RAIN ATTENUATION PREDICTION FOR SATELLITE COMMUNICATIONS LINK AT KU AND KA BANDS OVER BANGLADESH

By

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POSTGRADUATE DIPLOMA IN INFORMATION AND COMMUNICATION TECHNOLOGY

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The project titled "**Rain Attenuation Prediction for Satellite Communications Link at Ku and Ka Bands over Bangladesh**" submitted by Md. Kamruzzaman, Student No. DP 0731028, Session December 2007, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Postgraduate Diploma (ICT) held on June 26, 2013.

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Candidate's Declaration

It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Md. Kamruzzaman

Dedicated

To

My Parents

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List of Abbreviations

AC	Adaptive Coding
BER	Bit Error Rate
CE	Central
DRR	Data Rate Reduction
EIRP	Effective Isotropic Radiated Power
FMT	Fade Mitigation Technique
ITU	International Telecommunication Union
IOR	Indian Ocean Region
LOL	Lock of Loss
LHCP	Left Hand Circular Polarization
LT	Long Term
MW	Mid Western
MATLAB	Matrix Laboratory
NE	North East
RF	Radio Frequency
N	Northern
RHCP	Right Hand Circular Polarization
ST	Short Term
SE	South Eastern
SW	South Western
S	Southern
ULPC	Up-Link Power Control

Acknowledgement

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Kamruzzaman
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Abstract

The growing demand of microwave communications system has overcrowded frequency band below 10 GHz. The system designers and RF engineers are forced to shift at higher band frequencies because of large bandwidth, smaller equipment and less interference. But, signal power degradation due to attenuation, depolarization and scintillation are the prominent impairments in these bands, coping up with which is a challenge in satellite communications system. Attenuation is mainly due to rain and is more at Ku and Ka band frequencies. This leads to higher BER and also frequent loss of lock in the receiver and required to be predicted in an efficient manner. For reliable communication link in any specific region, the attenuation is required to be predicted a-priori. It is essential to have reliability 99.99% for standard satellite or microwave communications link.

We attempted to obtain annual rainfall rate variation, attenuation due to average annual rainfall rate and comparison of attenuation with ITU and major eight different parts of Bangladesh. The selected areas are central, mid western, north western, north eastern, northern, south eastern, south western and southern zone. We have collected daily rainfall data from those eight major zones from 1948-2011 years over the Bangladesh. Daily rainfall data is accumulated to get annual rainfall data in millimeter. Annual rainfall data is converted to yearly rain intensity and this annual rain intensity is used to obtain rain attenuation prediction purposes for any specific region. Finally, obtained specific attenuation in eight different zones is compared with ITU-R rain attenuation based on rain intensity.

The work provides in depth knowledge of the attenuation variation characteristics in the aforesaid band and presents major working components for specific rain attenuation prediction in key parts of Bangladesh. Bangladesh Government is going to launch first commercial satellite in geo-stationary orbit. This rain attenuation profile will be helpful to design Ku and Ka band transponder and calculate link budget for advance communication satellite.

Chapter 1
Introduction

1.1 Background and present state of the problem

Due to the growing demand in the bandwidth in satellite channels and the lower bands being densely populated, satellite channels need to shift to the higher band like Ku and Ka. But, in these higher frequencies the electromagnetic waves traversing through the tropospheric region of the atmosphere suffers from different impairments like Attenuation, Scintillation, depolarization etc. Rain is a dominant source of attenuation at frequencies more than 10GHz in tropical and subtropical regions [1]. The design of a variety of telecommunication systems, the dynamic characteristics of fading due to atmospheric propagation are of concern to optimize system capacity and meet quality and reliability criteria [2]. Raindrops absorb and scatter radio waves, leading to signal attenuation and reduction of the system availability and reliability [3]. Rain attenuation can cause the largest attenuation and is usually the limiting factor at Ku, Ka-band satellite link design [4-5].Details of different impairments and their relative typical values are mentioned in section 1.1.1. These impairments sometimes lead to satellite communication link failure. As it is inappropriate to provide adequate fixed link margin a-priori, proper prediction knowledge is required to compensate attenuation in an efficient manner. For a reliable communication system, unavailability time during a year has to be kept at 0.01 percent [6-7]. Knowledge of the 1 min rain rate distribution is important for the prediction of rain attenuation at any location [8]. There is a need to calculate the attenuation due to rain from knowledge of rain rates for satellite link [9]. Rain attenuation profile all over Bangladesh is not observed in depth earlier based on rain data collected from eight different parts of country. We attempt to predict rain attenuation for major zones of Bangladesh considering available long term rain data and compare those results with ITU recommended rain intensity.

1.1.1 Various Impairments

The following are the most prominent impairments observed in this band of signal while the latter traverse through the troposphere.

a. Rain Attenuation: Rain is a dominant feature of attenuation at frequencies above 10 GHz. Ku/Ka band signals lose their power while propagating through troposphere due to the attenuation effects of Rain, gases etc. Rain attenuation increases with increasing rain rate. Rain attenuation at Ka band can exceed even 20 dB for small percentage of time, in a year. Rain attenuation can normally be neglected at frequencies below about 5 GHz.

b. Depolarization: Depolarization is a phenomena introduced when energy transferred from one polarization state to orthogonal polarization state that can be cause by the atmosphere, mainly cloud and rain . Depolarization occurs because individual raindrops absorb energy from radio waves (i.e the drops are heated) and because some energy in the waves is scattered out of the path. These interactions depend on the number of raindrops encountered (hence on the rain rate) and on their distribution of sizes and shapes. Co-polar attenuation in Ka band is on the order of 1-3 dB.

c. Scintillation: Scintillation is a variation of the amplitude of received carrier caused by variations of the refractive index of the troposphere and the ionosphere. It can also be caused by rainstorms. In general, the impact of rain attenuation is on communication signals is predominant. Scintillation, however, becomes important for low fade margin system operating at high frequencies and low elevation angles. In the Ka band and above and low elevation angles ($\lessapprox 15^o$), Scintillation may contribute as much as rain or even more, to the total fade measured , especially for time percentage larger than 1%, and therefore for low fade margin systems. Some applications in the Ku and Ka band will be aimed at Very Small Aperture Terminal (VSAT) services with low fade margins. So, there is a need to quantify propagation phenomena in the low fade margin range. The peak to peak amplitude of the variations at Ku band and medium latitudes can exceed 1 dB for 0.01% of the time.

d. Gaseous absorption: A loss close to 1 dB can be associated with oxygen and water vapour absorption.

e. Cloud attenuation: Cloud along the propagation path can attenuate Ku and Ka band frequencies. Typical values are in the order of 1 dB or more.

f. Atmospheric noise: The atmosphere has an equivalent black body temperature. Wet antenna and snow on the antenna causes additional signal losses. These loses can be as large as a few dB.

1.2 Motivation of the work done

Rain attenuation varies in a very complex manner with the rain intensity as well as the elements like the location, elevation angle, polarization etc. in addition to its natural variation with frequency. Attenuation is mainly due to rain and is more at Ku and Ka band frequencies. This leads to higher BER and frequent loss of lock in the receiver. Moreover, in a tropical country like Bangladesh, the rain is convective in nature. This type of rain is characterised by high intensity within a small area of occurrence. In Bangladesh rain attenuation profile is not obtained earlier based available rain data from major parts of Bangladesh. Islam M. R., Rahman M.A., Eklas Hossain S. K. and Azad M. S have analyzed the rain fade on earth space communication links in subtropical region but not specifically for Bangladesh. So, it is required to be estimated rain attenuation in major parts of Bangladesh like central zone, mid-western zone, north eastern zone, northern zone, north western zone, south eastern zone, south western zone for efficient link budget calculation to keep the link alive. We have divided our country into flat zones as well as highly attenuated zones which is not also done earlier.

The long term cumulative annual rainfall data are available for most of the countries of the world. This work has presented the cumulative rainfall data collected for sixty years in eight different parts of Bangladesh. Using appropriate conversion model, the long-term annual rainfall data has been converted to rain intensity data. The rain intensity proposed by International Telecommunication Union (ITU-R) as well as converted data are used to predict the rain fades for earth-to-satellite at Ku and Ka-Bands. Long term annual rainfall data is useful to predict the rain fade for earth-to-satellite links operating at different frequency bands. We can investigate the performance of Ku and Ka-Bands during rains in a subtropical region.

Main drawbacks of fixed margin derived from long term predictions are power drainage during the non-attenuative time and excess outage due to attenuation occurred by rain. By knowing the attenuation profile in major parts of Bangladesh. We can choose minimum drainage of power. Therefore, effective use of transmitted power can be confirmed.

1.3 Scope and Objectives of the work

1.3.1 Scope

This project work is involved an extensive review on the available ITU model describing annual rain fade distribution on line-of-sight links. There are many fade duration models that was published in order to predict the rain attenuation. The long term cumulative annual rainfall data are available for most of the countries of the world. The cumulative rainfall data is collected from Bangladesh Meteorological Department (BMD) for sixty years in eight different parts of Bangladesh. Using appropriate conversion model, these long-term annual rainfall data is used to convert into rain intensity data. The rain intensity proposed by International Telecommunication Union (ITU-R) as well as converted data are useful to predict the rain fade for earth-to-satellite at Ku and Ka-Bands. Based on the site information such as longitude, latitude, elevation angle, height above the sea level, polarization and percentage of time exceedance for an average year , specific attenuation prediction will be estimated.

This rain attenuation statistics are developed by using Matlab simulation software. The result from this rain attenuation profile is used to compare with the available ITU empirical models.

1.3.2 Objectives

This work attempts to investigate the impacts of rain fade to the performance of satellite links in most important zones of Bangladesh in Ku and Ka bands. The main objectives of this research work are:

a) To develop a model which will predict rain attenuation over major areas of Bangladesh
b) To develop annual rainfall variation in eight different zones in Bangladesh
c) To compare the predicted attenuation with ITU-R attenuation based on rain intensity.

1.4 Organization of this thesis

The subsequent chapters of this thesis have been organized in the following manner. Chapter-2 provides popular prediction and mitigation techniques for the tropospheric impairments typical for a radio wave in C, Ku and Ka band. The following Chapter-3 provides the Methodology of the work done including theoretical details, the collection of rain data, approach of the work and the calculation of long-term rain attenuation statistics from point rainfall rate. Chapter-4 discusses the result obtained with work done. It also deliberates the issues concerned with the same and comparison with ITU-R recommended model. Finally, Chapter-5 provides the conclusion of the work done which consolidates all observations in a nutshell and also indicates the future course of activities.

Chapter 2

Prediction and Mitigation Techniques on RF links

2.1 Introduction

Rain Attenuation on satellite communication link and different types of prediction techniques are discussed in this chapter. The popular mitigations techniques have also been discussed.

2.2 Rain Attenuation on Satellite Communication Link

Today‟s most of the Satellite transmissions are carried on C-band, Ku-band or Ka band frequencies. When satellite communication link is operating at the higher frequency (more than 10 GHz), the strength of the satellite signal may be temporarily reduced under severe rain conditions. To compensate for these potential effects, earth stations located in heavy rain areas are designed with extra fixed margin power i.e. more transmit power is pumped from ground station continuously. C-band transmissions are virtually immune to adverse weather conditions. It is called reliable band in satellite communication system. But, rain is a dominant source of attenuation for Ku and Ka band frequencies.

Signal power attenuation due to rain is a common characteristic of both microwave and satellite transmissions. It is the interference and noise caused by raindrops on electromagnetic signals traversing the atmosphere. When this phenomenon occurs, the transmission is weakened by absorption and scattering of the signal by raindrops. The level of attenuation is the product of a number of variables, and to minimize its effect, a rain fade margin should be included when designing satellite services and equipment. The rain fade margin is the amount of extra power for communication link added to the signal strength to compensate the possibility of rain attenuation. In most cases the reduction in signal strength due to rain does not surpass the rain fade margin and does not have any noticeable effect on transmission. Lack of fade margin, lock of loss in the receiver is happened. Therefore, service is interrupted.

Generally, rain attenuation increases as the signal frequency increases. Therefore, transmissions at C-band (6/4 GHz) will experience insignificant attenuation, while transmissions at Ku-band (14/12 GHz), Ka-band (20/30 GHz) will experience greater attenuation. For C-band signals to be affected would require rain storms approaching hurricane conditions. Signals at higher frequencies can be affected by less severe storms.

This is due to the wavelength of each frequency and the size of the raindrop through which the signal has to travel. Signals at 6/4 GHz have a longer wavelength than signals at 14/12 GHz, and are less susceptible to rain attenuation. For example, a 6/4 GHz frequency has a wave-length of approximately 7 cm, and a 14/12 GHz frequency has a wavelength of approximately 2 cm. Any raindrop in the signal travelling path of which the wavelength is half the diameter of the signal will cause attenuation.

How long a transmission will be affected by rain attenuation and how deep the attenuation will be is determined by the amount and duration of rainfall. Normally, signal strength can be affected for two to three minutes during an average rainfall, and up to 15 minutes for extremely heavy rain periods. However, attenuation periods of up to 15 minutes are extremely rare, and although signal strength may be affected, there will be no noticeable effect on transmission as long as the attenuation does not exceed the allocated rain fade margin.

To offset the effects of external forces on satellite transmissions, satellite service provider must builds a link margin into its calculations when designing satellite services. The rain fade margin is a component of the link margin and is a calculation of expected rain attenuation over one year. It is based on rainfall data, elevation angle, and weather patterns. This margin gives each customer more power than needed at any given time. As a result, service is rarely affected by rain attenuation.

2.3 Prediction Techniques

Rain attenuation is the most important and conspicuous impairment for signals in Ku and Ka Band. The rain attenuation varies in a very complex manner with the rain intensity and as well as the elements like the location, elevation angle, polarization etc. in addition to its natural variation with frequency. In the tropical region, where the rain features are conspicuous and diversified, the rain characteristics show considerable variations over time and space. The attenuation at any fixed location also shows large statistical variations. Considering the diversity of the attenuation features and the design requirement, the prediction may be done over a long term or short term basis. These two categories of the prediction, viz. Long Term and Short Term predictions are discussed in the sections following.

2.4 Long Term Prediction

The long-term prediction models provide the attenuation exceedance values which give the percentage of time of the year for which a given value of attenuation is exceeded. This is used for fixed margin calculation for a given design value of outage.

Main drawbacks of fixed margin derived from long term predictions are power drainage during the non-attenuative time and excess outage due to attenuation level non-conforming to model. Mathematical models are available that give the exceedance curve for a given location based on the total rain accumulation and other meteorological data. Some of the popular Long terms models are

(a) ITU model: ITU-R 618-9

(b) SAM Model: The SAM model was developed by Strutzman and Dishman with NASA support to provide a simplified technique for hand calculation. It assumes that rain extends from the earth station‟s elevation above sea level to an effective storm height.

(c) Excel model: Assumes an exponential spatial variation of the rain rate with distance

(d) Garcia Model etc

2.5 Short Term Prediction

To overcome the limitations of long term prediction near real time short term prediction is used. Short term prediction at any instant provides the probable attenuation values at immediate next instant where the interval is of the order from few seconds to few minutes. Using this, the margin of a link can be adaptively controlled. This leads to lesser drainage of resources in the link. Short term prediction model provides the inherent features of the temporal parameters already obtained which predicts the next instant. Prediction with large over determination of attenuation will lead to drainage of resources whereas any under prediction will lead to loss of lock. To maintain the continuity of service with minimum resource wastage, a good ST prediction should optimally predict the attenuation to have minimum drainage of resources due to over-prediction and minimum probability of service interruption due to under-prediction.

Short term prediction techniques can be broadly classified into:

a) Statistical

b) Neural network and

c) Regression based predictions.

2.5.1 Statistical Prediction

Statistical prediction predicts the future value of attenuation using the current value and the maximum likely value for attenuation to take subsequently, the latter being obtained from large ensemble of past data. Conditional probability distribution derived from ensemble of past values. Popular examples of such a statistical based model are the Van de Kamp 2 sample model, CNES model etc.

2.5.2 Neural Network Prediction

Neural Network adapts the statistical variations by learning from the incoming time series, along with simultaneous prediction. Real time recurrent network are suitable for this kind of prediction. Typically, Neural Network predictors are used with a-priori training which requires large volume of data, although predictions can be done by using In-situ learning algorithms. The computation complexity for both these types of predictor is fairly high. This type of prediction scores fair even when the relation is highly non-linear. Learning can be priori training based as done by Chambers & Otung, or it can be in-situ as done by Roy, Acharya and Sivaraman.

2.5.3 Regression based Prediction

Regression based prediction investigates the relationship of the backward variables. When paired with suitable assumptions, it can be used to predict the value of a variable from the parameters it is depending on. The key relationship in regression is established through the regression equations. Attenuation of prediction is based on the assumption quasi-static dynamics of temporal attenuation variation. Different types of Regression equations are Linear, Non-Linear and Curvilinear. When the weights associated with the past values are solved using linear equation, this method is called Linear Regression. Similarly, the equations can be developed using non-linear relationship of past values to future values which is known as non-liner regression. On the other hand, the relation between variables when the regression equation is nonlinear quadratic or higher order. This is known as curvilinear.

Different examples are as follows:

Linear regression : $a_0+a_1x+a_2x+a_3x= y$

Non-Linear : $a_0+a_1x+a_2x^2+a_3x^3= y$

Curvilinear : $a_0+ a1dx+a_2d^2x+a_3d^3x= dy$

Where, x is the past data and y is the predicted value.

Maseng & Bakken proposed a dynamic stochastic model of rain attenuation based on the lognormal stationary distribution of rain attenuation defined by two parameters, median and standard deviation.

2.6 Mitigation Techniques

Fade Mitigation Technique is an adequate arrangement through which the atmospheric fades occurring to a propagating signal may be compensated judiciously with optimal resources to sustain the continuity of the link.

A typical FMT consists of three interdependent modules, viz. Prediction Decision and Implementation. Figure 2.2 below shows the schematic of such a typical control loop for a FMT. Here, the activities like the measurement, prediction and decision has been shown in different boxes. The outcome of the decision will be used for the implementation of the mitigation technique.

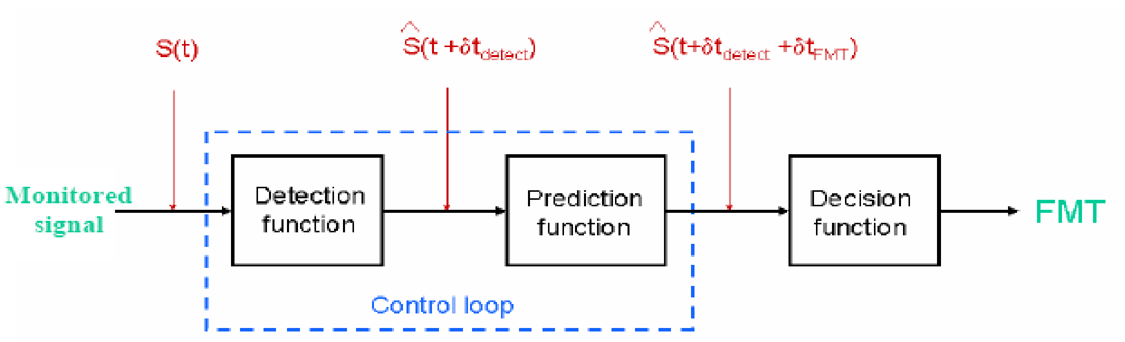

Figure 2.1: Schematic diagram of a FMT

So, to mitigate the tropospheric attenuation of microwave satellite signals above 10GHz using any standard Fade Mitigation on Technique (FMT), it is essential to have a priori knowledge about the level of attenuation. A good mitigation technique should have minimum drainage of resources and probability of lock of loss (LOL) in the receiver. Fade Mitigation Technique (FMT) rely on the principles of Up-Link Power Control, Data Rate Reduction and Adaptive Baud rate and Site Diversity.

There are different standard types of mitigation techniques, some of which are described in the sub-sections below.

2.6.1 Up-Link Power Control (ULPC)

With ULPC, the output power of a transmitting Earth station is matched to compensate the up-link or downlink (in case of non-regenerative repeater) impairments. In the case of regenerative repeaters, up and down links budgets are independent. So, ULPC acts only on the up-link budget. ULPC is used to keep a constant level of all the carriers at the input of the repeater, while maintaining the uplink budget close to target. Transmitter power is increased to counteract fade or decreased when more favorable propagation conditions are recovered so as to optimize satellite capacity. This FMT is simple to implement since it requires only the introduction of the minimum and the maximum power of the Earth station power amplifier as well as the power increment. At this level it is important to recall that for this technique it is possible to play on the granularity, i.e. the minimum resolution of the power increment, which is not possible so easily with other FMT. A schematic diagram of the Power Control Technique is shown below in figure 2.2 for a bent pipe satellite link.

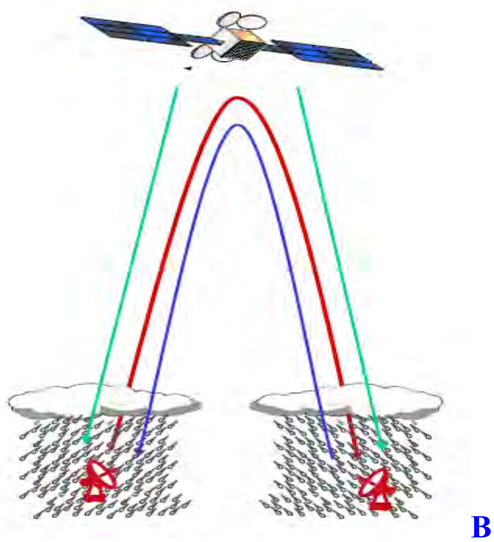

Figure 2.2: Schematic diagram of Power control

Here a communication link is established from A to B shown in red. The measurements of the attenuation are done separately by each A and B for their respective sides using a beacon reference transmitted from the satellite, shown in green. Any attenuation observed by A in his side is compensated by increasing the transmission power at A while attenuation observed by B in his side is indicated to A by a signalling link, shown in blue. In response of this, A increases his power to compensate the downlink attenuation.

2.6.2 Data Rate Reduction (DRR)

Another technique consists in decreasing the information data rate to maintain a constant BER even during the fade. The technique is called Data Rate Reduction or alternatively Data Rate Adaptation (DRA). The principle lies in the fact that a minimum constant value of E_b/N_0 is required to maintain the BER. Now, the relation between E_b/N_0 and C/N_0 is governed by the data rate R and is given by

$$E_b / N_0 = (C/N_0) / R$$

Now, as the C/N_0 degrades due to the propagation impairments, still the E_b/N_0 may be maintained by reducing the R equivalently. So, here, user data rates should be matched to propagation conditions. Nominal data rates are used under clear sky conditions with no degradation of the service quality with respect to the system margin, whereas reductions of data rates are introduced according to fade levels.

2.6.3 Adaptive Coding (AC)

The communication links are always enforced with the Forward Error Correction techniques. This results in introduction of redundant bits to the information bits which are used at the recipients end to detect and correct any error in demodulating the data bits. Now, due to the propagation impairments, causing large fading, the probability of erroneous detection increase. During this time, the FEC may be made more stringent by adding large numbers of redundant bit. Again, this can be relaxed when the fade vanishes. So, adaptive coding consists in implementing a variable coding rate matched to impairments originating from propagation conditions.

AC coding can be implemented in two ways. On the one hand, it can be done with accompanied increment in bandwidth thus maintaining the data rate. Otherwise, it can be implemented with constant bandwidth, sacrificing the data for the overhead FEC bits.

2.6.4 Joint FMT

Joint FMT is a very promising solution to improve the performance of a Sat-Com system. It is a combination of either ULPC with AC/ DDR or a combination of the three techniques.

2.6.5 Signal Processing

For this type of fade mitigation, an on board processing (OBP) have been introduced. Where the OBP is used to translate the digital carriers arriving at the satellite to base band for processing and onward transmission back to earth. For example, when the rain attenuation occurs, the OBP will adjust the bandwidth so that all users get the same bandwidth. It is doesn"t matter if the bandwidth is too small as long as users still can use the service during that time.

The use of OBP separates the uplink from the downlink and each part of the link can be treated separately in developing a link budget.

2.6.6 Diversity

There are three types of diversity available. Diversity can be categorized as:

a) Time diversity: It is only used when OBP are being used on the satellite. Additional slots in the TDMA frame can be assigned to the rain affected link so that the same signal can be sent at a slower rate, essentially lowering the bandwidth and raising the C/N.

b) Frequency diversity: Switch from high frequency to the lower frequency. For example, a rain affected Ku-band link could be switched to C band, which is not attenuated significantly by rain. This technique only can be done if the satellite operates in a number of frequency bands.

c) Site diversity: High attenuations are due to regions of heavy rain, which are typically concentrated over a small geographical extent. Two earth stations at two distinct locations can establish links with the satellite which at given time suffer attenuations separately. The signals are thus could be routed to the station less affected by rain which is known as site diversity. Since heavy rain occurs in geographically small cells, there is a probability that equally heavy will not affect both stations at the same time. For appropriate design of the site diversity, it is required to obtain the joint conditional statistics of the rain at the two locations. A schematic for the site diversity is given in figure 2.3 below.

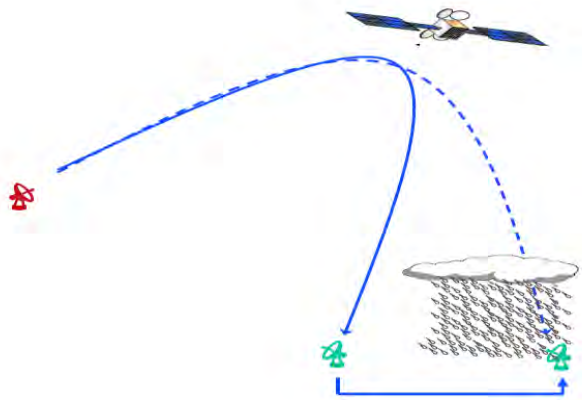

Figure 2.3: Schematic diagram of a Site diversity

2.7 Summary

Communication link running on higher radio frequency more than 10 GHz suffers considerably due to signal power degradation. Rain is the principal factor for decaying transmission power. Prediction techniques are important to obtain attenuation as a result of propagation impairments. At the same time, Mitigation techniques are essential to compensate those attenuated power. In this chapter, we can get information on rain attenuation for different frequency bands, well-known prediction and mitigation techniques.

Chapter 3

Methodology

3.1 Introduction

This chapter highlights on the Basic Principles, Input Data and Approach. It also gives key parameters of used satellite, Site Information and theory of attenuation calculation process.

3.2 Basic Principles

Attenuation by rain can be predicted accurately if the rain is precisely described all the way along the path. The long term cumulative annual rainfall data are available for most of the parts of Bangladesh. The annual rainfall data is collected during the year 1948 to 2011 from seven major parts of Bangladesh based on availability. Using appropriate conversion model, the long-term annual rainfall data has been converted to rain intensity data. The rain intensity proposed by International Telecommunication Union (ITU-R) as well as converted data are used to predict the rain attenuation for earth-to-satellite at C, Ku and Ka-Bands. The rain attenuation statistics is obtained from annual rainfall rate.

3.3 Input Data

Daily Rain Data (in mm) is collected from eight different zones all around Bangladesh. Data collected zones are Central, Mid Western, North Western, South Western, Northern, North Eastern, Southern and South Eastern Zone. These zones are shown in Figure 3.4. Rain data collection sites information is given in Table 3.2. Intelsat satellite 906, stationed at 64.15° E on Indian Ocean Region (IOR) providing the Telecommunication and broadcasting services is used for our work. The signal is transmitted from the ground station/satellite earth station to Intelsat satellite 906. Satellite and satellite earth station is shown in Figure 3.3. The latitude and longitude of the site located at Mohakhali, Dhaka are 23.786^0N and 90.4111^0E respectively. The elevation of the satellite from the site is 49.51^0. For specific attenuation calculation, we considered the signal for linear as well as circular polarization. The satellite details with key parameters are given in section 3.3.1, Table 3.1.

3.3.1 Satellite information

Intelsat 906 satellite has the footprint on Asia and the pacific region. It operates in both C-band and Ku band frequencies. Major parameters are shown in the Table below:

Table 3.1: Intelsat 906 satellite key parameters (Source: www.intelsat.com)

Satellite Location		64.15^o E
C Band key parameters	Total Transponders	Up to 72 (in equiv. 36 MHz units)
	Polarization	Circular (LHCP or RHCP)
	Downlink Frequency	3625 to 4200
	EIRP (Edge of coverage to beam peak)	
	Global Beam	31.0 up to 35.7 dBW
	Hemi Beam	36.0 up to 41.0 dBW
	Zone Beam	36.0 up to 44.4 dBW
	Uplink Frequency	5850 to 6425 MHz
	G/T Range (Edge of coverage to beam peak)	
	Global Beam	-11.2 up to -6.3 dB/K
	Hemi Beam	-8.0 up to -1.6 dB/K
	Zone Beam	-7.4 up to +5.9 dB/K
	Edge of Coverage SFD Range	-89.0 to -67.0 dBW/m^2
Ku Band key parameters	Total Transponders	Up to 22 (in equiv. 36 MHz units)
	Polarization	Linear (Horizontal or Vertical)
	Downlink Frequency	10.95 to 11.70 GHz
	Uplink Frequency	14.00 to 14.50 GHz
	G/T Range (beam peak)	
	Spot -1	Up to 9.2 dB/K
	Spot-2	Up to 9.3 dB/K
	Edge of Coverage SFD Range	-87.0 to -69.0 dBW/m^2

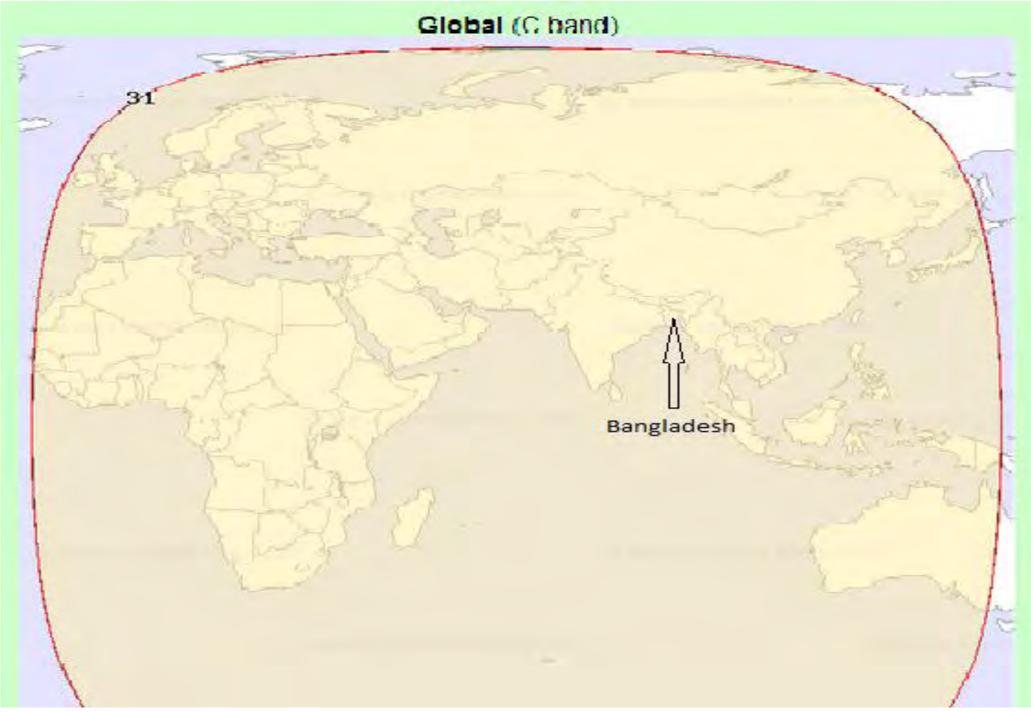

Figure 3.1: Global Coverage for C-Band Transponder

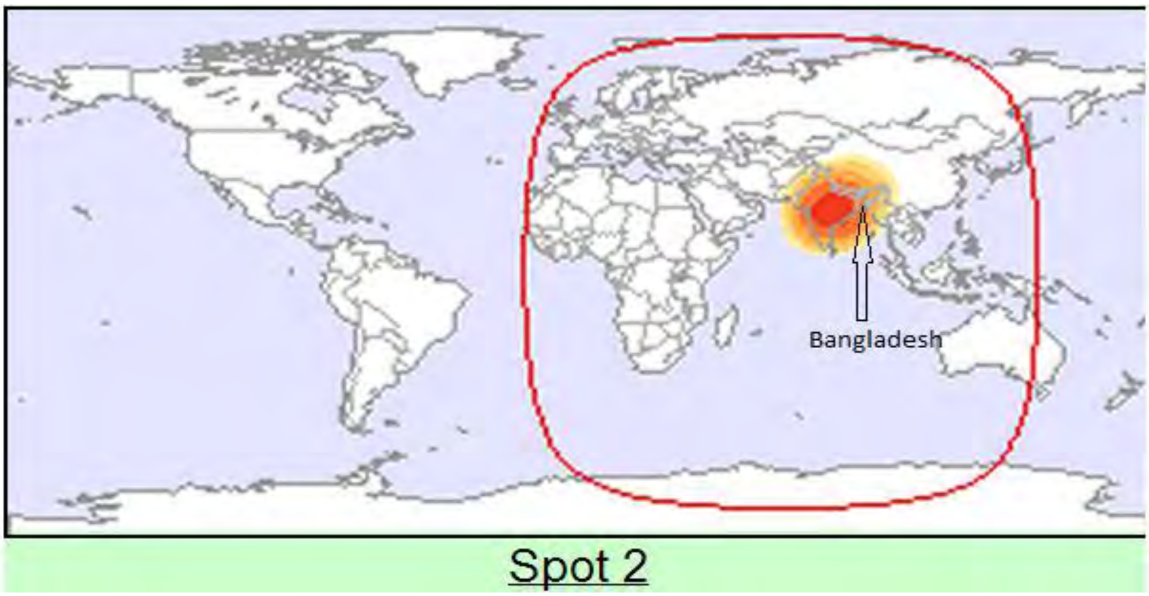

Figure 3.2: IS-906 satellite Ku band coverage

Figure 3.1 and 3.2 shows Intelsat satellite 906 coverage for C-band and Ku-band transponder respectively over Bangladesh. This satellite has footprint in Asia and the Pacific region. So, selection of satellite located at 64^{o}E orbital position is appropriate for our work.

3.3.2 Site Information

We have chosen eight sites for ground communication equipment and satellite earth station. Practically, One station is located at Mohakhali, central location of capital Dhaka. Other station is located at Betbunia, Rangamati within Chittagong Division the South Eastern part of Bangladesh. Distance of Betbunia is around 300 km towards south eastern direction from capital city Dhaka. Site locations with positions and look angle are given in Table 3.2 below:

Table 3.2: Site Information

Site	Position		Look Angles	
	Latitude	Longitude	Elevation	Azimuth
Central, Mohakhali, Dhaka	23.786^{0}N	90.4111^0 E	49.51^0	230.82°
Mid Western, Faridpur	23.60^{0}N	89.85^{0}E	50.2^0	230.1^0
North Eastern, Sylhet	24.8978^{0}N	91.8714^{0}E	47.6^0	231.2^0
North Western, Rajshahi	24.3667^{0}N	88.6^{0}E	50.5^0	227.7^0
Northern, Rangpur	25.7504^{0}N	89.2559^{0}E	49.3^0	227.1^0
South Eastern, Betbunia, Rangamati	22.633^0 N	92.13^0 E	48.90^0	234.50^0
South Western, Khulna	22.8088°N	89.2467^0 E	51.2^0	230.3^0
Southern, Barisal	22.7000°N	90.3667^0 E	50.3^0	231.9^0

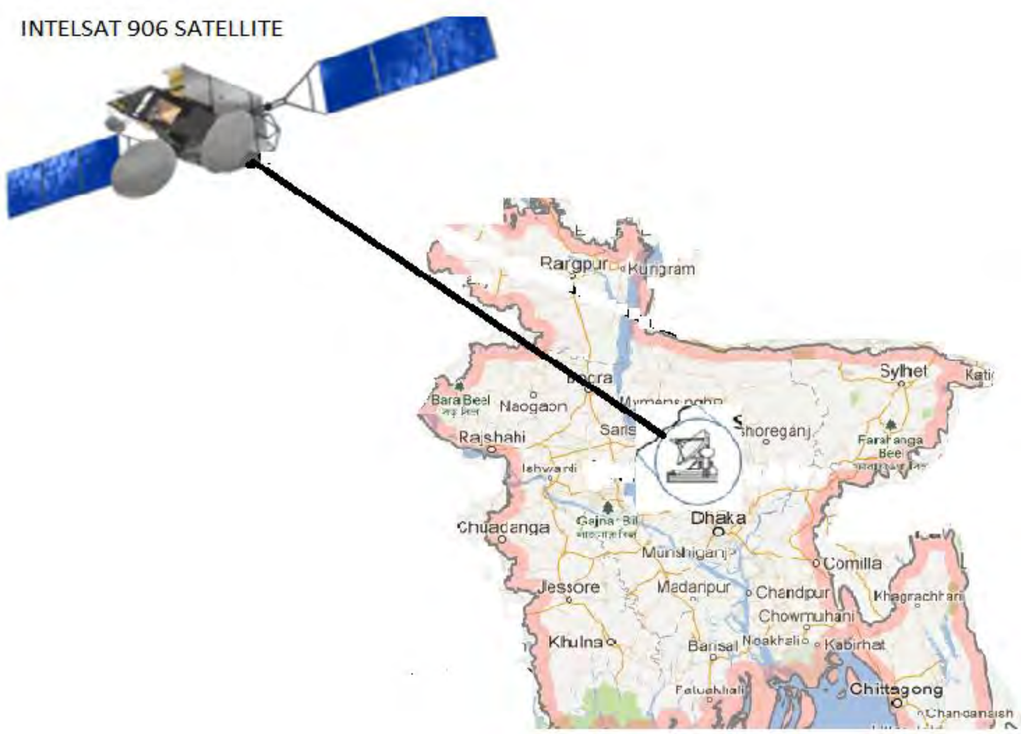

Figure 3.3: Satellite and Satellite Earth Station connectivity.

3.3.3 Rain Data Collection points

Bangladeshi climate is tropical with a mild winter from October to March, and a hot, humid summer from March to June. It has a subtropical monsoon climate characterized by wide seasonal variations in rainfall, moderately warm temperatures, and high humidity [1]. Average maximum and minimum winter temperature of Bangladesh is 29oc and 11oc respectively. On the other hand, Average maximum and minimum summer temperature of Bangladesh is 40oc and 21oc respectively. It locates at 88o to 93o longitude (East) and 20o to 27o Latitude (North). Because of its location just south of the foothills of the Himalayas, where monsoon winds turn west and northwest.

Figure 3.4: Bangladesh map with rain data collection sites

Bangladesh receives the heavy average precipitation which can be classified into eight distinct regions. Figure 3.4 shows Bangladesh map indicating major zones and Table 3.3 gives daily rain data (in mm) collection site with their longitude, latitude and height above the sea level.

Table 3.3: Daily Rain data collection centre

Sl. No.	Name of the Location	Latitude (N)		Longitude (E)		Elevation from sea level(Meter)
		Deg.	Mts.	Deg.	Mts.	
01	Dhaka	23	46	90	23	8.45
02	Faridpur	23	36	89	51	8.10
03	Sylhet	24	54	91	53	33.53
04	Rajshahi	24	22	88	42	19.50
05	Rangpur	25	44	89	16	32.61
06	Chittagong	22	21	91	49	33.20
07	Khulna	22	47	89	34	2.10
08	Barisal	22	43	90	22	2.10

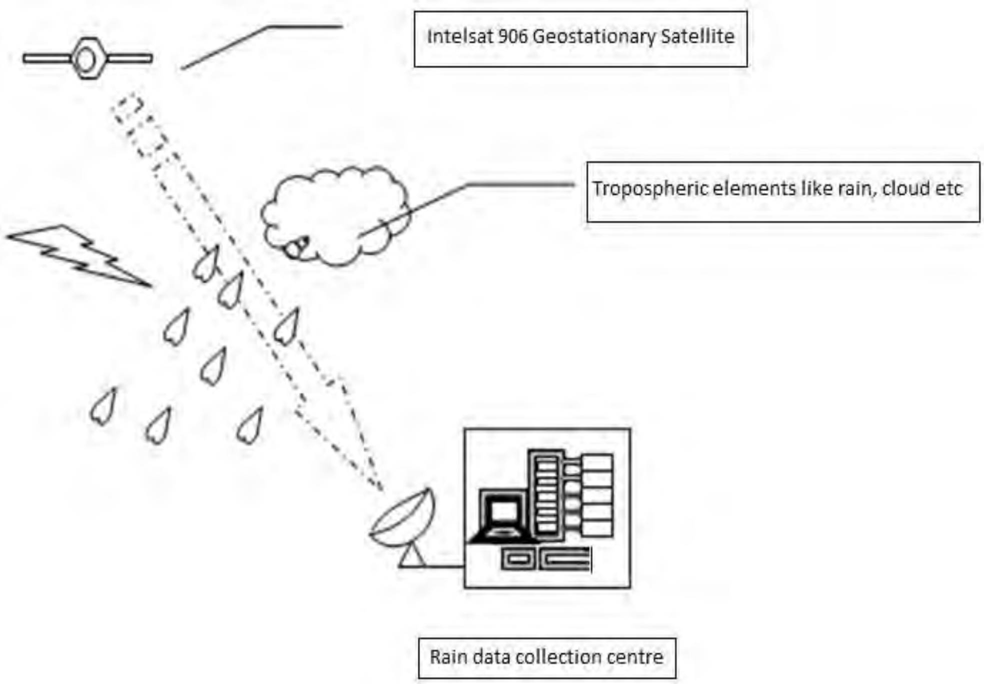

Figure 3.5: Schematic Block diagram for the Satellite and rain data collection Platform

In practical scenario, rain originating from troposphere region and sample collection in any centre is shown in figure 3.5. Though we have collected rain data from 35 different stations all around Bangladesh, only eight major cities are selected to calculate specific attenuation.

3.4 Approach

3.4.1 Pre-processing of Data

Daily rain data measured in millimetres unit from eight major parts of Bangladesh. Firstly, data from 35 observation points were used as rain data collection point. For each location, monthly data is considered as a sum of daily data. Secondly, these 12 months data were accumulated to get total annual fall rain data. Only one location from every zone is selected for calculation of rain attenuation on that specific zone. The processed annual rain fall data is converted to one minute rain rate data. Finally, Rain attenuation statistics is obtained from annual rain fall rate.

3.4.2 Conversion of rain statistics to rain intensities

Common rain attenuation prediction methods require 1- min rain rate data, which is scarce in the tropical and subtropical region [8]. However, yearly rainfall data are available at many meteorological stations. A method for converting the available rainfall data to the equivalent 1 min rain rate cumulative distribution (CD) would be very useful for radio engineers for link budget calculation. For this reason 1 min rain rate CD can be estimated by the use of the Moupfouma model and long-term mean annual rainfall data [1].

Several studies have shown that the Moupfouma model with refined parameters can best describe the 1 min rain rate distribution in tropical regions [8]. Moupfouma found that the 1 min rain rate CD could be expressed as [2]

$$p(R >= r) = 10^{-4}\left(\frac{R0.01+1}{r+1}\right)^{b} \exp\left(u[R0.01 - r]\right) \text{ -------------------------------- } (1)$$

where ***r*** [mm/h] represents the rain rate exceeded for a fraction of the time, and b is approximated by the following expression:

$$b = \left(\frac{r - R0.01}{R0.01}\right)\ln\left(1 + \frac{r}{R0.01}\right) \text{ --- } (2)$$

The parameter u in equation (1) governs the slope of rain rate CD, and depends on the local climatic conditions and geographical features. For tropical localities

$$u = \frac{4\ln 10}{R0.01}\exp\left(-\lambda\left[\frac{r}{R0.01}\right]^{\gamma}\right)$$ -- - (3)

where λ *and* γ are positive constants. Based on the measured **1** min rain rate CD at several locations in Malaysia, Singapore and Indonesia [8], it was found that in tropical regions the best values for the parameters λ and γ are given in Table 3.4:

Table 3.4: Parameters λ and γ

Annual Rain Intensity	λ	γ
M<3000	0.707	0.060
M>3000	0.398	-0.125

Thus, the Moupfouma model requires three parameters λ, γ and $R_{0.01}$. M is the mean annual rainfall. The first two parameters are easily determined from Table 3.4. To estimate $R_{0.01}$, it is suggested that it be derived from the value of M at the location of interest.

Several techniques have been described for the estimation of $R_{0.01}$ from the long-term mean annual rainfall *M.* These include the Morita model, Hosoya *et al.*model, Ajayi *et al.* model, Tropical India regression model and Chebil model [6]. All these five models use the power law relationship

$R_{0.01} = \alpha M^{\beta}$ -- (4)

where α and β are regression coefficients. In Chebil model the regression coefficients α and β are defined as [6]

$\alpha = 12.2903$ and $\beta = 0.2973$ -- (5)

Using Chebil model, long-term mean annual rainfall data has been converted to 1 min rain rate data and presented in Chapter 4 (Result and Discussion) Table 4.1.

The highest rain intensity is observed at south eastern region of Bangladesh at 136 mm/hr and lowest at North western zone is 111 mm/hr. The rain intensity recommended by ITU-R map is found 95 mm/hr for Bangladesh [7] which is far lower than converted rain intensity from measured long term annual rainfall.

3.4.3 Calculation of long-term rain attenuation statistics from point rainfall rate

The following procedure provides estimates of the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 55 GHz. The following parameters are required:

$R_{0.01}$:	point rainfall rate for the location for 0.01% of an average year (mm/h)
hs:	height above mean sea level of the earth station (km)
θ:	elevation angle (degrees)
φ:	latitude of the earth station (degrees)
f:	frequency (GHz)
R_e:	effective radius of the Earth (8 500 km).

If local data for the earth station height above mean sea level is not available, an estimate can be obtained from the maps of topographic altitude given in Recommendation ITU-R P.1511. The geometry is illustrated in Figure 3.6

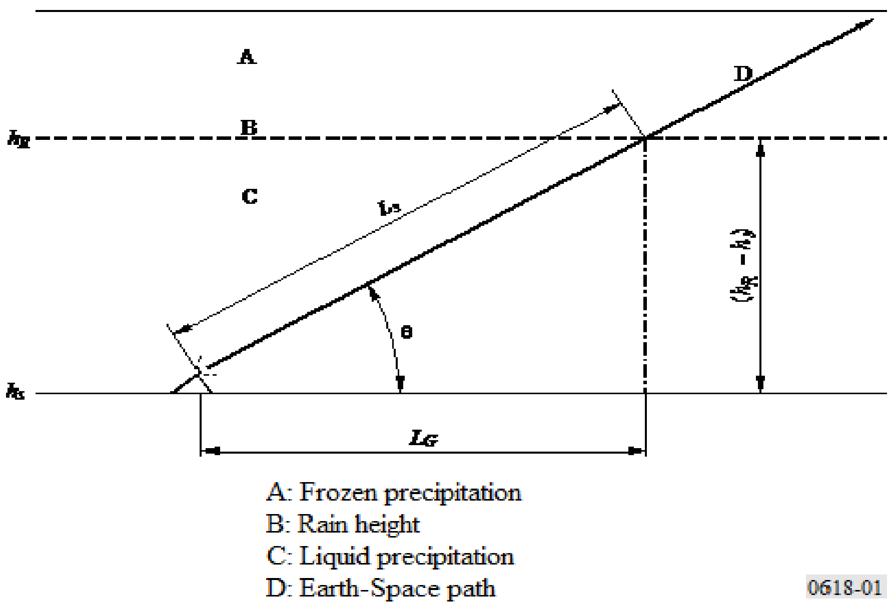

Fig-3.6: Schematic presentation of an earth space path giving the parameters to be input into the attenuation prediction process.

Step 1: Determine the rain height, h_R, as given in Recommendation ITU-R P.839.

Step 2: For $\theta \geq 5°$ compute the slant path length, L_s, below the rain height from:

$$L_s = \frac{(h_R - h_s)}{\sin\theta} \quad \text{km} \quad \text{...(6)}$$

For $\theta < 5$, the following formula is used:

$$L_s = \frac{2(h_R - h_s)}{\left(\sin^2\theta + \frac{2(h_R - h_s)}{R_e}\right)^{1/2} + \sin\theta} \quad \text{km} \quad \text{........................ (7)}$$

If $h_R - h_s$ is less than or equal to zero, the predicted rain attenuation for any time percentage is zero and the following steps are not required.

Step 3: Calculate the horizontal projection, L_G, of the slant path length from:

$$L_G = L_s \cos\theta \quad \text{km} \quad \text{.. (8)}$$

Step 4: Obtain the rainfall rate, $R_{0.01}$, exceeded for 0.01% of an average year (with an integration time of 1 min). If this long-term statistic cannot be obtained from local data sources, an estimate can be obtained from the maps of rainfall rate given in Recommendation ITU-R P.837. If $R_{0.01}$ is equal to zero, the predicted rain attenuation is zero for any time percentage and the following steps are not required.

Step 5: Obtain the specific attenuation γ_R, using the frequency-dependent coefficients given in Recommendation ITU-R P.838-3 and the rainfall rate, $R_{0.01}$, determined from Step 4, by using:

$$\gamma_R = k\,(R_{0.01})^{\alpha} \quad \text{dB/km} \quad \text{.. (9)}$$

Frequency dependant co-efficient for estimating specific attenuation at linear (vertical) polarization

Table 3.5: k and α values for 4, 12 and 20 GHz frequency

Co-efficient	C-Band (4 GHz)	Ku Band (12 GHz)	Ka Band (20 GHz)
K	0.0002461	0.02455	0.09611
α	1.2476	1.1216	0.9847

Table 3.6: k and α values for 6, 14 and 30 GHz frequency

Co-efficient	C-Band (6 GHz)	Ku Band (14 GHz)	Ka Band (30 GHz)
K	0.0004878	0.04126	0.2291
α	1.5728	1.0646	0.9129

Frequency dependant co-efficient for estimating specific attenuation at circular polarization considering elevation angle 49.51 degrees

Table 3.7: k and α values for 4, 12 and 20 GHz frequency

Co-efficient	C-Band (4 GHz)	Ku Band(12 GHz)	Ka Band (20 GHz)
K	0.0001766	0.0242	0.0939
α	1.3547	1.1516	1.0199

Table-3.8: k and α values for 6, 14 and 30 GHz frequency for circular polarisation

Co-efficient	C-Band (6 GHz)	Ku Band(14 GHz)	Ka Band (30 GHz)
K	0.0005967	0.0393	0.2347
α	1.5830	1.1002	0.9311

Step 6*:* Calculate the horizontal reduction factor, $r_{0.01}$, for 0.01% of the time:

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\frac{L_G\,\gamma_R}{f}} - 0.38\left(1 - e^{-2L_G}\right)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Step 7: Calculate the vertical adjustment factor, $v_{0.01}$, for 0.01% of the time:

$$\zeta = \tan^{-1}\left(\frac{h_R - h_s}{L_G\, r_{0.01}}\right) \qquad \text{degrees}$$

For $\zeta > \theta$,
$$L_R = \frac{L_G\, r_{0.01}}{\cos\theta} \qquad \text{km}$$

Else,
$$L_R = \frac{(h_R - h_s)}{\sin\theta} \qquad \text{km}$$

If $|\varphi| < 36°$, $\quad \chi = 36 - |\varphi| \quad$ degrees

Else, $\quad \chi = 0 \quad$ degrees

$$\nu_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}\left(31\left(1 - e^{-(\theta/(1+\chi))}\right)\frac{\sqrt{L_R\,\gamma_R}}{f^2} - 0.45\right)}$$

Step 8: The effective path length is:

$$L_E = L_R \, \nu_{0.01} \quad \text{km} \qquad (11)$$

Step 9*:* The predicted attenuation exceeded for 0.01% of an average year is obtained from:

$$A_{0.01} = \gamma_R \, L_E \quad \text{dB} \qquad (12)$$

Step 10*:* The estimated attenuation to be exceeded for other percentages of an average year, in the range 0.001% to 5%, is determined from the attenuation to be exceeded for 0.01% for an average year:

If $p \geq 1\%$ or $|\varphi| \geq 36°$: $\beta = 0$

If $p < 1\%$ and $|\varphi| < 36°$ and $\theta \geq 25°$: $\beta = -0.005(|\varphi| - 36)$

Otherwise: $\beta = -0.005(|\varphi| - 36) + 1.8 - 4.25 \sin \theta$

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{-(0.655 + 0.033 \ln(p) - 0.045 \ln(A_{0.01}) - \beta(1 - p) \sin \theta)} \quad \text{dB} \qquad (13)$$

This method provides an estimate of the long-term statistics of attenuation due to rain. When comparing measured statistics with the prediction, allowance should be given for the rather large year-to-year variability in rainfall rate statistics (ITU-R P.678).

3.5 Summary

Key components of the work such as ITU-R recommendations, experimental satellite, ground station information, rain intensity from annual rain data and procedural steps are vital to get specific attenuation in different regions of any country. This chapter provides working parameters, methods and theoretical ideas to estimate rain attenuation for different percentage of time of an average year.

Chapter 4

Result and Discussion

4.1 Introduction

In this chapter, probability distribution of annual rainfall, statistical annual rainfall variations, comparison of predicted rain attenuation with ITU and different zones of Bangladesh are discussed. Results and discussions and work synopsis are also mentioned.

4.2 Probability distribution of annual rainfall all over Bangladesh

Rain Data is collected during the years 1948 – 2011 from eight different zones. Total 35 stations are used to obtain probability distribution of annual rainfall all around Bangladesh. Annual rainfall within 50 mm range is stacked and considered as each segment. It is observed that maximum and minimum rainfall in Bangladesh is 1017 mm and 6095 mm respectively from 60 years rain data. Probability of distribution graph is shown figure 4.1.

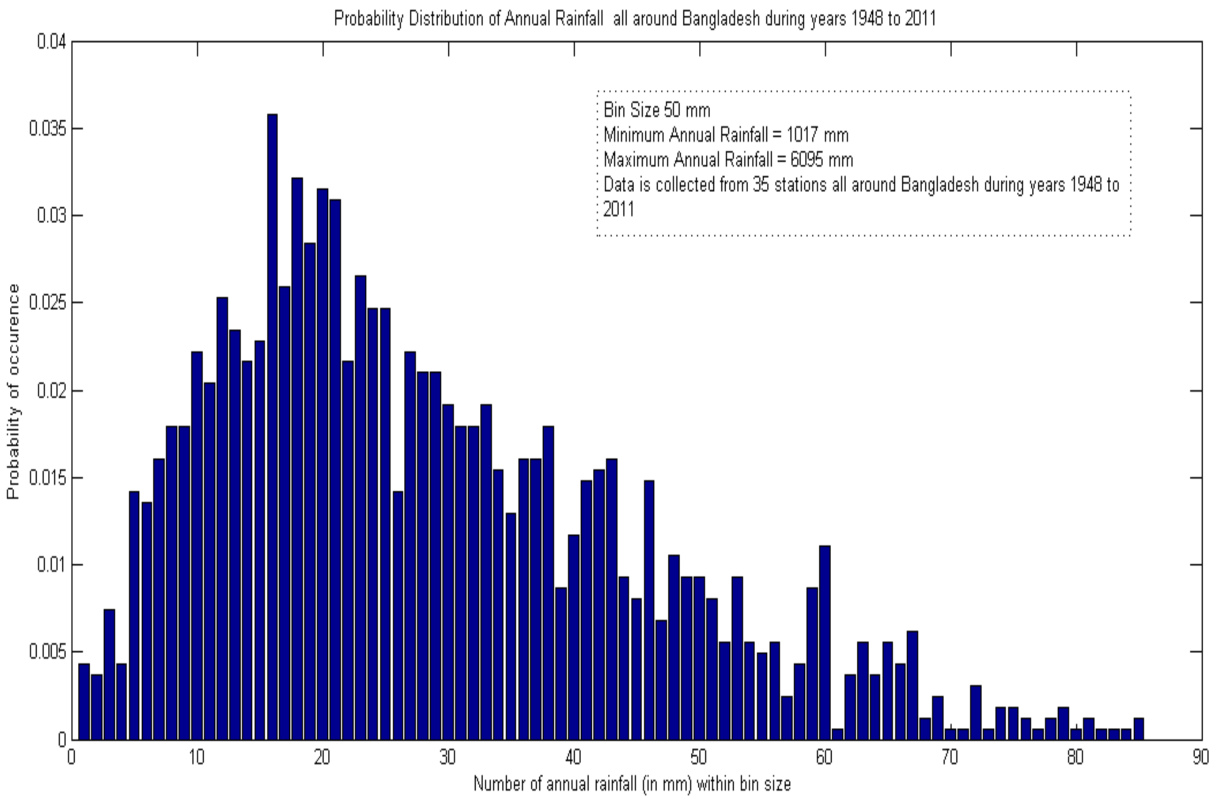

Figure 4.1: Probability distribution of annual rainfall (in mm) for all regions of Bangladesh.

4.3 Annual Rainfall Statistics in Bangladesh

Heavy rainfall is characteristic of Bangladesh. With the exception of the relatively dry western region of Rajshahi, where the mean annual rainfall is about 1633 mm, most parts of the country receive around 2000 mm of rainfall per year. Maximum mean annual rainfall is observed at Chittagong in south eastern zone which is 3200mm. After conversion in rainfall rate (mm/hr), minimum and maximum rainfall rate is 111 mm/hr and 136 mm/hr observed in north western zone and south eastern zone respectively. ITU recommended rain intensity is 95 mm/hr which is much more lower than the minimum rainfall rate in Bangladesh.

Zone wise measured mean annual rainfall data and corresponding converted rain intensity is expressed in Table 4.1

Table 4.1: Measured mean rainfall and converted rain intensity

Name of Zone	Measured Mean Annual Rainfall in mm	Converted Rainfall rate , R0.01, mm/hr
Central	2.1127183e+003	120
Mid Western	1.8590672e+003	115
North Eastern	2.6877339e+003	129
North Western	1.6334967e+003	111
Northern	2.0488421e+003	119
South Eastern	3.2161013e+003	136
South Western	1.7374404e+003	113
Southern	2.4117472e+003	124
ITU Map [7]		95

Average precipitation of Bangladesh is collected from eight distinct regions. Different zones are named as Central, Mid Western, North Eastern, North Western, Northern, South Eastern, South Western and Southern Zone. The annual rainfall variation during the year 1948 to 2011 for eight regions in Bangladesh is shown graphically from Figure 4.2 to Figure 4.9.

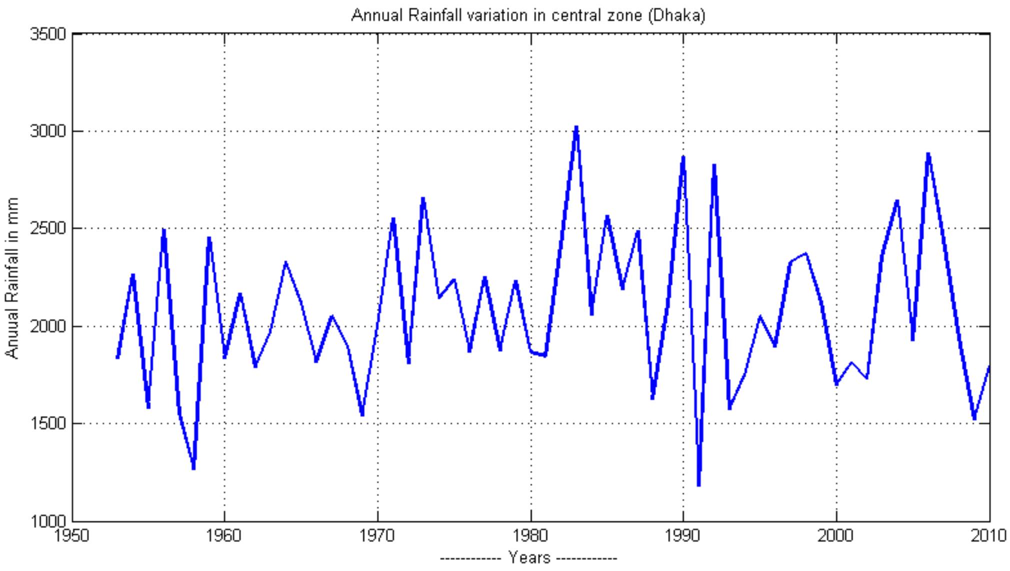

Figure 4.2: Annual rainfall variation measured in central zone (Dhaka) during the Year 1952-2010.

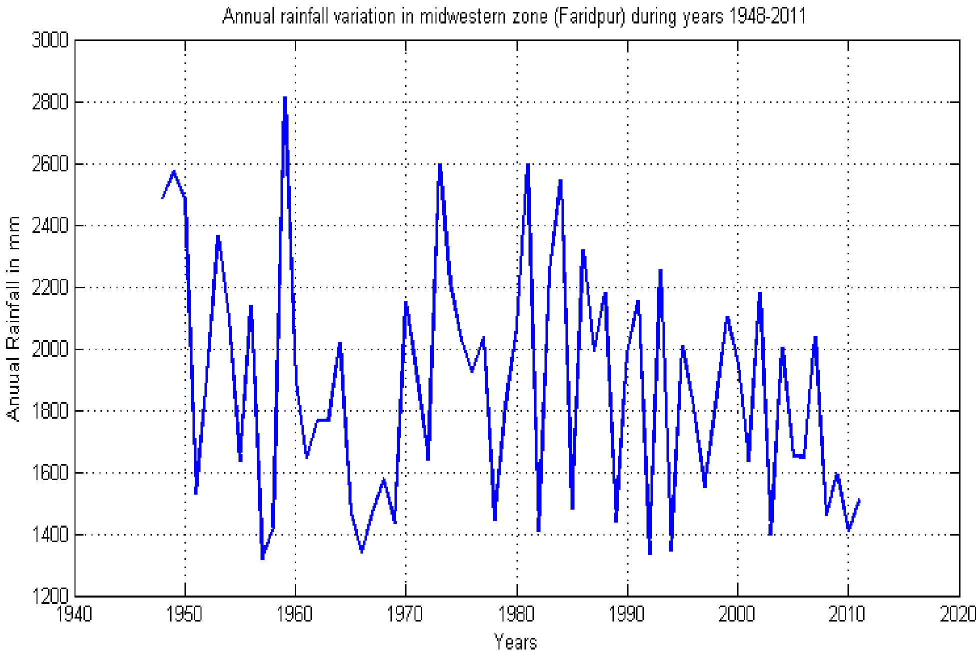

Figure 4.3: Annual rainfall variation measured in Mid-Western zone (Faridpur) during the Year 1948-2011.

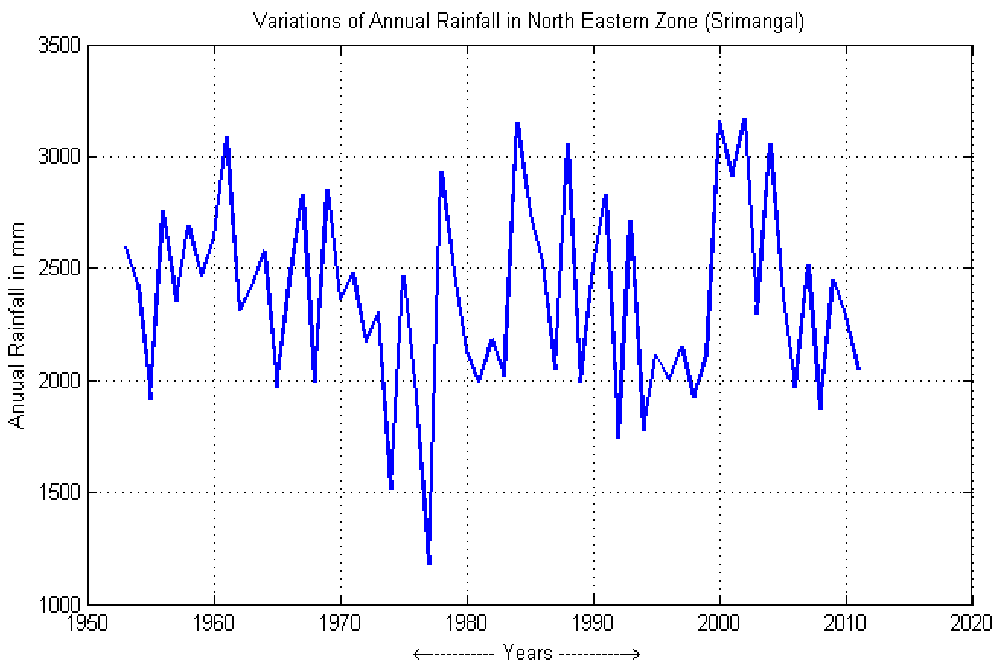

Figure 4.4: Annual rainfall variation measured in North-Eastern zone (Srimangal) during the Year 1952-2011.

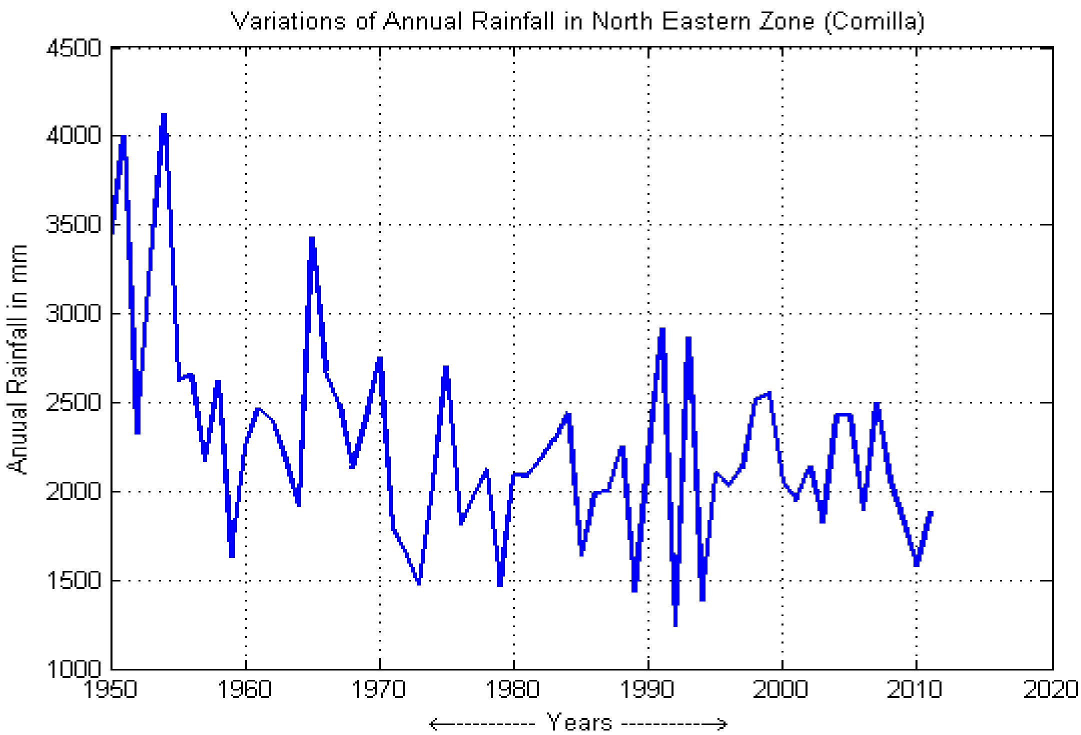

Figure 4.5: Annual rainfall variation measured in North-Eastern zone (Comilla) during the Year 1950-2011.

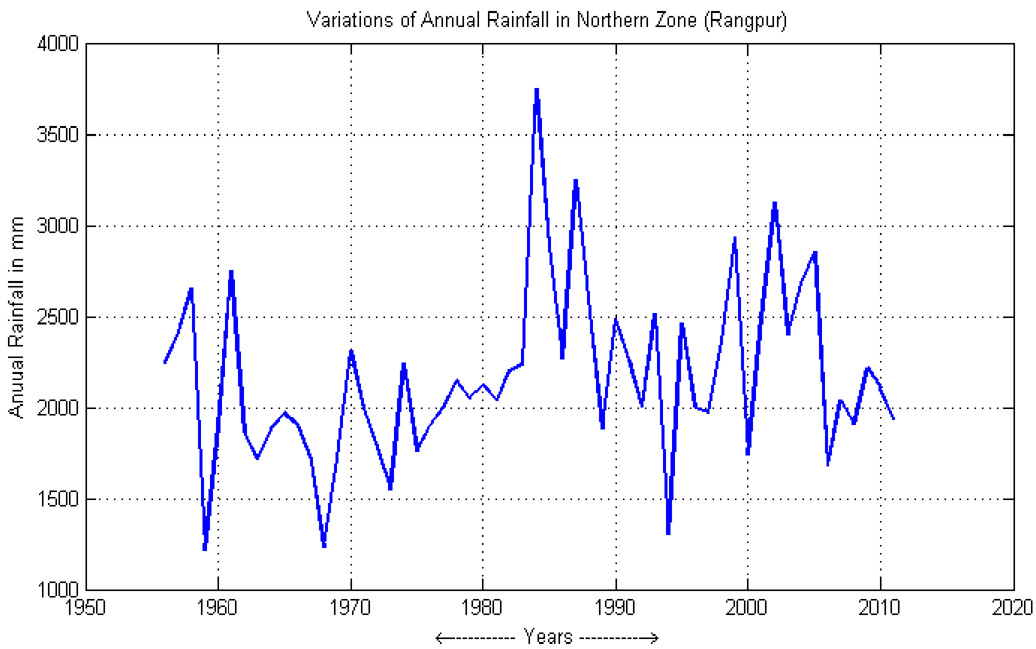

Figure 4.6: Annual rainfall variation measured in Northern zone (Rangpur) during the Year 1955-2011.

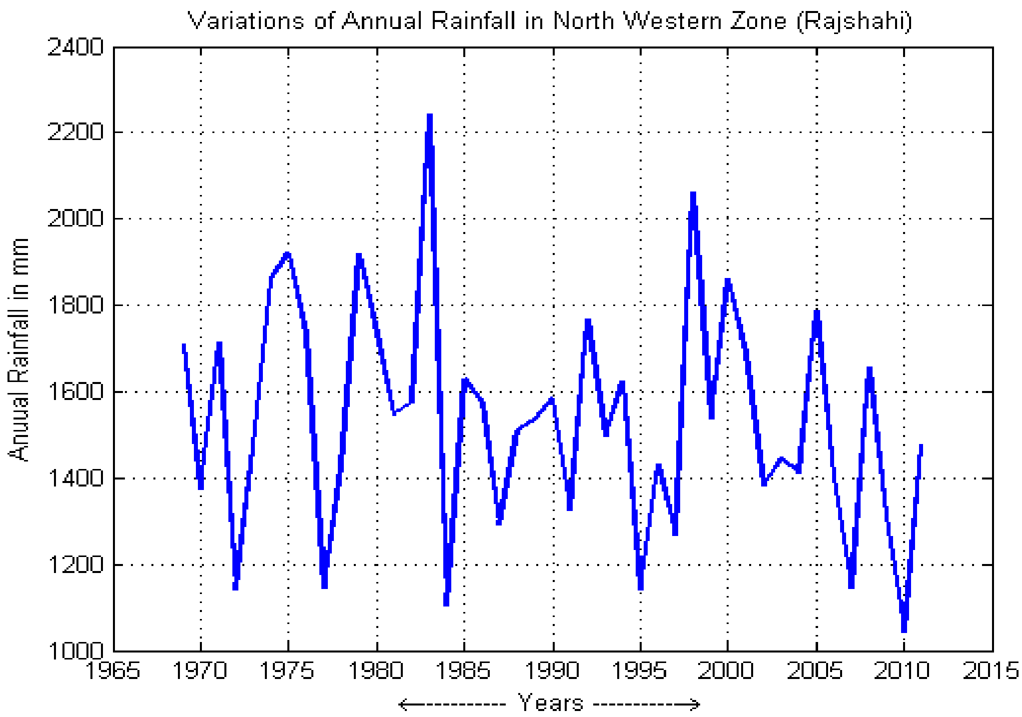

Figure 4.7: Annual rainfall variation measured in North-Western zone (Rajshahi) during the Year 1967-2011.

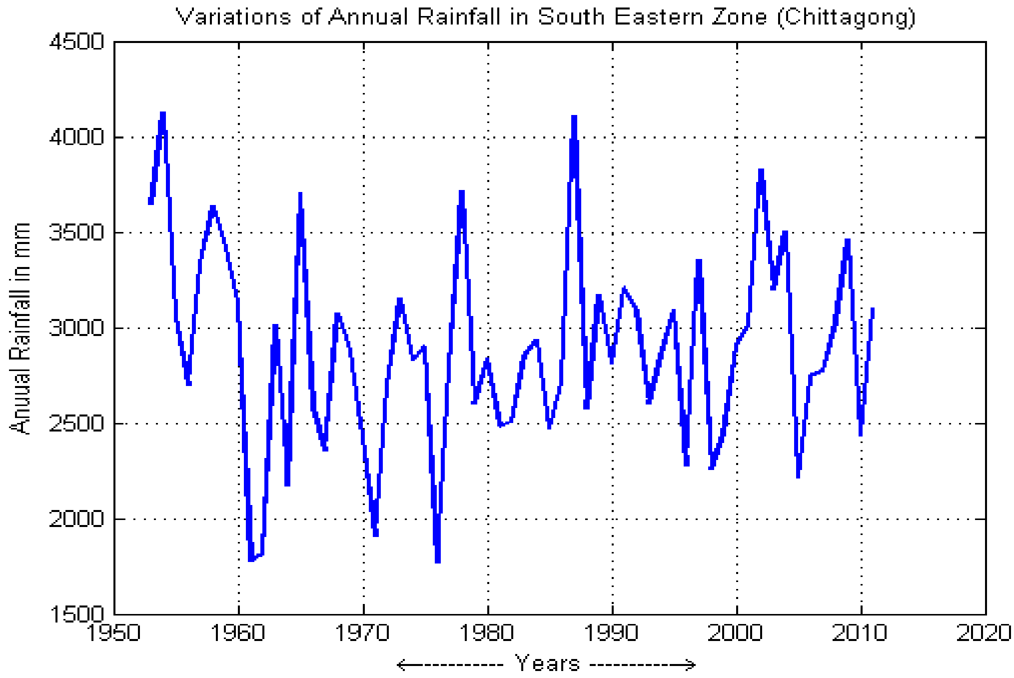

Figure 4.8: Annual rainfall variation measured in South-Eastern zone (Chittagong) during the Year 1948-2011.

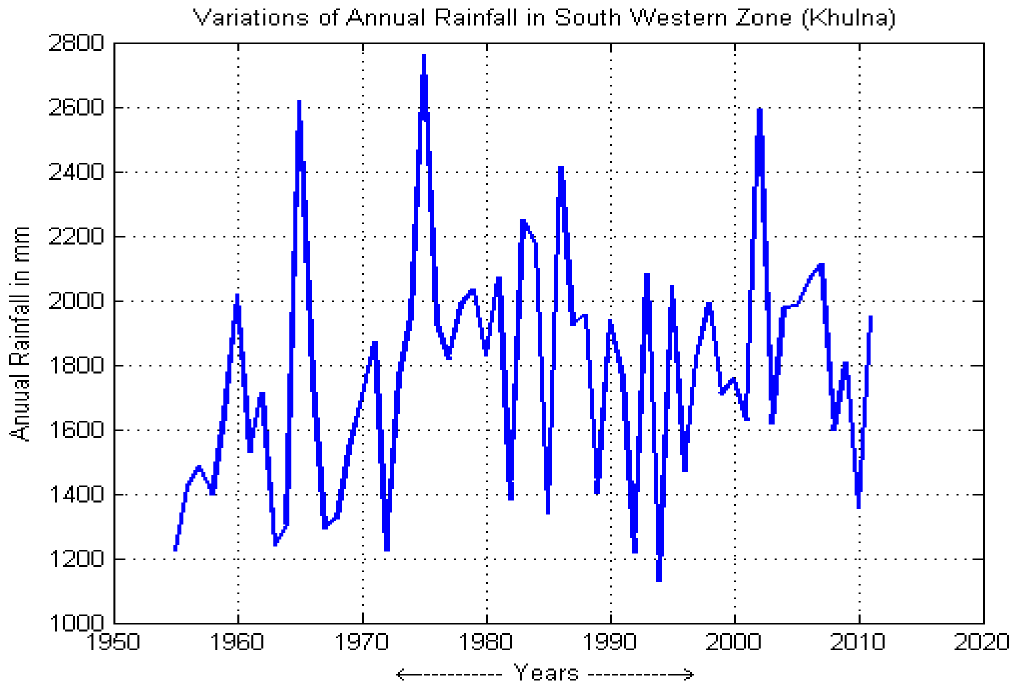

Figure 4.9: Annual rainfall variation measured in South-Western zone (Khulna) during the Year 1955-2011.

4.4 Comparison of Rain Attenuation Variations with ITU and Eight Different Zones of Bangladesh in C, Ku and Ka Band Frequencies

Rain attenuation comparison at C, Ku and Ka band frequencies for different zones of Bangladesh with ITU is shown in be Table 4.2. Signals are considered vertically polarized.

Table 4.2:Attenuation comparison at 0.01% of time exceeded for an average year (linear)

Freq. in GHz	Different zones and ITU attenuation (in dB) at A0.01% (Linear Polarization)								
	Central	Mid Western	North East	North West	Northern	South East	South West	Southern	ITU
4	0.4137	0.3918	0.4659	0.3766	0.4122	0.472	0.3778	0.42	0.3307
6	0.5513	0.5146	0.6331	0.4882	0.547	0.6596	0.4947	0.5688	0.4009
12	16.537	16.0129	17.6792	15.6286	16.4841	17.948	16.6249	16.7527	14.3141
14	22.2912	21.6166	23.6714	21.0886	22.1553	24.0638	21.2503	22.608	19.3641
20	40.2887	39.1557	42.4862	38.2357	40.0841	43.3626	38.5972	40.9959	35.0911
30	74.3594	72.4248	77.8773	70.8043	73.8851	79.7494	71.6098	75.7114	65.002

Table 4.3:Attenuation comparison at 0.01% of time exceeded for an average year (Circular)

Freq. in GHz	Different zones and ITU attenuation (in dB) at A0.01% (Circular Polarization)								
	Central	Mid Western	North East	North West	Northern	South East	South West	Southern	ITU
4	0.4747	0.448	0.5383	0.4294	0.4728	0.5468	0.4312	0.4828	0.373
6	3.1621	3.1621	3.4297	2.948	3.1679	3.5031	2.9625	3.2076	2.6675

From Table-4.2, it is observed that attenuation at C band for 4 GHz and 6 GHz frequency is 0.4 and 0.5 dB respectively when the signal is vertically polarized. In this case, difference between 4 GHz and 5 GHz is 0.1 dB only. But from Table- 4.3, attenuation at 4 GHz and 6 GHz frequency is 0.4 dB and 3 dB respectively when the signal is circular polarization. At 4 GHz frequency, rain attenuation for linear polarization and circular polarization is almost same. But, at 6 GHz frequency attenuation for circular polarization is 2.5 dB is more than attenuation for vertically polarized signal. Attenuation Table is made based on 0.01% of time exceeded for an average year.

For Ku and Ka band frequency, signal is considered vertically polarized. For 12, 14, 20 and 30 GHz frequency , rain attenuation is around 16 dB, 22 dB, 39 dB and 73 dB respectively. All these three bands C, Ku and Ka band, Rain attenuation prediction is obtained based on ITU-R recommended rain rate and converted rain intensity from long term rain data available in eight different zones of Bangladesh. The difference of predicted rain attenuation based on rain rate measured in Bangladesh and ITU at C-Band 4 GHz and 6 GHz frequency is only 0.1 dB. On the other hand, for Ku and Ka band 12 GHz, 14 GHz, 20 GHz and 30 GHz frequency, difference with ITU is 2 dB, 3 dB, 5 dB and 10 dB correspondingly.

Attenuation due to rain is calculated for different percentage of time from the 0.01% of time exceeded of an average year. Below figures 4.9 to 4.16 shows the attenuation for different areas of Bangladesh and ITU at different percentage of time and different frequency band.

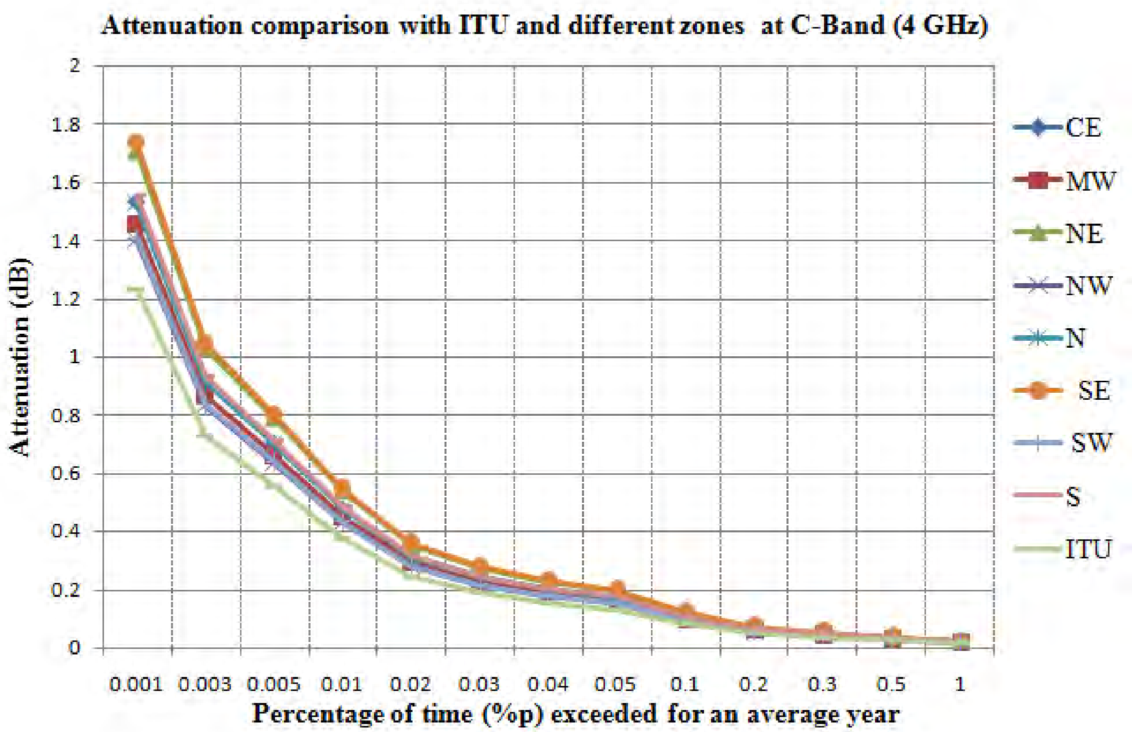

Figure 4.10: Variation of predicted rain attenuation (For C-Band, 4 GHz, circular polarization) at different percentage of time exceeded for an average year.

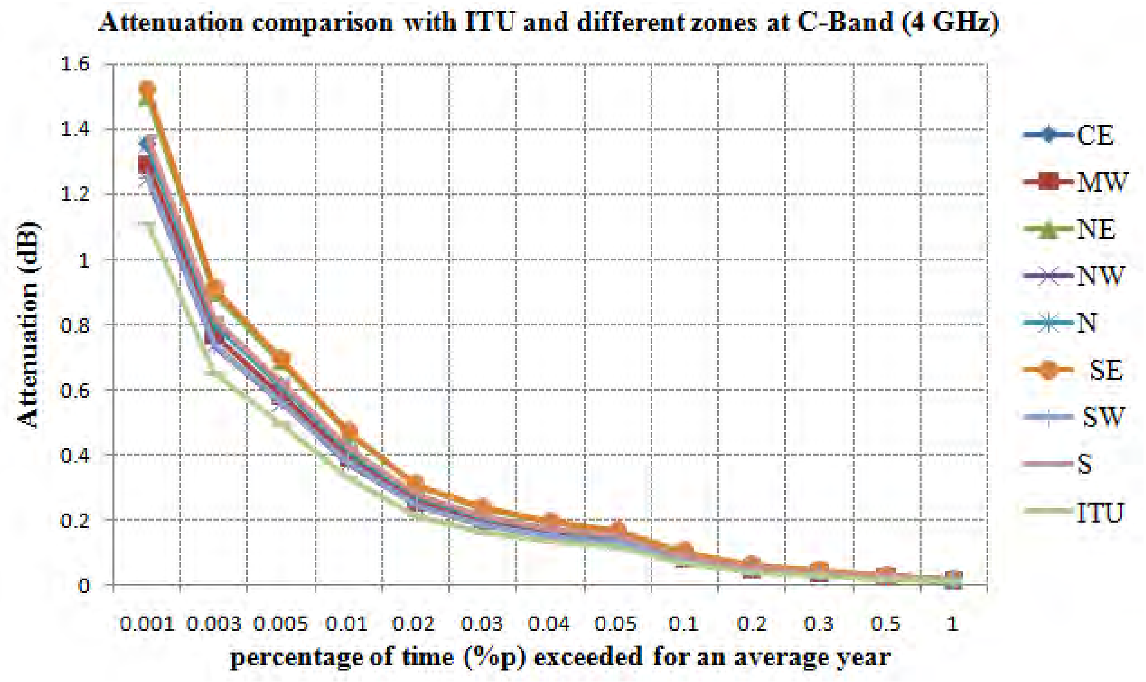

Figure 4.11: Variation of predicted rain attenuation (For C-Band, 4 GHz, linear polarization) at different percentage of time exceeded for an average year.

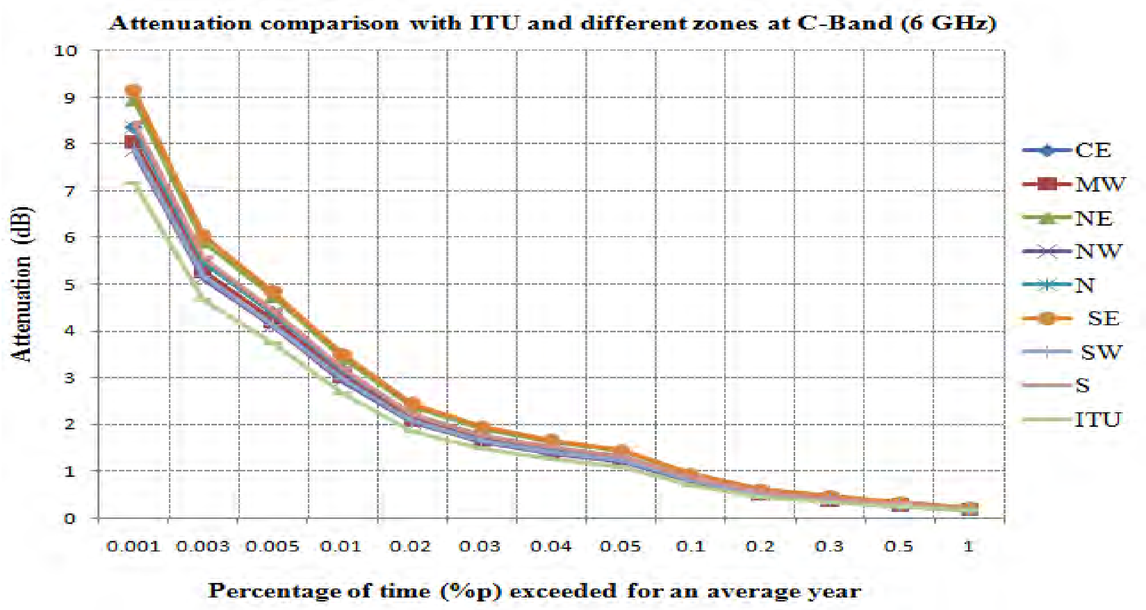

Figure 4.12: Variation of predicted rain attenuation (For C-Band, 6 GHz, circular polarization) at different percentage of time exceeded for an average year.

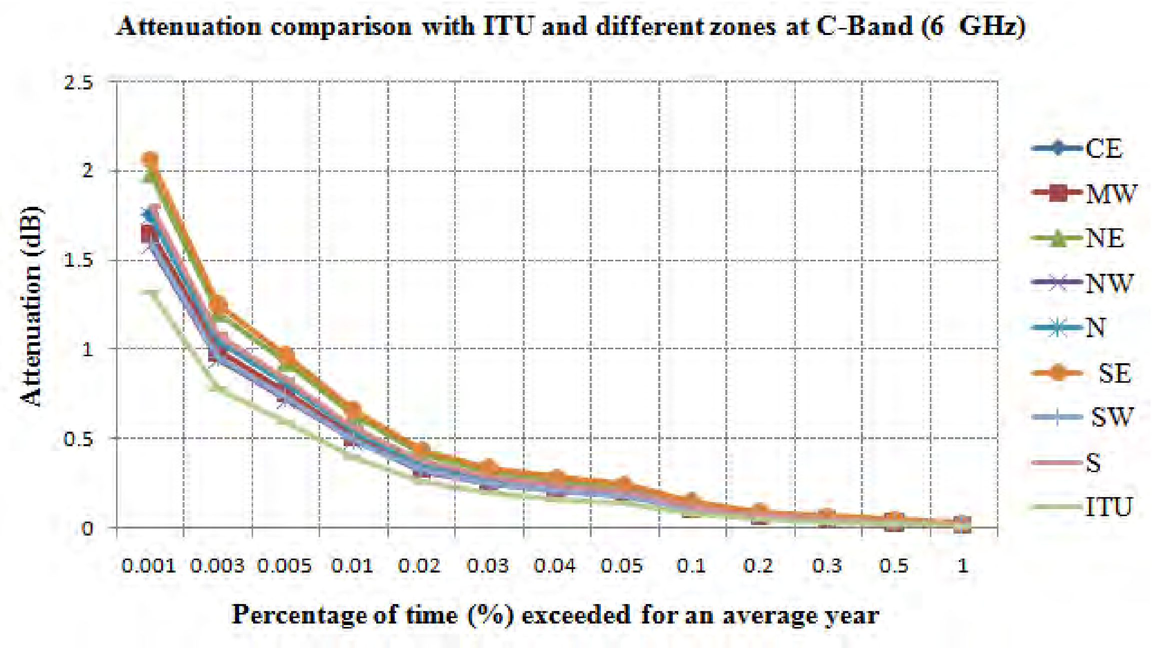

Figure 4.13: Variation of predicted rain attenuation (For C-Band, 6 GHz, linear polarization) at different percentage of time exceeded for an average year.

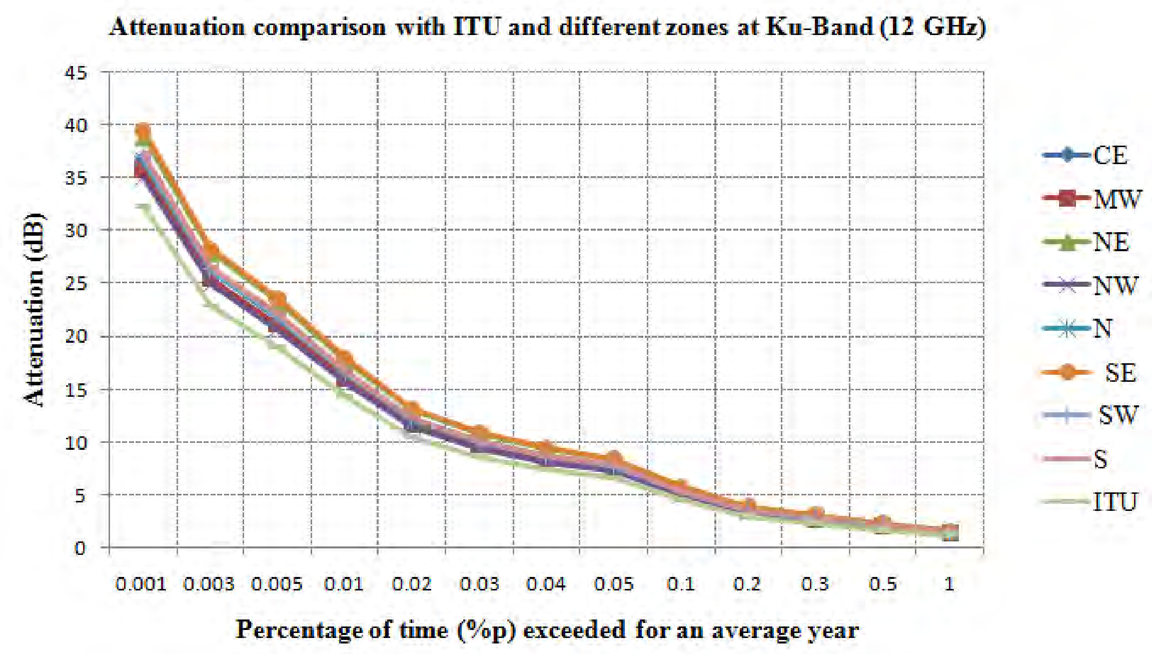

Figure 4.14: Variation of predicted rain attenuation (For Ku-Band, 12 GHz, linear polarization) at different percentage of time exceeded for an average year.

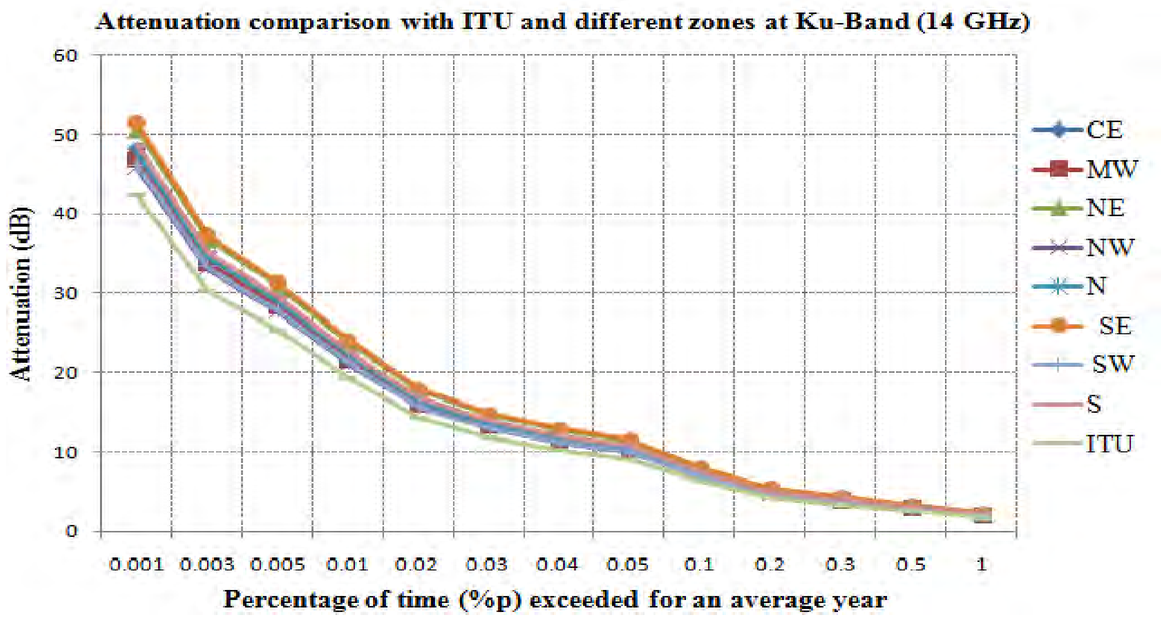

Figure 4.15: Variation of predicted rain attenuation (For Ku-Band, 14 GHz, linear polarization) at different percentage of time exceeded for an average year.

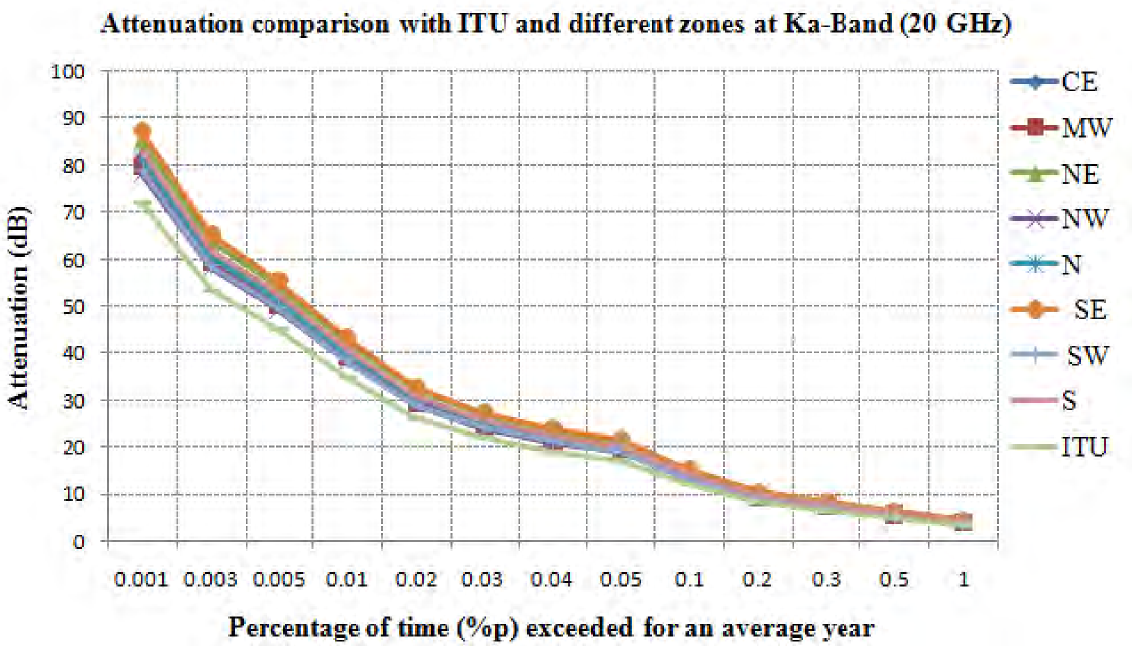

Figure 4.16: Variation of predicted rain attenuation (For a-Band, 20 GHz, linear polarization) at different percentage of time exceeded for an average year.

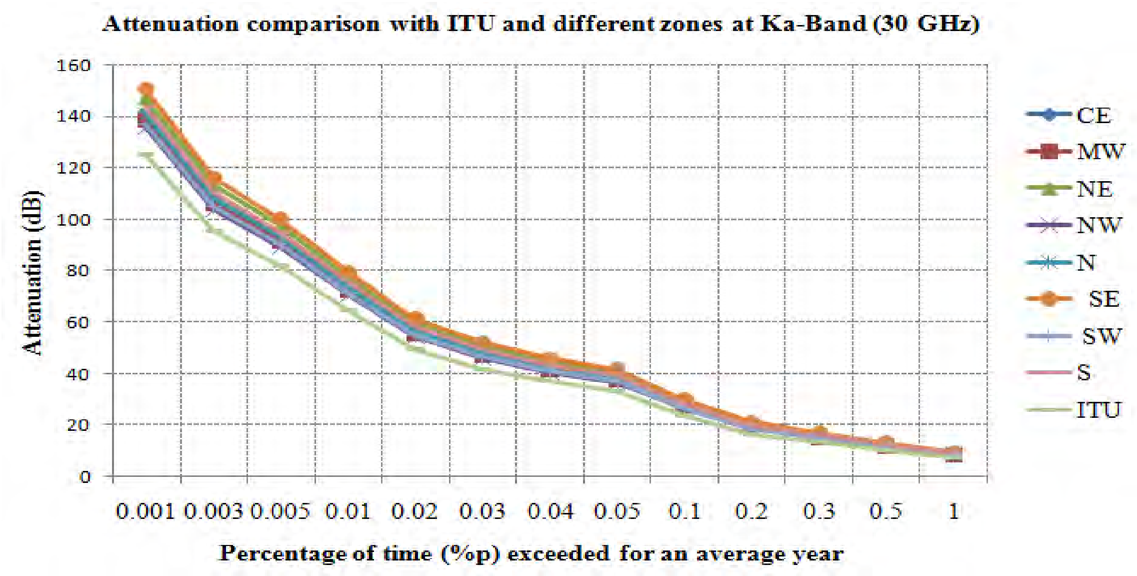

Figure 4.17: Variation of predicted rain attenuation (For Ka-Band, 30 GHz, linear polarization) at different percentage of time exceeded for an average year.

From Figure 4.10 to 4.17, it can be derived that predicted rain attenuation for central, mid western, north western, northern, southern and south western zone are almost same and these zones are less attenuated zones. On the other hand, north eastern and south eastern have higher rain attenuation. Differences of attenuation between less rain attenuated zones and higher attenuation zones are approximately 1.5, 2.5, 3 and 5 dB for 12, 14, 20 and 30 GHz frequency are respectively.

4.5 Result and Discussion

Probability distribution of annual rainfall is obtained based on available rain data from 35 (thirty five) stations in Bangladesh. Zone wise annual rainfall variations are given graphically from Figure 4.2 to 4.9. Predicted attenuations are also shown in graphically from Figure 4.10 to 4.17. Attenuation variations in eight different zones of Bangladesh and ITU-R recommended attenuation based rain intensity are derived. At 4 GHz frequency, rain attenuation for linear polarization and circular polarization is almost same. But, at 6 GHz frequency attenuation for circular polarization is 2.5 dB more than attenuation for vertically polarized signal. For Ku and Ka band frequency, signal is considered vertically polarized. For 12, 14, 20 and 30 GHz frequency, rain attenuation is around 16 dB, 22 dB, 39 dB and 73 dB respectively. The difference of predicted rain attenuation based on rain rate measured in Bangladesh and ITU at C-Band 4 GHz and 6 GHz frequency is only 0.1 dB. On the other hand, for Ku and Ka band 12 GHz, 14 GHz, 20 GHz and 30 GHz frequency difference with ITU is 2 dB, 3 dB, 5 dB and 10 dB correspondingly. Comparing prediction rain attenuation all around Bangladesh, it can be derived that rain attenuation in central, mid-western, north west , northern, south east and southern are quite same and these areas can considered flat attenuation zones. On the other hand, north eastern and south eastern zones are highly attenuated zones in Bangladesh. Difference of attenuation between flat attenuated zones and highly attenuated zones for 12, 14, 20 and 30 GHz frequency are approximately 1.5, 2.5, 3 and 5 dB respectively.

4.6 Work Synopsis

In this work the background of the work has been understood enhancing the knowledge on the prediction estimation models. Different types of prediction techniques are also covered. Annual rainfall (in mm) and their corresponding rain intensity for eight different zones of Bangladesh are measured. Regression co-efficient k and α for estimating specific attenuation are also presented. We considered the frequency C, Ku and Ka band those are operating at 4 GHz, 12 GHz, and 20 Hz respectively for down link purposes. And 6 GHz, 14 GHz and 30 GHz frequency are considered for uplink purposes in C, Ku and Ka band respectively. Satellite used for this experiment is Intelsat IS-906 located at 64^{o} E orbital position and Earth station locations are considered in eight different zones. Selected earth locations are Mohakhali, Dhaka for central zone, Faridpur for mid-western zone, Sylhet for south eastern zone, Rajshahi for north western zone, Rangpur for northern zone, Betbunia, Rangamati for south eastern zone , Khulna for south western zone and Barisal for southern zone. Earth station locations, their longitude, latitude, elevation angle and azimuth angle are calculated as well. Considering all the parameters mentioned above and using 10 (ten) steps for calculation of long-term rain attenuation statistics from point rainfall, we obtained rain attenuation for various frequency band. Signals are considered circular and vertical polarization for C-Band at 4 GHz and 6 GHz frequency. For Ku and Ka Bands at 12, 14, 20 and 30 GHz frequency, signals are considered only vertical polarization.

4.7 Summary

Above simulations and experimental results prove that developed model has obtained rain attenuation profile in different eight zones of Bangladesh. Results are derived from available rain data from Bangladesh. Specific attenuation from this model is compared with ITU-R recommended attenuation based on rain intensity and shown in graphically. This attenuation profile will help to calculate link budget and fixed margin for earth-space satellite communication links. This model does not cover the limitations of long term rain attenuation prediction model such large volume of rain data, drainage of power at non-attenuative time and loss of lock at the receiver during excess of margin.

Chapter 5

Conclusion

In this chapter, conclusion and future work are mentioned.

5.1 Conclusion

Rain is the principal source of attenuation at frequency more than 10 GHz. Because of densely congested lower bands frequency up to 10 GHz, scientists/engineers are moving to higher bands such Ku and Ka. But, Signal power degradation at Ku and Ka band due to rain can frequently lock of loss our receiver and therefore interrupt services. For reliability 99.99%, it is very much important to estimate rain attenuation properly for microwave communication link in any region where the rain is convective in nature like Bangladesh. This work is done to obtain rain attenuation variation all over Bangladesh and this result is compared with attenuation based on ITU recommended rain intensity. It is observed that rain attenuation at C-Band below 6 GHz is not significant as compare to Ku and Ka band. Rain attenuation at higher band like 14 GHz, 20 GHz and 30 GHz frequency, it is a great challenge to keep link alive with high reliability. Bangladesh Government is going to launch commercial satellite in geostationary orbit within a few years. This experiment will be helpful for link budget calculation and measurement of required power towards earth-space and space-earth direction for used transponders in Ku and Ka band.

5.2 Future Work

Rain attenuation prediction based on long term data helps to provide fixed margin for any satellite or microwave communication links to provide given design value of outage. Main drawbacks of fixed margin derived from long term predictions are power drainage during the non-attenuative time and excess outage due to attenuation level non-conforming to model. Future work can be done to mitigate rain attenuation automatically for any communications link. In this case, the margin of a link can be adaptively controlled instead of fixed.

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Appendix-1

MALAB Program

%Program to get annual rainfall rate and mean rain rainfall rate for different zones

```
clc
clear all;
close all;
d=fopen('E:\satcom_project\Rain Data from BMD\Daily_RainData_ZoneWise\Dailyraindata_Centralzone_3stations\D_RD_CentralZone_DhakaStation.txt','r');

s1=[];
 while 1

        line=fgetl(d); % read the raw data line by line

        if ~ischar(line)
           break
        end

        if ~isempty(line)
                v1=[];
                v=line(21:144); % select 31 days data


                data=[];

                   % Program to select daily rainfall data
                   for i=1:4:length(v)
                         i;
                         da=v(i:i+3);
                         da1=str2double(da);
                         data=[data da1];

                   end

                   data;

                   s = sum(data); % Sum of monthly data
                   s1= [s1; s];   % Monthly data is stored

             end



 end
```

```
fclose(d);

 s1;
 month = length(s1);
 year= month/12; % Total Years

  a_data = 0;
 a_data = [];

 % program to sum yearly data

for j=1:12:month

   y_sum = sum(s1(j:j+11));
   a_data = [a_data; y_sum]; % To store annual rainfall data
end

a_data;

 ev = find(a_data>=1000); % To exclude annual rainfall value less than 1000 mm

ss = a_data(ev); % To store annual rainfall data value more more than or equal to 1000

length(a_data);

% m_rain = sum(a_data)/year % Average rain fall for long period available data

a_rainfall = mean(ss) ;  % Average annual rainfall data

length(ss)

 years = 1954:2011;

 length(years)
 plot(years,ss);

 bar(ss);

%   % Program to store Annual Rainfall
%  result = [];
%  result = [result;ss];
%  filename = 'E:\satcom_project\Rain Data from
BMD\Daily_RainData_ZoneWise\Dailyraindata_all_zones\88.txt';
%  save(filename, 'result' ,'-ASCII');

 % Program to store mean Rainfall

 %  filename = 'E:\satcom_project\Rain Data from
BMD\Daily_RainData_ZoneWise\Dailyraindata_all_zones\mean_rainfall_south_western.
txt';
```

```
%  save(filename, 'a_rainfall' ,'-ASCII');

%  End of program to obtain annual rainfall rate

% program to get converted rainfall rate ,R0.01 , mm/hr

 a = 12.2903;   % Regression co-efficient alpha
b = 0.2973;    % Regression co-efficient beta

M = 2.4117472e+003; % Mean  Annual rainfall

R = a*M^b;      % R0.01 rain rate (The power law relationship)

% End of program to get converted rain intensity at 0.01% time exceed of an average year
```

% probability distribution program

```
clc
clear all;
close all;

result=[];

    for mm=1:8

                fn=[num2str(mm,'%d') num2str(mm,'%d') '.txt'];

                    if ~exist(fn)

                         continue
                     end

                 % To read total annual rainfall data zone wise
                 % and store them in a single vector

                 d=fopen(fn);

                 file_name=fn;


                 da=textread(fn);

                 result = [result; da];

                % r=append(result,da)

                 fclose(d);
```

```
% xxxxxxxxxxx Reading and Storing end xxxxxxxxxxxxxxx

x = sort(result,'ascend');  % Sorting the data

mv = max(x);  % Maximum value of  sorted data
miv = min(x);  % Minimum value of stored data

end

st=[];

for i=min(x):50:mv-50

a=i;
b=a+50;

r1=find ((x>=a) & (x<=b));
r2=x(r1)
c=length(r2);

st=[st; c];

end
st ; % Stored elements 0-0.5, 0.5-1.0 range ----------------

d   = sum(st);
d1 = st/d;

d2 = find(d1>0);
d3 = d1(d2);
figure
plot(d3);

figure
bar(d3);
```

% End of probability distribution program

% program to get rain attenuation variation for different zones of Bangladesh and ITU recommended rain intensity

```
clear all;
close all;

% program to get rain attenuation statistics  from rainfall rate

 % step-1 : Determine Rain Height (HR) , ITU-R 839

hr = 5-0.075*(23.77-23);  %rain height  for latitude more than 23 deg (dhaka city)

%hr = 5;          % rain height hr = 5 km for 23 deg latitude

hs = input('Enter the height above sea level :  ')/1000;  % height  above the sea level in km

x1 = input('Enter the elevation angle : ');

 x =  x1*pi/180; % elevation angle

% step-2 : Slant path length below rain height

ls = (hr-hs)/sin(x); % slant path length

% step-3: Horizontal projection length in km

lg = ls*cos(x);

 % step-4 : obtain rainfall rate, R0.01

 r = input('Enter annual rainfall rate in mm/hr :');

% step-5 : Obtain specific attenuation yr using frequency dependent
% co-efficient

% At frequency   f= 4  GHZ, kH= 0.0001071; aH= 1.6009; kV = 0.0002461 ; aV=
1.2476;

 %   f   =  4;
% kH  = 0.0001071;
% aH  = 1.6009;
% kV  = 0.0002461;
% aV  = 1.2476;

 % k = 0.000591;  % itu 838
% a = 1.075;       % itu 838

 % At frequency   f= 6  GHZ, kH= 0.0007056; aH= 1.5900; kV = 0.0004878; aV=
1.5728;
```

```
 % f = 6;
% kH= 0.0007056;
% aH= 1.5900;
%  kV = 0.0004878;   % 838-3
%  aV = 1.5728;        % 838-3

 % k = 0.00155;      % itu 838
% a = 1.265;          % itu 838

 %At frequency  f= 12GHZ, kH=0.02386, aH=1.1825, kV= 0.02455, aV= 1.1216

 %f = 12;
% kH= 0.02386;
% aH= 1.1825;
% kV =0.02455;
% aV= 1.1216;

% k = 0.0168    ; % itu 838
% a  =1.200;     % itu 838

  % At frequency f= 14; kH= 0.03738; aH= 1.1396; kV= 0.04126; aV= 1.0646

% f = 14;
% kH=  0.03738;
% aH= 1.1396;
% kV =0.04126;
% aV= 1.0646;

 % At frequency f = 20; kH=0.09164 , aH= 1.0568; kV= 0.0961; aV= 0.9847

 % f = 20;
% kH=  0.09164 ;
% aH= 1.0568;
% kV =0.0961;
% aV= 0.9847;

 % %     30  kH=0.2403;  kV= 0.2291; aH= 0.9485; aV=0.9129


  f = 30;
%  kH = 0.2403;
%  kV = 0.2291;
%  aH= 0.9485;
%  aV = 0.9129;

 % y   =  cos(x)^2;
% pa = input ('Enter the polarization angle :  ');
% y1 =  cos(2*pa*pi/180);
% y2 = y*y1;
```

```
% k = (kH + kV + (kH - kV )*y2)/2;   % for circular polarization

%  a = (kH*aH + kV*aV +(kH*aH - kV*aV)*y2) / (2*k);

 %    k = input(' Enter the co-efficient value of k  :  ');
%    a = input ('Enter co-efficient value of alpha  :  ')  ;

k =0.2291;
a = 0.9129;

 yr = k*r^a;       % dB/Km

  % step-6 : horizontal reduction factor

m1 = lg*yr/f;

m2 = 0.38*(1-exp(-2*lg));

m3 = 0.78*sqrt(m1-m2);

 hrf = 1/(1+m3);

% hrf = 1/(1+0.78*sqrt(lg*yr/f)-0.38*(1-exp(-2*lg)))


 %  step-7: vertical adjustment factor

z1 =(hr-hs)/(lg*hrf);

z2 = z1*pi/180;

z = inv(tan(z2));

 if z>x

    lr =  lg*hrf/cos(x);

else
    lr=ls;

end
lr;

% x1 = sqrt(sin(x));
%
% x2 = 31*(1-exp(-x));
%
% x3 = sqrt(lr*yr);
%
% x4 = x3/f^2;
```

```
%
% x5 = 1+x1*(x2*x4-0.45);
%
% vrf1 = 1/x5;

vrf = 1/(1+sqrt(sin(x))*(31*(1-exp(-x))*(sqrt(lr*yr)/f^2)-0.45));

% step-8  effective path length

le = lr*vrf;

% step-9 : predicted attenuation for 0.01% excedence

att = le*yr;


 % step-10
% for p<1% and latitude <36 deg and elevation angle >=25 deg
% beta =  –0.005(| latitude| – 36)

%p = 0.001;

Ap1 = []; Ap2 = [];

for p = 0.001:0.001:1
b = -0.005*(23.77-36);

pow = -1*(0.655+0.033*log(p)-0.045*log(att)) - b*(1-p)*sin(x);

Ap   = att*(p/0.01)^pow;
Ap1 = [Ap1; Ap ]; % Attenuated value for specific percentage of outage
Ap2 = [Ap2; p ];   % Percentage of outage
Ap3 = [Ap2 Ap1];  % Column wise Attenuated and percentage value
end
Ap3;

%axis([.1 0.5  0 40]);

%plot(Ap2,Ap1);

 % End of attenuation variation program
```