

a. Existing field test

In this section the thesis will compare link qualities of existing systems with that of proposed approach. To accomplish this task existing systems parameters were collected for each three temporary studios as in Tables 7.7 & 7.8. Afterwards RM simulation tool was used to simulate link parameters, i.e., Field strength, net propagation loss and Fade Margin. One thing to note here is that existing systems parameters were collected at a power level of 1W. Thus, to make the comparison field level the simulation for the existing system is performed at 10 W since proposed solution models operate at the mentioned wattage.

TX power (Janmida,stadium,Milliniyame hall)	30dbm
Polarization	Vertical
(Latitude /Longitude) Janmida	9°2'35'' N / 38°46'10'' E
(Latitude ,Longitude) stadium	9°0'45.4''N / 38°45'19.7''E
(Latitude ,Longitude) Milliniyame hall	8°59'26.7''N / 38°47'23''E
Antenna height of janmida	4.5m
Antenna height of stadium	3.5m
Antenna height of Milliniyame hall	3.5m

Table 4-7 the practical parameter of MW link in EBC.

	TX-Janmida and RX-EBC	TX-Stadium and RX-EBC	TX- Milliniame hall and RX-EBC
RX.power	-66dbm	-52dbm	-78dbm
Polarization	Vertical	Vertical	Vertical
(Latitude ,longitude)EBC	9°1'7.3''N/38°45'6.7''E	9°1'7.3''N/38°45'6.7''E	9°1'8.2''N/38°45'5.6''E
Antenna height in EBC	1.5m	1.5m	1.5m

Table 4-8 practical measurements that transmitted from three temporary studio to EBC. Furthermore, while simulating for proposed solution best repeater link quality is selected for each three temporary studios.

Existing system simulation result with 10w									
	Transmitter temporary studio in Janmida			Transmitter temporary studio in Stadium			Transmitter temporary studio in Millinium		
	E-field (dbμv/m)	Total propagation loss(db)	Margin (db)	E-field (dbμv/m)	Total propagation loss(db)	Margin (db)	E-field (dbμv/m)	Total propagation loss(db)	Margin (db)
Receiver on Ebc	33.8	151.4	18.05	80.7	104.4	48.97	52.3	132.8	20.59
Proposed solution with the best repeater with 10w									
	Janmida to sites, and sites to EBC			Stadium to sites, and sites to EBC			Millinime to sites, sites to EBC		
	E-field (dbμv/m)	Total propagation loss(db)	Margin (db)	E-field (dbμv/m)	Total propagation loss(db)	Margin (db)	E-field (dbμv/m)	Total propagation loss(db)	Margin (db)
Goma koteba	149	221.3	85.48	161.2	210	96.73	146.5	223.9	82.83
Legehare	144.6	225.5	81.08	162.6	207.7	99.11	144.4	225.9	80.92
Abonepirose	143	226.7	80.48	147.7	228.6	84.04	130.7	239.6	66.98
Intoto	139	231.3	75.58	137	232.4	74.45	139.6	230.8	76

Table 4-9 shows the comparison between existing system link parameters and proposed solution.

CHAPTER FIVE

5. Conclusion and Recommendation for Future Work

5.1 Conclusion

Quality of service of the entire live program broadcasting is highly dependent on the quality and availability of Microwave Link. But due to topological nature of Addis Ababa and intensive construction of new tall buildings make it difficult for line of sight communication. Due to this inherent truth current systems quality is degrading drastically. Thus, the thesis has taken three intensively utilized temporary studios of Ethiopian Broadcasting Corporation to demonstrate a possible mitigation technique to overcome the mentioned problem. The utilized technique involved a careful selection of repeater stations that are in LOS with the temporary studios and analysis of link qualities via selected performance parameters. Using the mentioned approach, the first phase of the thesis proposed 250m antenna height and ten suitable repeater stations.

The second phase of the thesis has selected repeater stations that have the best link quality with that of the temporary studios. Based on the simulated results GomaKuteba, Legehar, Abunepetros and Intoto have been selected as having the best link quality with the temporary studios. Furthermore, Gomakuteba has been found to be the best link for Janmeda & Milinum hall, and Legehar for Stadium. Even though these sites showed remarkable results, there is a site, i.e.,hanamariam , which showed worst case link performance to one of the temporary studio, i.e., stadium. The thesis mitigated this problem with the help of hopping mechanism, i.e., link from stadium was routed to Gomakuteba and then to Hanamariam. Finally, the thesis has made a comparison with existing systems and that of proposed system based on selected performance criteria. The comparison has shown that in average the field strength has improved by 61.66% whereas the propagation loss has in average increased by 42.41%. Finally, it was also visible that the fade margin has improved by 64.44%. Even though, the propagation loss has increased by 42.41%, which is expected, the overall system performance is promising.

5.2 Recommendation for Future Work

In this thesis a careful planning and detailed analysis of microwave site selection and tower height estimation are done. But the thesis can be furthered taking the below recommendations into account.

- ✓ It is known that EBC has existing analog TV transmission, but currently EBC is on the verge of shifting to digital transmission. Thus, it will use additional transmission sites which have good coverage for digital transmission. This on the other hand will require site and tower height selection.
- ✓ In Addis Ababa is several terrestrial antennas are used but not all with good coverage area or point to point communication for different reasons. Thus, to improve coverage and reception of such terrestrial antennas, it is interesting to conduct a research on site selection and antenna height estimation.

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Appendix A

Appendix A.1: Introduction Radio Mobile Program

Radio Mobile is a computer simulation program used for predicting radio coverage of a base station, repeater or other radio network. Ground elevation and various radio parameters are taken into account to predict radio coverage around a single or multiple radio sites.

After coverage is calculated for a geographic area, a map can be overlaid on the coverage plot to show various locations and resulting coverage along roads and in areas of cities, towns, etc.

The program is extensive and has many options, parameters and settings. Only a few are covered here. The user is encouraged to experiment once becoming familiar with the basics of program operation.

The paper consists of 2 parts

1. The first part describes radio propagation in general, including the mathematics of propagation calculation.
2. The second part describes the Radio Mobile program and some of the basics and input parameters required to use it.

Appendix A.2: Propagation Modes

Line of sight is simply that – if the distant site is optically visible (using your eye) from the transmitter antenna location on the tower, it is considered within the coverage area. This is referred to as “optical line of sight coverage”. The optical line of sight method does not take into account reflections, Fresnel Zones or the slight bending of radio waves along the surface of the earth. Radio path loss between 2 sites that are within line of sight uses “free space loss” only. No other loss parameters are considered.

We all know that radio waves travel in straight lines. The early mathematics of radio propagation considered that radio and light were essentially the same and travelled in the same manner. If a distant site could be seen optically, radio communication was possible. Therefore, there is an option to show optical line of sight coverage.

Radio Mobile uses a computer algorithm called the Longley Rice model to determine signal loss for non-Line of Sight radio paths. Line of sight paths use a calculation called the “two ray” method. This method takes into account Free Space Loss only.

Appendix A.3: Propagation and Signal Loss

There are 2 signal losses that add together as distance loss and atmospheric loss between a transmitter and receiver site. Both can be calculated between the transmitter and receiver sites.

Calculations can use a number of computer algorithms for path loss. Radio Mobile uses the Longley-Rice model for propagation calculation.

1. Free Space loss

Free Space loss is the loss due to the distance between sites. It does not take into account obstructions. It assumes that the sites are completely in the clear, hence the term “Free Space”. It may also be called “Line Of Sight loss”. One accepted equation for calculating Free Space Loss is:

$$\text{FSL (dB)} = 36.57 + 20 \cdot \log_{10}(\text{Distance in miles}) + 20 \cdot \log_{10}(\text{Frequency in MHz})$$

2. Diffraction Loss

Diffraction loss is the additional loss that occurs due to an obstructed path. The path may be obstructed by trees, hills, buildings or other objects. Diffraction loss also results as the distance between sites increases and the curvature of the earth obstructs the path. The earth obstruction is commonly referred to as the “earth bulge”.

It can be calculated based on the location of the obstruction along the path and its height. There are a number of computer algorithms that will calculate diffraction loss. The Radio Mobile program uses the Longley-Rice algorithm.

Diffraction loss is calculated and added to Free Space Loss to determine overall propagation loss between transmit and receive antennas.

Total Loss between Sites: Total path loss between 2 sites is calculated by adding together all the dB values including Free Space Loss and Diffraction Loss.

Appendix B

Appendix B: First Time Program Start up Options

When Radio Mobile is used for the first time, a number of settings and options must be set for your own operating environment. The following Option parameters may or may not be required for your operating environment. Select “Options” from the toolbar.

1. GPS

Radio Mobile has the ability to accept GPS data from a GPS receiver. GPS data must be in standard GPS NEMA data format.

Data can be saved in a text file for later use comparing a GPS location to a coverage plot. The various input parameters, com port, etc. are set in this window.

2. APRS

Automatic Packet Reporting System (APRS) is primarily an Amateur Radio application where interactive packet data (transmit and receive) is stored to indicate location of a receiver along a route or map. Map location data is shared with all other operators who may be monitoring an APRS network. Active units can be displayed on a map and shared with other users.

3. Internet

A number of Internet options must be checked and/or set under “Internet Options”

4. Proxy

Proxy settings are used if Internet access available uses a Proxy server. Set the proxy name and port, if assigned.

5. Web Update

Web update can automatically check if there are any program updates to Radio Mobile. Check the box “Check every time when the program starts” for a verification of the latest Radio Mobile Version.

Alternatively, for a manual update, click “Help” and “Check for program update”. A dialogue box will be returned stating the version of program is either “up to date” or that a new version is available. If a new version is available, the option is presented to download the new version. Note that downloading a new version does not change any of the program settings previously defined by the user.

There are 2 Internet locations that may be visited to check for program updates, one at cplus.org; the second at ve2dbe as shown. It is best to check both of these locations, in case one is not available at the time of checking the program version currently installed.

6. SRTM

SRTM specifies type and how SRTM files will be obtained.

- ✓ First, files may be obtained from the Internet as required.
- ✓ Second, files may be obtained from the Internet and locally stored on the computer hard drive for later use.
- ✓ Third, files may be obtained from the local hard drive only. The option is convenient when Internet access is not available.

The local file location must be specified where files will be stored when downloaded. These files will then be available for future use.

7. Geographic Map Files

Map files identify various geographic maps that may be used to merge with a coverage map. These maps will show roads and other significant points to provide a local reference for the coverage plot.

A file in the Radio Mobile program, `Map_Link.txt` file in the Radio Mobile directory, must be edited as described during program installation. Until this file is edited, some of the maps will be grayed out and not be available for merging with a Radio Mobile coverage plot.

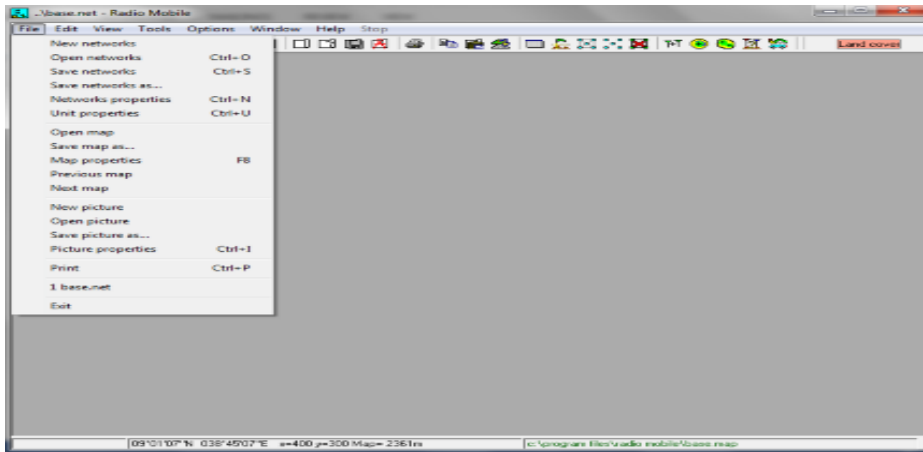
Note that, after editing the `Map_Link.txt` file, the program must be restarted for the changes to take effect. The following Internet map services may be available:

- ✓ Open Street Map
- ✓ TerraServer
- ✓ Toporama
- ✓ Virtual Earth
- ✓ Google Map
- ✓ YahooMap

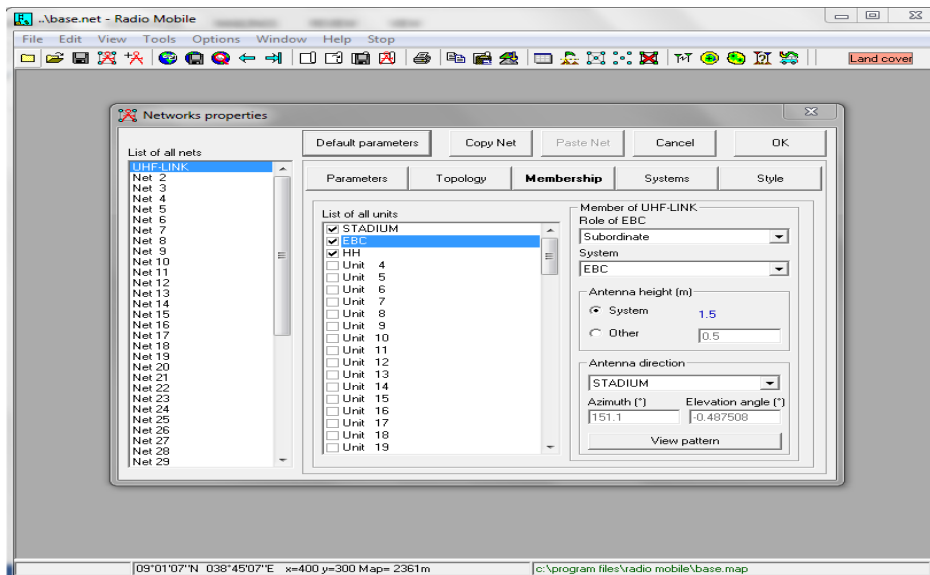
Appendix C

Appendix C.1: HOW TO USE RMS TOOLS

1. Open the RM software
2. Open file you can get



3. You can open Network property



Then after getting this

Networks property (overall collection point for the base stations, mobiles, handhelds, etc.)

- i. Parameters
 - a. Net name(name of the specific site location)
 - b. Insert min and max frequency(plus or minus 4 to the carrier frequency)
 - c. Set polarization to Horizontal

- d. Set mode of variability to broadcast and
 - % of time = 50
 - % of locations =50
 - % of situation =70
 - e. Set climate to Equatorial and
 - Surface refractivity (N-units) 360
 - Ground conductivity(s/m) 0.005
 - Relative ground permittivity 15
 - f. Set additional loss to be zero(0)
 - ii. Topology (communication method)
 - activate visible and
 - voice net
 - iii. Membership (Units are selected as members of the correct Network and System is defined for each unit in each Network)
 - a. Choose "net name" from "list of all nets", set Net 1
 - b. From "list of all units" activate "unit 1" and choose from "Role of unit1" command and then select "system 1"
 - c. From "list of all units" activate "unit2"and choose from "Role of unit2" subordinate and then select "system 2"
 - d. Antenna height (m)
 - For command, activate "system"(if not necessary receiver antenna)
 - For subordinate, activate "others" and write the antenna height (like for UHF TV receiver antenna =4m)
2. System (operating parameter for radio unit)
- a. Insert transmitter power in watt
 - b. Set antenna type to
 - c. Receiver threshold
 - d. Line loss
 - e. Antenna Gain
 - f. Insert antenna height
 - g. Set additional antenna loss to be zero (0)

3. Style (refers to the label and icon identifying the specific unit)

- Activate all left boxes in the left
- Set the right b

Vi. Click ok

2. Unit properties (represents a location or location for radio unit)

- a. Enter latitude and longitude
 - i. Write unit name (for instant, unit 1)
 - ii. Enter North Latitude (+ number) and East Longitude (+ number).
 - iii. Place cursor at unit position (if the unit already has a defined location)
 - iv. In “ styhle-unit1”, activate “Enabled”(specifies whether the radio unit will be displayed on the map.) and in its side activate “center”(Useful when multiple units are displayed)
 - v. Click ok

3. Map properties

- a. Enter North latitude and East longitude or click“ use cursor position” and then ok
- b. Select a unit(unit name for instant, unit 1)
- c. Activate “Adjust unit elevation” and “ merge picture” boxes
- d. Set “size (pixel)” to 2000(width) by 2000(height) and “size (km)” to 200 (only for height)
- e. Click Extract
- f. Select” internet open street map” and then click ok
- g. Select “Keep in a new picture” and then click ok

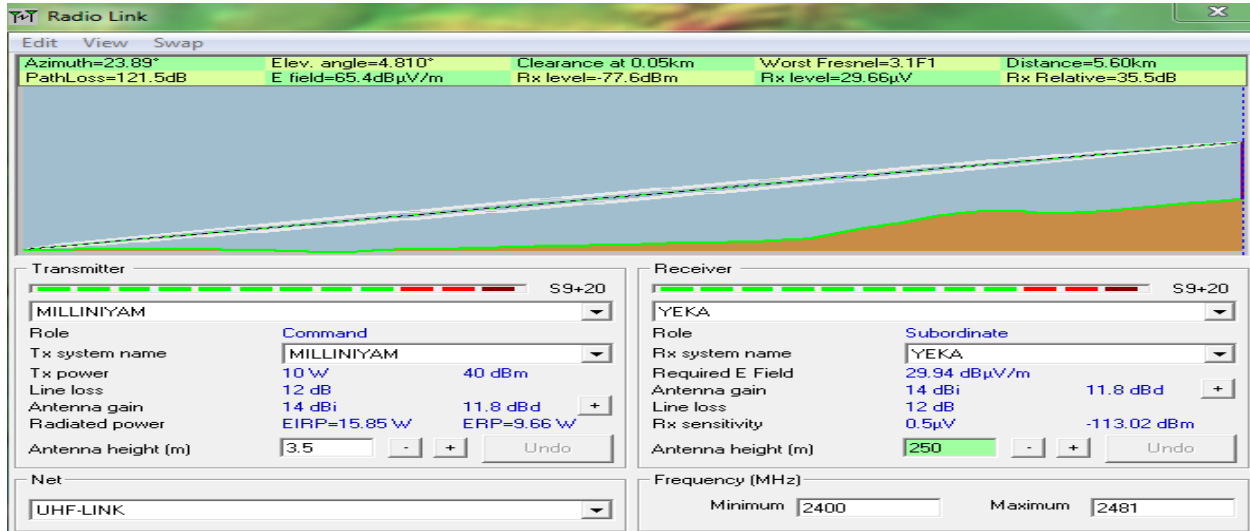
4. Picture properties

- a. Activate “Gray scaled slope”(It is best to show the map as a gray scale)
- b. Set “contrast =0”and “brightness =100”
- c. Click Draw
 - a. Click Draw
 - h. Select “Keep in a new picture” and then click ok

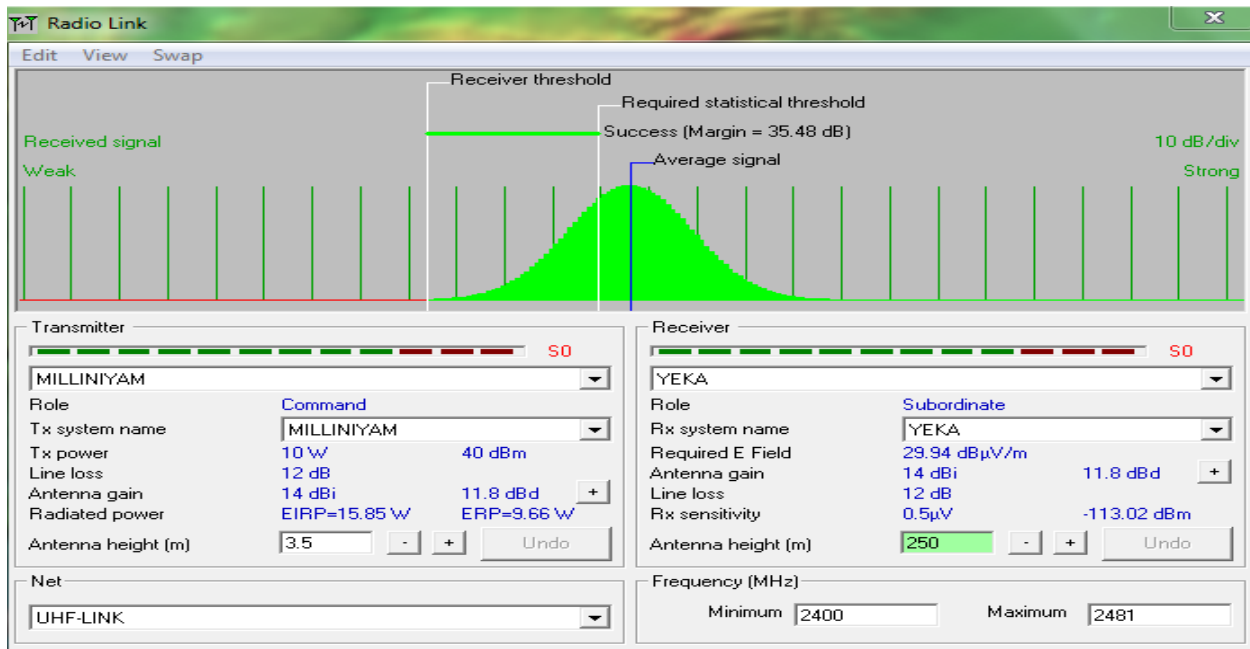
The above procedure is the same for point to point communication and the coverage area the only difference is the parameter that used

Appendix c.2: For Line of sight communication

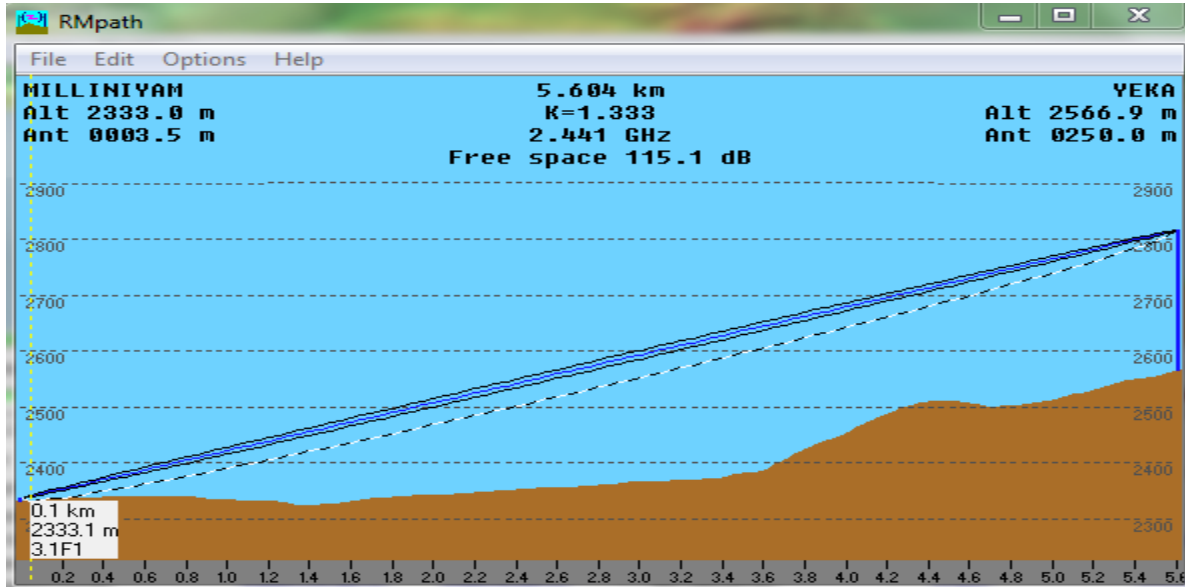
7. You can go to the open radio link  then you can see this



Inside radio link open view then open Distribution then you can get



Then again back to radio link open Edit to Export to RM path if you select ok save Kml File immediately get this



Back to Edit open and Export to Google earth save to kmlfile(KML) you get



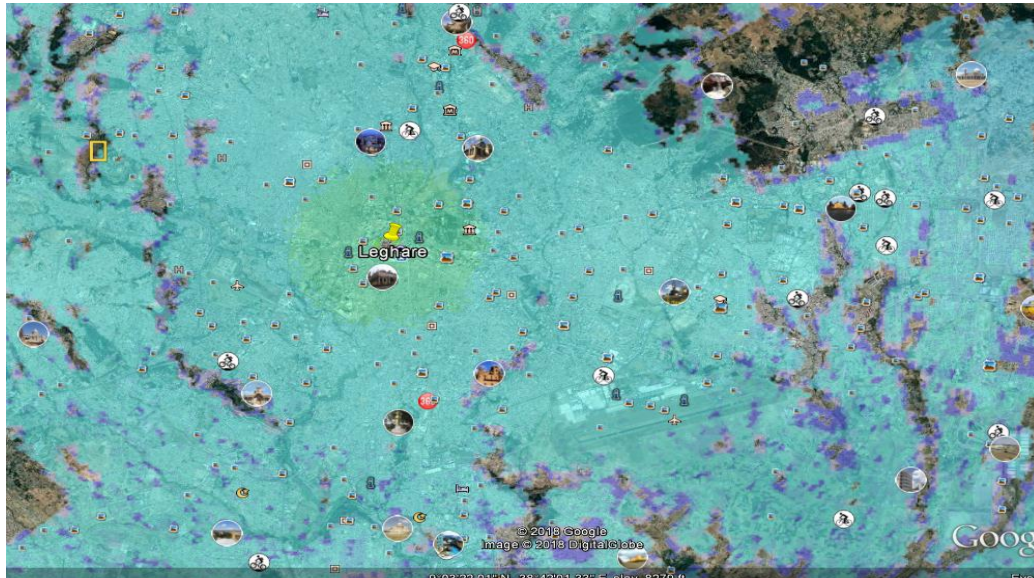
Appendix c.3: For coverage area

7. Polar Radio coverage

- b. In “link Direction”, activate “center Tx-mobile Rx”
- c. In “plot” activate “fill area”, “solid” and “rainbow”(to show coverage signal)
- d. In Threshold, activate “dBuV/m” and set “from =50 to =200”
- e. Set “Radial Range” to Min = 0.01 and Max= 75
- f. Azimuth Range Min = 0, max =360(give a complete circle)and step =1

- g. Antenna pattern, “activate use network antenna setting”
- h. Click Draw
- i. Select “Keep in a new picture” and then click ok
- j. Open“ file” select “Save as picture” (set to GIF)**
- k. Then it will connect to Google Earth.**

If you open the file that you save that is GIF file get this



From Legehar transmitting the signal to see the coverage



From Goma Koteba transmitting the signal to see the coverage