INVESTIGATION OF SIGNAL DEGRADATION DUE TO RAIN ON SATELLITE DOWNLINK AT KU-BAND FOR TROPICAL CLIMATE

by

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λ	latitude of the earth station[deg]
H_s	altitude of the earth station[km]
θ	elevation angle of the link[deg]
f	frequency of the link[GHz]
k and α	the regression coefficients for specific attenuation
$R_\mathrm{p}(p)$	point rainfall rate distribution of an average year in the site of the earth station[mm/h]
$R_{0.01}$	point rainfall rate at 0.01% of the time of an average year in the site of the earth station [mm/h]
h_R	average effective rain height [km]
$H_0(p)$	average yearly distribution of the effective rain height [km]
A and β	the coefficients for worst month
L_{eff}	effective path length through rain [km]
$A_{0.01}$	attenuation exceeded for 0.01% of an average year [dB]
A_p	attenuation to be exceeded for other percentages of a average year [dB]
M	the average annual total rainfall depth, mm
p	percentage of time

γ	specific attenuation [dB/km]
A	total attenuation [dB]
H_ε	effective rain height [km]

PENYIASATAN TENTANG ROSOTAN ISYARAT DISEBABKAN OLEH HUJAN PADA SATELIT KE BUMI DI JALUR KU BAGI IKLIM TROPIKA

ABSTRAK

Rosotan isyarat yang disebabkan oleh hujan adalah satu masalah yang besar di dalam penghantaran isyarat gelombangmikro. Kesan rosotan hujan adalah lebih ketara pada frekuensi yang lebih tinggi. Pelbagai penyelidikan dan ujikaji telah dilakukan di negara-negara bermusim. Di negara-negara tropik yang mana terkenal dengan kadar hujan yang tinggi, situasinya seperti tidak memberi harapan. Ini adalah disebabkan data yang dilaporkan untuk kawasan ini adalah tidak mencukupi disebabkan iklim yang kritikal dan berubah berbanding dengan kawasan bermusim. Oleh sebab itu, prestasi sistem komunikasi di negara-negara tropikal ditimpa dengan teruk pada musim hujan. Oleh sebab itu, pengukuran kadar hujan dan pelemahan telah dijalankan di Universiti Sains Malaysia, Nibong Tebal. Taburan longgokan kadar hujan dan rosotan yang dihasilkan daripada data yang disukat telah diuji dan dibandingkan dengan model-model ramal yang sedia ada. Kebanyakan model ramalan tidak memberi ramalan yang baik di kawasan yang kadar hujannya tinggi. Keputusan ujikaji telah dianalis untuk memahami potensi dan limitasi setiap model ramalan. Berdasarkan kepada penghadan model-model yang sedia ada, model pelemahan hujan ITU-R telah dibangunkan. Dalam model yang dibangunkan parameter yang dimasukkan seperti ketinggian hujan, yang telah diperakukan oleh ITU-R dan cara yang digunakan oleh ITU-R untuk mengira pelemahan tertentu telah diubahsuai. Model yang dicadangkan telah dibandingkan dan diuji dengan data-data eksperimen yang diperolehi dari kawasan-kawasan pengukuran dan model itu juga telah digunakan untuk ramalan pada lokasi yang berbeza di Nigeria, Kenya dan Papua New Guinea. Model yang dicadangkan telah

menghasilkan taburan longgokan yang baik, dengan ralat rms rendah pada lokasi dimana ujikaji telah dijalankan dan pada lokasi yang berbeza untuk ketiga-tiga kawasan yang dinyatakan di atas.

INVESTIGATION OF SIGNAL DEGRADATION DUE TO RAIN ON SATELLITE DOWNLINK AT KU-BAND FOR TROPICAL CLIMATE

ABSTRACT

Attenuation due to rain is a major concern in transmission of microwave signals. The effect of rain attenuation is more pronounce when signals are being transmitted at higher frequencies. Many theoretical and experimental studies of rain attenuation have been carried out at temperate regions of the world. In the tropical regions, however, which are famous for heavy rains, the situation is not very encouraging. This is because the data coverage for these regions remains inadequate due to the complex and varying climatic behaviors compared to the temperate regions. Thus, the communication systems in tropical countries is affected unconstructively during the heavy rain season. Therefore measurement of rainfall rate and rainfall attenuation were done in Universiti Sains Malaysia, Nibong Tebal. The cumulative distributions of rainfall rate and attenuation derived from the measured data are presented and compared with existing prediction models. Most of the existing prediction models do not perform well in high rain rate regions. The comparison results were analysed to understand the potentials and limitations of each prediction model. In order to overcome the disadvantages in existing models, ITU-R rain attenuation model was developed. In this proposed model, the input parameter of rain height, h_R recommended by ITU-R and the determination of the power law coefficients to calculate rain height were developed. The proposed model was compared and tested against measurement site data and the model was applied for prediction at Nigeria, Kenya and Papua New Guinea. The model gave a good representation of cumulative distribution with an overall low rms for measurement sites and three different location mentioned above. Systems that are poorly designed lead to an increase in transmission errors, or worst, to an outage in the

received signal. In order to avoid outage in the received signals, the systems for tropical regions need to be designed using this proposed model which is purely modified based on data from tropical countries.

CHAPTER 1

INTRODUCTION

1.1 Background

There are many satellites rotating around earth which help us to communicate. The satellite communications role is keep increasing in our daily life use. The high definition television and the internet all work through the satellite technology. Information is transmitted using microwaves. The microwave signals being used in satellite communication can have very high frequencies in atmosphere. The increasing demand of satellite technology caused utilisation of higher frequencies in order to have wider band for usage. Utilization of higher frequency bands such as the Ku band for satellite communications provides a number of important benefits. It relieves congestion in the lower frequencies which are shared with terrestrial links, it exploits the larger bandwidths available at higher frequencies, and provides cheaper implementation of spectrum conservation techniques and a more efficient use of the geostationary curve (Sarat Kumar K, 2008).

A basic satellite communication consists of many earth stations on ground and a satellite in space. Satellite communication link can be divided in two different manners. They are uplink and downlink. where for uplink earth stations function as transmitter (to send information signal) and satellite in space become the receiver (to receive information signal). For downlink earth station is receiver and satellites in space become the transmitter. The great distance between the transmitter and receiver will cause power reduction in information signal. When the power start to spread out, it will shrink the distance of the information signal travels, whereby the receiver at downlink only will able to receive weaker signal. Once the signal starts to frail it can be easily infected and attenuated by the atmospheric effects.

There are several impairments that can cause attenuation of the information signals, which are rain attenuation, gaseous absorption, cloud attenuation, melting layer attenuation, tropospheric scintillations, and low-angle fading. It is well known that among all other impairments rain is the dominant propagation impairment at the frequency above 10 GHz or higher frequency spectrum at the Ku-Band. The propagation effects over the earth-space path caused by rain are in the form of attenuation, depolarization, and scintillation. At such high frequencies, the sizes of falling raindrops are close to a resonant sub-multiple of the signal wavelength. The droplets, therefore, are able to absorb, scatter, and depolarize the radio waves passing through the earth's atmosphere (Crane, 1996, Ippolito, 1986). Absorption and scattering by rain at frequencies above 10 GHz can cause a reduction in transmitted signal amplitude (attenuation), which in turn reduce the reliability, availability and performance of the communications link (Omotosho, 2009). This phenomenon is known as outage time where the amount of time during which the satellite system performance will be below the design threshold value and it will not be usable. To overcome this problem, one-minute rainfall rate and rain attenuation need to be studied and used to calculate the expected amount of rain attenuation to prevent the unavailability or outage time from occurring (Crane,1996, Ajayi,1996a, CCIR Study Group, (1983).

When considering parameters affected by propagation impairments factor, it is necessary to specify the parameters on a statistical basis, which are usually specified in percentage of time. This percentage of time is normally described as the percentage of time in a month, in a year or the parameter equals to or exceeds a certain value so that the link margin can be established.

Link margin is the amount of extra power in the system to withstand propagation fades and mispointing losses (K.A Rahim, 2009).

In different rainfall regions, earth stations are scattered differently. Making real-time measurements data at the preferred earth station is a very effective way to obtain rainfall rate value. But it is not economically feasible to measure rainfall rate in this manner in all parts of the world (J.E.Allnut, 2007). The lack of measured rainfall rate data from sites of interest resulted in the development of rainfall rate prediction models. These prediction models have been used to estimate rainfall rate in concentration sites. Many prediction models are available for the use of communication designers to predict rainfall rate (Ashok Mathur, 2001). Many researchers have developed models that can be used to estimate one-minute rainfall rate distributions. Most of the rainfall rate models were developed based on the rainfall data collected in temperate regions and very few in tropical and equatorial which famous for heavy rainfall such as Moupfouma (1995), ITU-R P.618-7 (2001) and Crane (1986).

In order to predict accurate rain attenuation, rainfall rate must be obtained first either by experiment or by using prediction models. One-minute rainfall rate cumulative distribution plays an important role and an important input parameter as well in calculating the rainfall attenuation distribution. According to (Dissanayake, 1990; Juy, 1990; Pan and Bryant,1992; Matricciani,1993; Ong and Zhu, 1997) rainfall attenuation can be directly obtained from the measurement of beacon receiver or predicted from the drop-size distribution or knowledge of rainfall rate (Crane, 1996). Until now, the models of attenuation use the effective radio path length concept which is based on the rainfall rate distribution for the estimation of attenuation due to the rainfall (Gloria Tuquerres C, 1994). Therefore, one-minute rainfall rate cumulative distribution plays an important role in calculating the rainfall attenuation distribution. One-minute rainfall rate models are encouraged to be used to predict the local cumulative distribution of rain data for the locations where essential one-minute rainfall rate distribution cannot be obtained. The reason why rainfall rate must be in one minute because the evaluation of the effects of rain on satellite system design requires a detailed knowledge of the attenuation statistics for each ground terminal location at the specific frequency of interest (Crane, 2003).

1.2 Problem Statement

Even though many researchers have developed models that can be used to estimate one-minute rain attenuation distribution, there is still some puzzlement with regard to choosing the right model to predict attenuation for the location of interest. Thus, the existing prediction models need to be tested against the measured results from tropical regions, by this it can be known that these existing prediction models are applicable to the tropical climates. Each prediction model has its potentials and limitations. Based on the limitations of the existing models, rain attenuation model need to be modified. Therefore, it is a very important need to know the measured rain data from tropical regions in order to choose the right rain attenuation model.

1.3 Objectives of the Research

The main objectives of this research are:

i. To make comparison based on the experimental data of rainfall rate and rain attenuation obtained from USM site to the existing propagation models.

ii. To modify rain attenuation prediction model as an improved model to be used in tropical climate.

iii. To compare and verify the developed model with different data located in the different tropical sites

1.4 Research Scope & Limitation

The scope of this research consists of study on existing rain attenuation prediction model and to modify the prediction model of rain attenuation in tropical countries. The model modification mainly based on experimental data of tropical regions. The methodology diagram of overall research is illustrated in Figure 3.1. The scope of this project is segmented to the following steps.

The first and second steps are to study about the existing rainfall rate and rain attenuation prediction models respectively. Five types of rainfall-rate prediction models such as Moupfouma, ITU, Crane, KIT and RH were studied. The review was in term of models's input parameters, application of models, advantages and disadvantages of each model. The objective of this project is to analyze and develop the more efficient attenuation prediction model of rain attenuation. Therefore the fundamental knowledge of eight types of existing rain attenuation models such as ITU-R, DAH, Crane, CETUC, Glopez, R&K, Ong and Yamada model were collected. Summary of the comparison between measured rain attenuation data with the rain attenuation prediction models is shown in Table 4.3. The assumption on choosing the right rainfall rate and rain attenuation models are made based on root mean square (RMS) method. The RMS method used for testing was suggested by ITU-R P.311-10 (2001).

The fourth step is modifying the ITU-R model. The ITU-R model is simple to understand, easier to use and widely accepted by many researchers. However, the model underestimates measured rain attenuation when applied to tropical regions. Therefore, the ITU (ITU-R P.618-10, 2009) rain attenuation model was modified based on the USM measurement data and data obtained from ITB, KMITL, AdMU and USP sites. In this modified ITU-R model, the concept of rain attenuation prediction is retained. The method to obtain input parameter of rain height, h_R recommended by ITU-R and the determination of the power law coefficients to calculate rain height are modified. The modifications are based on effective path length, specific attenuation, elevation angle and rainfall rate.

Finally the proposed model was tested with other measurement sites. The purpose of this project is to propose an efficient and unification rain attenuation prediction model for tropical countries. Therefore the proposed model was tested for other measurement sites that are located in the K, N and P regions. The sites that were chosen were Kenya, Nairobi for Zone K, Nigeria, Ile-ife for Zone N and Papua New Guinea, Lae (Pan, 2001) for Zone P.

1.5 Research Contributions

The purpose of this research is not based on analysis studies alone but the research has put the future technology into the consideration. The rain attenuation which is predicted from the modified rain attenuation model can be used by satellite system engineers for the link budget purpose. Free space propagation (rain attenuation) is listed as one of the critical elements of a microwave link. An improved rain attenuation model were created in Nibong Tebal area. For future development using Wireless Networks and Satellite Television the system designer can apply the provided data to give more convenient services during rain time for USM and Nibong Tebal residences.

1.6 Organization of the Thesis

The content of this thesis includes a literature review of the necessary information needed to carry out the research. The thesis is divided into 5 parts as described below:

Chapter 1 is about a brief introduction on the background and the problem statement which motivated the research to be conducted.

Chapter 2 discusses informations about rain in tropical climate. It also describes how does rain attenuate radiowave and some information about the existing rainfall rate and rain attenuation prediction models.

Chapter 3 focuses on the methodology for this research. The measurement of rainfall rate and rain attenuation data to be used for this study and instruments that are used for this type of experiment are also explained in this chapter.

Chapter 4 is about analysis of data. The rainfall rate and rainfall attenuation data obtained from experiment will be represented in graph form with complete justifications. Furthermore, the results of the comparison of the measured rainfall rate and attenuation with the existing models are also discussed in details at this chapter.

Chapter 5 presents the development of rain attenuation models. The comparison was done between developed model with the measured data in terms of percentage errors and RMS values. The developed model was used for the prediction at different measurement site, to find whether the model can be applicable to the tropical site.

Chapter 6 gives the conclusion of the study to be carried out. Findings of the research, limitations encountered and recommendation for future works are also included.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

When the microwave signal travel between a satellite and an earth station it starts to interact with the natural atmosphere. The inconsistent and dynamic nature of the atmosphere especially rain makes it a non-conductive medium for transmission. Therefore, the fundamental knowledge of rain and how does it cause attenuation is a major theory behind this study to be understood (ITU-R P.838-3,2005).

In this chapter the important information of rain attenuation, rainfall in tropical climate and propagation models are described.

2.2 Rain attenuation

As higher frequencies are used for telecommunications, rainfall becomes a serious source of signal attenuation for microwave communications. Rain can cause uncontrolled variations in signal amplitude, phase, polarization, and angle of arrival, which result in a reduction in the quality of analog transmissions and an increase in the error rate of digital transmissions (Ippolito, 1986). Attenuation that occurs because of rain can critically reduce the reliability of communications operating through satellite links. Signal attenuation is the typical effect of rain on satellite and communication systems. Scattering and absorption are the two mechanisms involved in the attenuation of electromagnetic waves caused by raindrops. Scattering diffuses the signal, whereas absorption is involved in the resonance of waves in individual molecules of water. Absorption increases molecular energy, causing an increase in temperature that ultimately results in an equivalent loss of signal energy (J.E.Allnut, 2004).

Most satellites are located in geostationary orbit and its position is typically about 35,784 km away from the earth (Ayman, 2005). Rain only forms in the troposphere which extends 9-10km above the earth. When the microwave signal travel from satellite to ground station it will travel through the atmosphere before reach the ground station; a rain cell anywhere in the signal path will cause some reduction in the signal strength. A signal traveling through a rain cell will experience attenuation during only a small portion of its transmission path.

The severity of rain attenuation and depolarization depends on how hard it is raining (described by the "rain rate" in millimeters of accumulation per hour), not on the total rain accumulation (Charles W. Bostian, 1993). 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. There are several factors that contribute to the attenuation including weather patterns and elevation angle. The various regions covered by a satellite footprint experience different weather patterns. Rain patterns here refer to the rain period and rainy day. The lower the latitude of the earth station the higher the elevation angle, and the fewer atmospheres through which the signal must travel. The higher the latitude, the lower the angle and therefore the more atmosphere through which the signal must travel, the greater the probability of it having to travel through rain.

Attenuation will be lesser at 6/4GHz compare to the transmission at 14/12 GHz. For 6/4 GHz signals to be affected would require rain storms approaching hurricane conditions, whereas 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 pass. Any raindrop in the path of the signal, which approached half the wavelength in diameter, will cause attenuation. Since direct long-term measurements of rain attenuation on earth are not available for all locations, thus prediction model must be used to estimate the attenuation. The prediction of rain attenuation for the radio systems can be improved through a better knowledge of the special-temporal structure of rain. The rain structure depends on the other factors such as rain cell diameter and rain height. A different type of rain shows different spatial structure and thus different impact on the radio systems (Pawlina, 1999).

2.3 Tropical Regions and Rainfall Structure

The tropical zone, being near the equator, is not associated with the temperate seasons of spring, summer, and winter. The tropic regions, areas on the Earth where the sun reaches a point directly overhead once during the solar year, are located between Northern [23°26' (23.4°) N] and Southern [23°26' (23.4°) S] Hemispheres. The tropical rain belt as shown in Figure 2.1 dominates the weather in tropics. It oscillates to the southern tropics from the north in the Eastern Hemisphere over the course of the year**.** The northern tropics experience a dry season from October to March, throughout which the days are typically hot and sunny, with very little precipitation. During this time, the tropical rain belt lies in the Southern Hemisphere of the Indian Ocean and Western Pacific Ocean. When the rain belt lies in the Northern Hemisphere, roughly from April to September, a wet season occurs in the northern tropics, and a dry season takes place in southern tropics (Michelle, 2010).

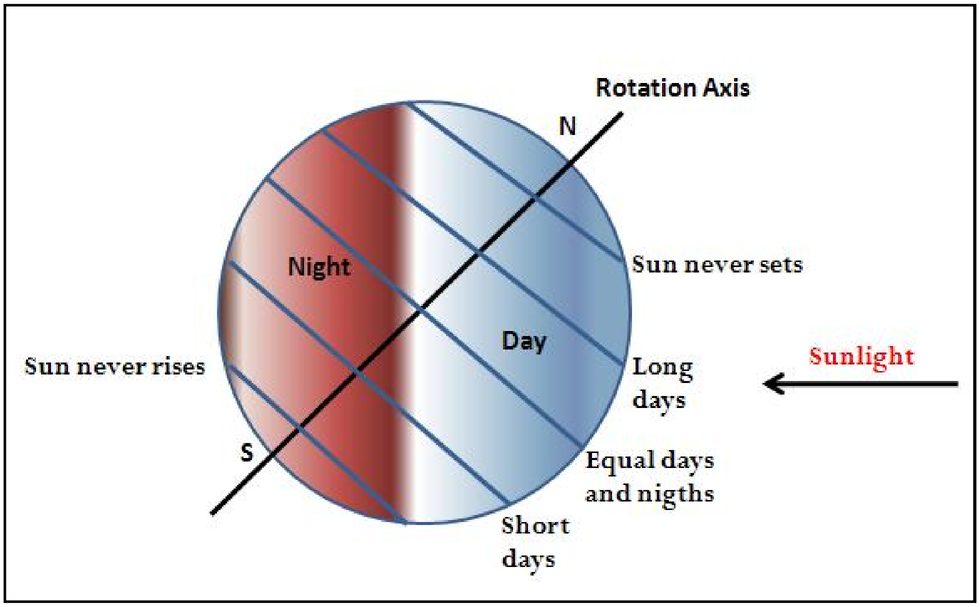

Figure 2.1 The Tropical Rain belt

2.3.1 Rainfall Structure

For system planning, the rainfall structure such as horizontal and vertical dimensions of rain cells, spatial and temporal variability of rain is very important. With these information, rain attenuation and scattering can be determined and rain attenuation mitigation technique such as site diversity can be applied (Allnut, 1989).

Rainfall is a natural, time varying phenomenon having complex structure due to its variability in space, duration and frequency of occurrence. In general, rain can be classified into four types they are: stratiform, convective, monsoon, and tropical rainfalls (ITU-R, 1994). Each type has individual characteristic which is various between each type such as rain intensity and rainfall time duration. In the tropical and equatorial region, which are famous for heavy rain, meteorologistis have classified rain precipitation in two categories they are stratiform and convective (Ajayi, 1996, Timotty, 2003, Ramachandran and Kumar, 2004).

The convective rain is arises because of vertical atmospheric motions resulting in vertical transport and mixing, that can be very powerful and lead to the thunderstorms and high rainfall rates (Mandeep, 2006). Convective rain flow occur with high rain rates for short durations and in a cell extending over much smaller horizontal extent. The cell usually extend for only several kilometers, but can extend much greater vertical heights because of convective upwelling up to 9-10 km greater than the average freezing level at a given location (A. Pawlina, 1999). Convective rain is associated with clouds that are formed, in general, below the 0°C isotherm and are stirred up by strong winds (Kareem, 2003). Convective rainfall is heavier and the drops are larger. Convective precipitations are generally identified with intermittently strong vertical velocities (>1± 1 ms^{-1}) and high rainfall rates (>5mm/h) (Mandeep, 2006). Figure 2.2 shows convective rain phenomena.

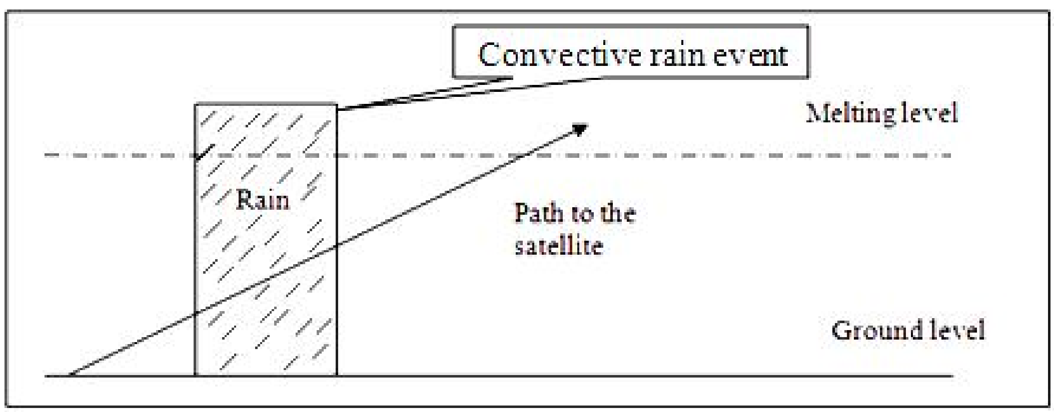

Figure 2.2 Convective rain phenomena (Y.Y.Ng, 2009)

Stratiform rain is generated in cloud layers containing ice and results in widespread rain at rainfall rate less than 10mm per hour. Stratiform precipitations that is resulted from the formation of small ice particles in the upper growing nuclei becomes unstable and as they pass through the melting layer extending from 500m to 1 km below the 0^0 C isotherm turns into raindrops and falls down to the earth surface (Ajayi, 1996). Raindrop growth in a stratiform cloud is slow, so its rain consists of small drops. Stratiform precipitation areas are characterized by, small velocities (<1± 1 ms^{-1}) and low rainfall rates (<5mm/h) (Mandeep, 2006). Figure 2.3, shows that the widespread system of stratiform rain completely covers the path to the satellite from the ground up to the melting layer.

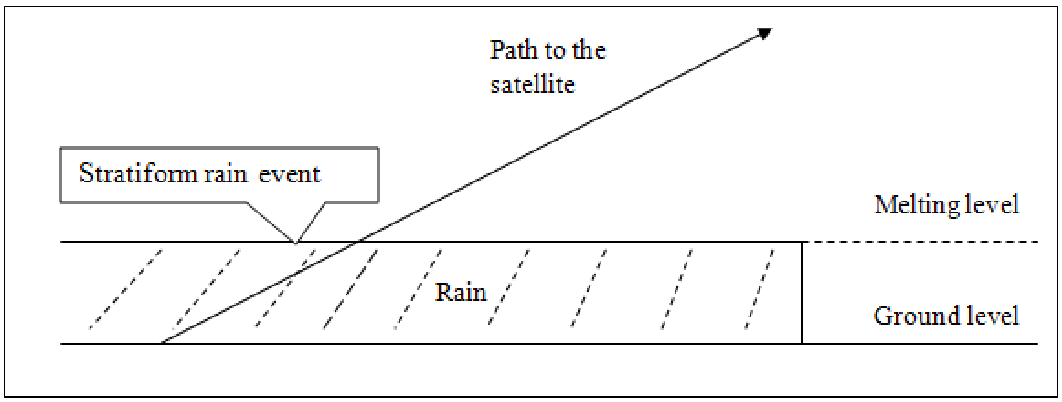

Figure 2.3 Stratiform rain phenomena (Y.Y.Ng, 2009)

2.3.2 The Occurrence of Rainfall and Rain Height

The intensity of rain is known as the rainfall rate, R and it is also defined as the volume of liquid water that falls through a unit area per unit time and is normally expressed in unit millimeters per hour (mm/h) (Olsen,1978). Statistically, the diameter of rain cell decreases as the intensity of rain increases (Allnutt, 1989; Nor Hisham Khamis, 1999)

Much of the water that is in the air is in the form of water vapour rather than as a liquid or solid hydrometeors. When the air temperature is in below than 0°C, the water start to freeze and the major hydrometeors are in ice form. At the temperature a bit higher than 0°C this ice starts to melt and falls as rain. Both ice and liquid water are heavier then air and the rising air currents are stopping them from falling to the ground. As water condenses out of the air it forms ice crystals which are small enough to be supported by rising air currents. These particles clump together and get larger until they become too heavy for air currents to support and at last fall as rain.

The nature non-uniform distribution of rainfall in both in space and time causes a major difficult in the prediction of rain attenuation. To overcome these difficulties most prediction methods use the concept of an equivalent rain cell, which should produce the same path attenuation as the random rain groups (Timothy, 2003). The procedures make use of an effective rain cell model which is parameterized in terms of rain rate, drop size distribution, and the rain height.

The terms, freezing height, rain height and melting layer are representing different parameters for the prediction models, as representing in Figure 2.4. The freezing height lies at the top of the melting layer and is defined by the 0°C isotherm height, and the particles above melting layer considered formed of ice. The melting process begins to take place when the snowflakes and other frozen particles fall to this height, which is known as melting layer. Rain height represents the boundary between the rain region and the snow region (S.K Sarkar, 1999).

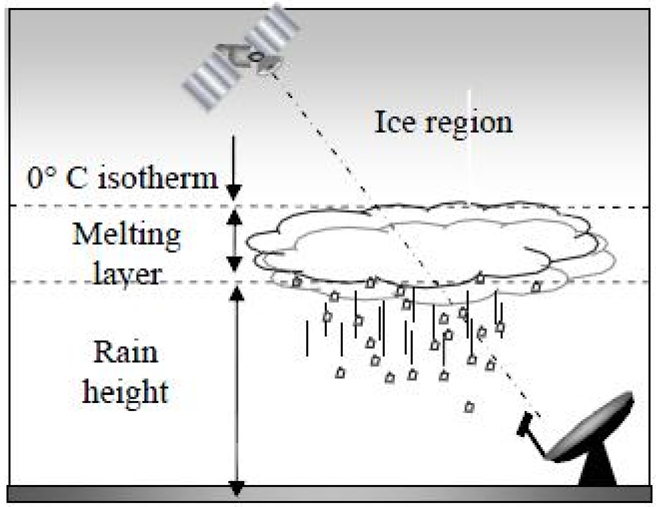

Figure 2.4: The three rain height terms (Ayman, 2005)

For system planning, the rainfall structure such as horizontal and vertical dimensions of rain cells, spatial and temporal variability of rain is very important. For slant-path propagation applications, such as satellite communications, the height of the rain structure is important. A region known as the ‘melting layer’ or the ‘bright band’ must be identified. Below this region, rain occurs and microwave propagation suffers attenuation due to rain. Above this region, no rain occurs and the propagation suffers only spatial attenuation. The convective rain in tropical region often has bright band above 10 km and also suffers from severe updraft (Pontes,1995; ITU-R P.839-2). However, the bright band region usually exists at the height of 4.5–5 km. The ITU recommended that rain height for tropical region is 5 km (ITU-R P.839-2).

The rain height can be vary according to seasonal period and types of rain (Ong, 2000). Identification of the melting layer can be done through radar reflectivity measurement. Figure 2.5 shows the height of the melting layer. However, during heavy rainfall season, rain can occurs below the melting layer. The uncertainty of the difference in height between rain event and the melting layer need to be investigated so that a reliable prediction of attenuation can be made.

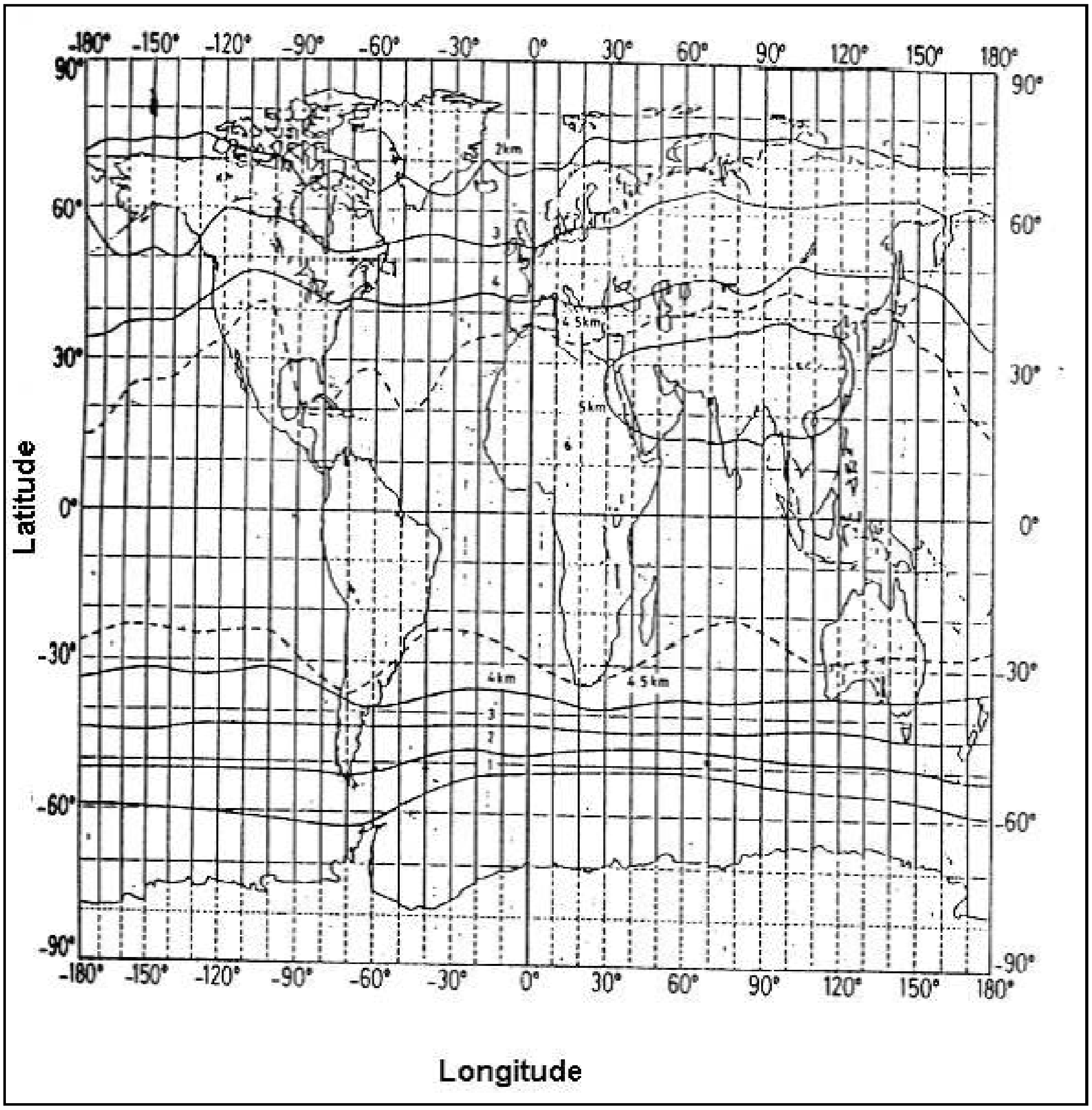

Figure 2.5 Height of melting layer (Allnutt, 1989)

2.4 Propagation Models

Even though the structure of rainfall of the location of interest are known, it would obviously be an impossible task to collect experimental rain data for all the frequencies, locations, and elevation angles under consideration for operational satellite systems. Therefore, a more reasonable approach is to use a predictive model based on and in agreement with, data from a variety of experiments.

Prediction models are used to provide the best possible estimates given the available information. Using these models, the rainfall rate can be known and thus, the attenuation due to rain can be predicted. There are several rainfall rate and attenuation models that are developed by many researchers. Among the developed models, few models which known as often-used models in tropical climate will be studied. The discussion about the well known rainfall rate and attenuation models is the focus of the section below.

2.4.1 Rainfall Rate Models

One-minute rainfall rate statistics are required to setup a communication link. More than estimate of the surface point rainfall rate distribution is required for the prediction of attenuation on terrestrial or earth to space (Crane, 1980). Rain displays significant spatial and temporal variation along a horizontal path and procedures are required to statistically estimate the instantaneous rainfall rate along the path. The distribution of rainfall rate is empirical and must be developed from available long-term observation of rain accumulation (Mandeep, 2006).

Besides of direct rainfall rate measurement, predictions model for rainfall rate are required for locations different from the limited number of stations or locations with sufficient long-term data for the preparation of a statistically reliable distribution estimate (Rice and Holmberg, 1973; Alasseur, 2004). Therefore explanation about few prediction rainfall-rate models such as Moupfouma, ITU, Crane, KIT and RH are discussed in this section.

2.4.1.1 ITU-R Global Rainfall Rate Model

The data files ESARAIN_PR6_v5.TXT, ESARAIN_MT_v5.TXT and ESARAIN_BETA_v5.TXT contain respectively the numerical values for the variables *Pr*6, M_T and β while data files ESARAINLAT_v5.TXT and ESARAINLON_v5.TXT contain the latitude and longitude of each of the data entries in all other files. These data files were derived from 40 years of data from the European Centre of Medium-range Weather Forecast (ECMWF).

Step 1: Extract the variables P_{r6}, M_T and β for the four points closest in latitude (Lat) and longitude (Lon) to the geographical coordinates of the desired location. The latitude grid is from +90° N to –90° S in 1.125° steps; the longitude grid is from 0° to 360° in 1.125° steps.

Step 2: From the values of P_{r6}, M_T and β at the four grid points, obtain the values P_{r6} (Lat,Lon), M_T (Lat,Lon) and $\beta(Lat,Lon)$ at the desired location by performing a bi-linear interpolation, as described in Recommendation ITU-R P.1144.

Step 3: Convert M_T and β to *Mc* and *Ms* as follows:

$$Mc = \beta\, M_T \tag{2.1}$$

$$Ms = (1-\beta)\, M_T \tag{2.2}$$

Step 4: Derive the percentage probability of rain in an average year, P_0, from:

$$P_0(Lat, Lon) = Pr_6(Lat, Lon)(1 - e^{-0.0079(Ms(Lat,Lon)/\,Pr6(Lat,Lon))}) \tag{2.3}$$

Step 5 : Derive the rainfall rate, *Rp*, exceeded for *p* % of the average year, where $P \leq \square P_0$, from:

$$R_p(Lat, Lon) = \frac{-B + \sqrt{B^2 - 4AC}}{2A} \tag{2.4}$$

where

$$A = a\, b$$

$$B = a + c \ln\left[P / P_0(Lat, Lon)\right] \tag{2.5}$$

$$C = \ln\left[P / P_0(Lat, Lon)\right] \tag{2.6}$$

and

$$a = 1.09$$

$$b = \left[M_c(Lat, Lon) + M_s(Lat, Lon)\right] / 21797\, P_0 \tag{2.7}$$

$$c = 26.02b \tag{2.8}$$

2.4.1.2 Crane Global Rainfall Rate Model

Crane (1980) rainfall rate model divided the world into eight regions based on total rain accumulation and the number of thunderstorm. Satellite and precipitation data were used to extend the climate over the oceanic, and Malaysia classified to region H and its rain rate distribution is given on Table 2.3.

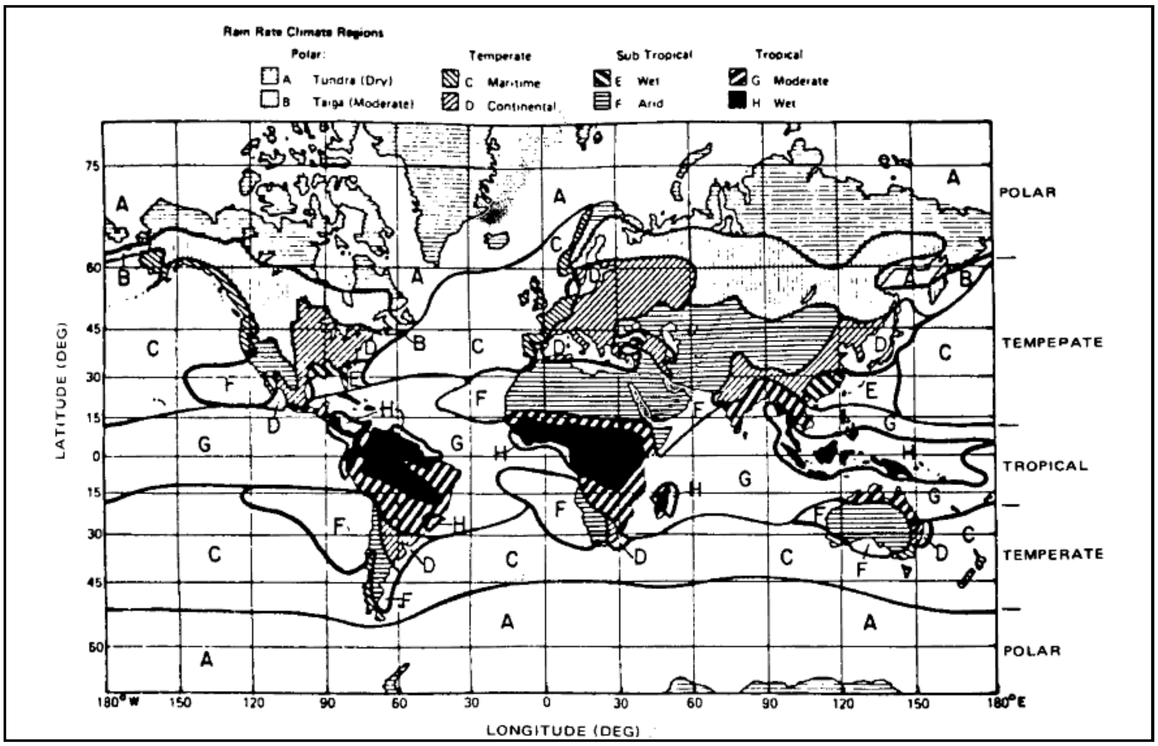

Figure 2.8. Global rain rate climate regions (Crane, 1980)

Table 2.1 Point Rain Rates (*mm/hr*) versus percent of year rain rate is exceeded for the regions (Crane, 1980)

Percent of year	Time	Rain Climate Region									
		A	B	C	D1	D2	D3	E	F	G	H
0.001	5 m	28	54	80	90	102	127	164	66	129	251
0.002	10 m	24	40	62	72	86	107	144	51	109	220
0.005	26 m	19	26	41	50	64	81	117	34	85	178
0.01	53 m	15	19	28	37	49	63	98	23	67	147
0.02	1.7 h	12	14	18	27	35	48	77	14	51	115
0.05	4 h	8	9.5	11	16	22	31	52	8	33	77
0.1	9 h	5.5	6.8	7.2	11	15	22	35	5.5	22	51
0.2	18 h	4	4.8	4.8	7.5	9.5	14	21	3.2	14	31
0.5	1.8 d	2.5	2.7	2.8	4	5.2	7	8.5	1.2	7	13
1.0	3.6 d	1.7	1.8	1.9	2.2	3	4	4	0.8	3.7	6.4
2.0	7.3 d	1.1	1.2	1.2	1.3	1.8	2.5	2	0.4	1.6	2.8

2.4.1.3 Moupfouma (refined) Rainfall Rate Model

The Moupfouma model was developed based on the conversion of rain tips from the tipping bucket rain gauges with a minimum integration time of 1-minute. The purpose is to reduce instabilities and sampling error involved in measuring high rainfall rates, which frequently happened at the measurement sites. The combination of the lognormal rainfall rate distribution, which provide the best fit for low rainfall rate and gamma rainfall rate distribution, which provide the best fit for higher rainfall rate, allows the prediction of the rainfall rate cumulative distribution in temperate and tropical climates. The model is shown below:

$$P(r) = 100\,[\,(R_{0.01}+1)/(r+1)]^{b}\exp[u(R_{0.01}-r)-\ln(10^{4})]\ \% \qquad (2.9)$$

with

$$b = [(r - R_{0.01})/R_{0.01}]\ \ln[1+ r/R_{0.01}] \qquad (2.10)$$

For tropical and sub-tropical localities $u(r)$ depends on the local climatology and geographical features which describes the slope of the rainfall rate curve

$$u(r) = \ln(10^4) / R_{0.01} \exp[-\lambda \, (r/R_{0.01})^Y] \qquad (2.11)$$

where

$$\lambda = 1.066 \text{ and } Y = 0.214$$

r is the rainfall rate (mm/h) exceeded during P(%) of the time in average year (mm/h), provided that r $\geq$ 2 mm/h

$R_{0.01}$ is the rain intensity exceeded during 0.01 percent of time in an average year (mm/h)

2.4.1.4 Rice and Holmberg Rainfall Rate Model

The model proposed by Rice and Holmberg estimates the percentage of an average year that t min surface rainfall rates exceed a given value (for t = intervals of 1 min to 1 day). For 1 min rates, the models uses two parameters for a specific location, the mean annual precipitation (M) and the ratio of annual thunderstorm rainfall to the total annual rainfall (β). For t >1 min, an additional parameter, the mean annual number of days with precipitation (D) $\geq$ 0.25mm (0.01in), is also used. M is available for almost all meteorological observation sites and the authors provide it as contours on a world map. The ratio β is not readily available and must be calculated from meteorological data. The model divided the rainfall into two types to permit the prediction of rainfall rate statistic from the total rainfall accumulation measured in an average year. The two types are mode 1 rain (M_1) and mode 2 rain (M_2). Mode 1 contained the high rainfall rates