Analysis of rain attenuation for Ku-band satellite telecommunication services in Indonesia

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Analysis of rain attenuation for K_u-band satellite telecommunication services in Indonesia

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Final report of graduation project
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Abstract

An increasing demand of the satellite telecommunication services in Indonesia urges the use of higher frequency bands than the C-band, for instance the K_u-band. However, a feasibility study must first be performed because the propagation models for tropical regions in this frequency band are still doubtful.

The results of the propagation measurements in the K_u-band which were succesfully conducted in Surabaya by EUT and ITS, gave a great contribution for future satellite telecommunication for tropical regions, especially Indonesia.

The rain attenuation prediction methods according ITU-R, Ajayi, Dissanayake-Allnutt and Pontes-Silva-Souza underestimate the rain attenuation at small percentages of time comparing to the measured rain attenuation in Surabaya.

Based on the measurement results which were collected in Surabaya, the Dissanayake-Allnutt method is modified by applying a curve fitting method with two variables. Using this modified Dissanayake-Allnutt method, the rain attenuation along a satellite path from the Surabaya earth station to the Palapa B4 is calculated.

The correctness of that result is investigated by introducing the elevation scaling technique. Using the scaling ratio derived from the Dissanayake-Allnutt method, the rain attenuation cumulative distribution for Surabaya with an antenna elevation angle 84°44' to the Palapa B4 is calculated which confirms the result above.

The feasibility of K_u-band telecommunication services in Surabaya, and in general in Indonesia can be determined. The rain attenuation exceeding 1% of the time is about 1 dB, thus the television broadcasting satellite services can be offered.

However, offering telephony and data communication services is difficult. Application of a site diversity system using two ground stations with a separation distance of 10 km overcomes this problem.

The diurnal characteristics of the rain attenuation show the rain attenuation accumulates in the evening hours. A more accurate feasibility analysis can be obtained by presenting the cumulative distributions in the form of the yearly statistics on 6-hourly basis.

Instead of 1 dB, a rain attenuation of 2 dB must be considered in designing the system receiver for television broadcasting to remedy the effects of rain between 12:00-24:00. Between 0:00-12:00, the rain attenuation exceeding 1% of the time is 0 dB.

The satellite telephony services are possible to be offered between 6:00-12:00 without using the site diversity technique. On other hours the site diversity technique application must be considered as a solution.

Contents

List of Symbols

A_e	excess rain attenuation
T_m	medium temperature
T_{sky}	sky temperature
T_{cs}	clear sky temperature
D	drop diameter
N(D)	drop-size distribution
N'(D)	number of drops per unit time per unit increment in diameter D crossing a unit area of a measurement device
N_T	total number of drops of all sizes
V(D)	terminal velocity
R	rain intensity
$P(R \geq r)$	probability of the rain rate R exceeding any given rain rate r
$R_{0.01}$	rain intensity being exceeded for 0.01% of the time
$A_{0.01}$	rain attenuation being exceeded for 0.01% of the time
R_p	rain intensity being exceeded for p% of the time
A_p	rain attenuation being exceeded for p% of the time
f	frequency
r_A	reduction factor
γ	specific attenuation
R_L^α	extended path averaged rain intensity
$R_{L,p}^\alpha$	value exceeded for the percentage of time p by R_L^α
H_0	0°C isotherm height of the atmosphere
h_s	height above mean sea level of the earth station
h_R	effective rain height
h_{FR}	0°C isotherm height during rainy condition
$Q_t(D)$	extinction cross section of a drop of diameter D
A	total path attenuation

L	radio path
L_e	effective path length
ϕ	latitude of the earth station
θ	antenna elevation angle
L_s	slant path length below the rain height
R_e	effective radius of the earth
L_G	horizontal projection of the slant path length
$r_{0.01}$	reduction factor for 0.01% of the time
$rh_{0.01}$	horizontal reduction factor for 0.01% of the time
$rv_{0.01}$	vertical reduction factor for 0.01% of the time
$L_{0.01}$	effective horizontal extent of rain for 0.01% of the time
τ	polarization tilt angle relative to the horizontal

List Abbreviations

INTELSAT	International Telecommunications Satellite Organization
ITU	International Telecommunication Union
ITUR	International Telecommunication Union Radiocommunication
Perumtel	Perusahaan Umum Telekomunikasi
ITS	Institute Technology of Surabaya
EUT	Eindhoven University of Technology
VSAT	Very Small Aperture Terminal
EED	Electrical Engineering Department
NUFFIC	Netherlands Universities Foundation For International Cooperation
L-P	Laws-Parsons
M-P	Marshall-Palmer

1. Introduction

Satellite telecommunications plays a major role in telephone transmission, television and radio broadcasting, computer communications, mobile communication, etc. The use of C-band (4/6 GHz) has been widely employed in tropical countries, such as Indonesia. The capacity in the C-band will become a limiting factor for the expansion of telecommunication services. A higher frequency band must be used to increase the capacity.

The K_u-band (11/14 GHz) may be introduced as a solution. However, it can be expected that the radiowave may be affected by a high attenuation during rainfall. The use of K_u-band for countries with tropical rainfall climates is not as straightforward as for countries with temperate climates. The present prediction models regarding attenuation induced by rain are only accurate for countries with temperate climates.

The shortage of accurate information on the propagation characteristics in the K_u-band cause many countries with tropical climates, including Indonesia, withhold their decision to introduce the K_u-band for satellite communication.

The results of this graduation work will reveal the feasibility of using this frequency for satellite communication in Indonesia. An accurate model to predict the rain attenuation for frequency K_u-band does not exist. However, some approaches can be considered to provide that feasibility analysis.

In Chapter 2, a brief illustration about the telecommunication services in Indonesia is introduced. The radiowave propagation measurements in the K_u-band in Surabaya which were conducted by Eindhoven University of Technology (EUT) and Institute Technology of Surabaya (ITS) are elaborated.

The characteristics of rain in the tropical troposphere is given in Chapter 3. The characteristics of rain must be studied to reveal its effects on the satellite signals. In

Chapter 4, four prediction models to calculate the rain attenuation along a satellite path are described. Those models are ITU-R method, Ajayi method, Dissanayake-Allnutt method and Pontes-Silva-Souza method. The rain intensity is an important parameter to predict the rain attenuation.

Based on the rain attenuation prediction methods in Chapter 4 and the results of the measurements which are given in Chapter 2, the rain attenuation along a satellite path from the Surabaya earth station to the Palapa B4 is calculated. The analysis to produce the rain attenuation cumulative distribution is described in Chapter 5.

Providing that rain attenuation cumulative distribution, the feasibility of K_u-band satellite telecommunication services for Surabaya, and in general for Indonesia, can be performed. In Chapter 6, the feasibility analysis is given. The possibility to offer television broadcasting, telephony and data communication services is investigated.

Many programs in Matlab and Pascal are written as the tools to make the analysis. Those programs and the processed data has been delivered to the author's supervisor. Finally, this work can be used for further study and can be applied in Indonesia.

2. Radiowave Propagation Measurements in Indonesia

Telecommunication using satellites plays an important role in our society. For people on one side of the world it is possible to communicate with the people on the other side as an impact of innovation of satellite communication. However to be able to perform reliable telecommunication services, the design of systems to receive satellite signals has to be conducted very precisely.

The designers need to know the atmospheric impairments of satellite signals. The characteristics of the medium (e.g. troposphere) strongly influence those impairments. The necessity to operate radiowave propagation measurements is to derive these characteristics and to analyze their influences on the satellite signals.

2.1. Background

Since President John F. Kennedy signed an Act of Congress in 1962, the International Telecommunications Satellite Organization (INTELSAT) was initiated. The INTELSAT was formally established on 20 August 1964 and now it becomes the world's most successful international cooperation with headquarters in Washington D.C., the United States of America (USA). In 1965, the INTELSAT launched INTELSAT I into orbit over the Atlantic Ocean. The communication frequencies used were 4 and 6 GHz bands, which is also called C-band.

The first 6/4 GHz earth stations within the INTELSAT system were located in temperate latitudes and operated very successfully. The using of satellite telecommunication services were then spread out all over the world. However, before designing a reliable telecommunication service for a particular place the propagation characteristics of the medium must be known first.

From the economical point of view, it is not recommended to conduct a measurement in one place, every time a satellite receiver for communication services will be installed. It is very expensive and time consuming to conduct one measurement research. The minimum of one year's data is needed to reveal the propagation impairments of satellite signals. It is also not practical, when every time a satellite telecommunication service is designed, a one-year measurement has to be conducted in advance. Therefore many methods have been developed to cover this unrealistic situation.

Considering that these telecommunication services extend all over the world, international restrictions must be discussed and followed. The International Telecommunication Union (ITU) formulates those regulations. This union consists of three sectors. One of those sectors is the Radiocommunication Sector (ITU-R). The Study Groups of ITU-R are responsible for the study of technical and operational questions relating specifically to radiocommunication without limit of frequency range and to issue recommendations. For that purpose, the ITU-R schedules a conference every two years.

Study Group 3 (formerly 5 and 6) is responsible in the area of radiowave propagation. Many radiowave propagation measurements with using frequency 6/4 GHz bands had been conducted, both in temperate regions and tropical regions. Therefore Study Group 3 had enough data to develop the methods which can be easily used to deliver an accurate prediction of the signal impairments. In designing satellite earth stations for new services, the ITU-R recommendations are used.

The explosive growth in demand led to the incorporation of 14/11 GHz and 14/12 GHz (Ku-band) services on the INTELSAT V series of satellites. The first of that series was launched in December 1980. This satellite generation has larger capacity. Initially, 14/11 GHz stations were mainly confined to temperate regions. However, new services have gradually been introduced over a wide geographical area. Inadequacies were discovered in existing attenuation prediction procedures, particularly for tropical areas.

The prediction of propagation impairments is an iterative procedure. Initial theoretical models are tested against measured results. The models are refined to conform with these data, becoming quasi-empirical models in the process. The availability of a substantial database of propagation effects measured on satellite links in temperate regions has permitted the prediction models for these climatic regions to become quite accurate, particularly in the frequency range between 10 and 20 GHz. However, this accuracy is not valid for tropical regions.

Many attempts were initiated to investigate the causes and to obtain additional tropical propagation data in the Ku-band that would permit refinement of the prediction models. A campaign of measurements in the tropical regions was established. The INTELSAT participated in this campaign. Some radiowave propagation measurements were conducted in South East Asia, tropical part of Australia, in South America (Peru, Brazil) and in equatorial part of Africa (Cameroon, Nigeria).

Most of those measurements were conducted by using only radiometers. The experiments in Peru and Brazil highlight the critical choice of physical medium temperature in the data analysis when it comes to converting sky noise temperature data to path attenuation data. Also the passive radiometer has a limited dynamic range up to about 10 dB. Some other experiments which used the beacon antennas to directly receive the satellite signals, illustrate that path attenuation in tropical regions exceeds this limit considerably. Therefore the best measurements must be conducted by using a beacon receiver and a radiometer simultaneously.

The measurements in Indonesia which were conducted by CNET (France) and PT. Telkom (formerly Perumtel) were operated by using a beacon receiver. The beacon antenna was pointed to the INTELSAT V (60° E longitude) at the frequency 11.198 GHz. Unfortunately the results of these measurements were not very satisfying.

Another series of measurements in the K_u-band in Indonesia which was conducted by Institute Technology of Surabaya (ITS), Indonesia, and Eindhoven University of Technology (EUT), the Netherlands, was using a beacon antenna and a radiometer simultaneously. The operation of these measurements was very successful. These measurements will be explained in more detail in this report.

Regarding the accuracy of ITU-R models for temperate region up to a frequency of 20 GHz, the commercial satellite telecommunication services in the temperate climate nowadays are using frequency 14/11 GHz (Ku-band). However the ones in tropical regions are still not moving from the C-band.

2.2 Indonesian telecommunication services nowadays

About two hundred million people live within 3400 mile-long archipelago of 13,677 islands which comprise the nation of Indonesia. Towns and cities are separated by dense forests, oceans, deserts or similarly inhospitable features. This situation is illustrated in figure 2.1.

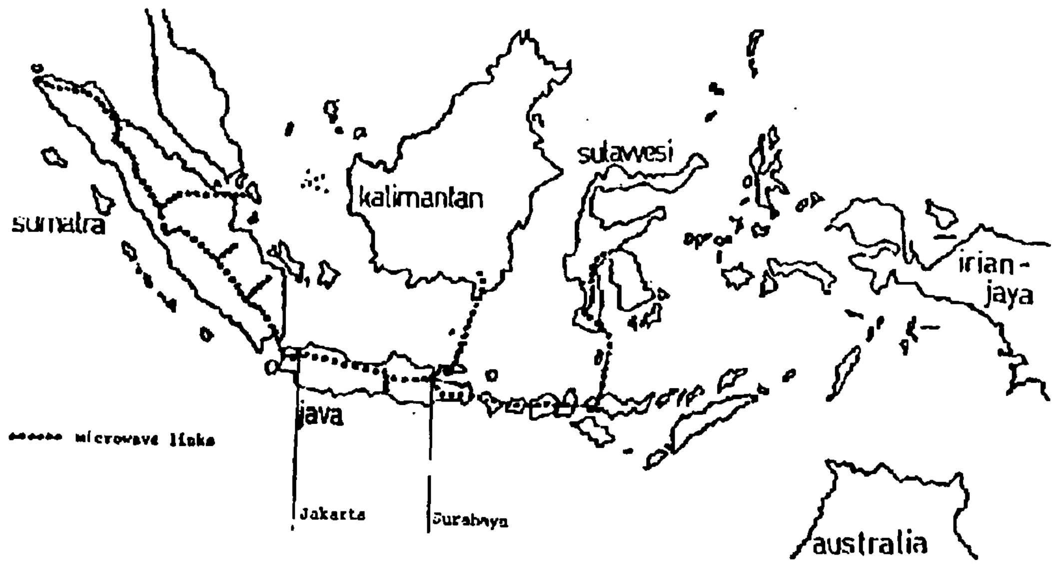


Fig. 2.1. Indonesian archipelago

The laying of transmission lines or the construction of terrestrial microwave links are daunting tasks, but communications life-lines are essential for Indonesia to grow economically. Then using satellite as a communication instrument becomes a very good alternative to be able to cover the isolated parts of the country. The telecommunications satellite services are, to a large degree, distance and terrain independent. Communications among many places in Indonesia can be conducted by combining the transmission lines and the radio communication links.

The series of Palapa A satellites was introduced in July of 1976 and operated by Perumtel, Indonesia's state-owned telecommunications company, which now becomes P.T. Telkom. The communication frequency used was C-band (3.7-4.2 GHz). This series was continued by the generation of Palapa B satellites in 1983 which used the same frequency. A master control station in Cibinong, near Jakarta (the capital of Indonesia), functions as the control of the Palapa system. It tracks and sends commands to the satellites and controls user traffic. A short description of the operating satellite, that is the Palapa B4 satellite, is included in this report.

Indonesia's Palapa B4 satellite was launched from the Kennedy Space Center in Cape Canaveral, Florida, on May 14, 1992. Its orbital was located on 118° E longitude. The Palapa B4 satellite downlinks within the 3.7 to 4.2 GHz range and provides telephone, television, facsimile, domestic video, voice and high speed data services. This satellite is also used to provide regional telecommunications services for neighbouring countries such as Singapore, Brunei, Malaysia, Thailand, Philippines, and Papua New Guinea and is expected to have a mission life of ten years.

The Indonesian government operates the satellite mostly for telephone/fax networking and domestic television broadcasting. However, the growth of welfare in Indonesia stimulates the increasing demands of the satellite telecommunication services.

The Indonesian independent television channel RCTI (Rajawali Citra Televisi Indonesia) began broadcasting through the Palapa B2P satellite, the latest operated satellite, in 1990 for Jakarta and its surrounding. One year later, another independent TV channel SCTV (Surabaya Citra Televisi) broadcasted for Surabaya and its surrounding, which was later expanded to reach Bali. Until now, the independent television broadcasting is growing and setting up channels in many other cities.

A campaign of using VSAT (Very Small Aperture Terminal) satellite networks commercially to big companies was conducted by a private telecommunication company, P.T. CSM (Citra Sari Makmur). These networks were operated for interactive data communications between head offices and the relating branch offices.

Moreover, since 1993 the government policy in the telephony networks has initiated the installation of new telephone stations to reach more customers in small towns and villages.

Those telecommunication services are still operated in the C-band. The lack of accuracy on the ITU-R models for tropical regions in the Ku-band hinders the operation of the series of Palapa satellites with Ku-band transponders. The clarity of propagation impairments in the Ku-band for tropical regions is strongly required because the use of telecommunication services in Indonesia with larger capacity is absolutely needed in the near future.

2.3. Radiowave propagation measurements in Surabaya

2.3.1. The conception of the measurements

The lack of data measurements in the K_u-band for tropical regions in the ITU-R data bank inspired the radiowave propagation measurements in Surabaya. In April 1988, INTELSAT issued a statement to conduct a one-year propagation measurements programme at a site location near to the Western Pasific Basin on an earth - INTELSAT V satellite path. The proposal of the Telecommunications Division of Electrical Engineering Department, Eindhoven University of Technology (EUT), to conduct measurements in Surabaya was selected. This one-year programme was later extended twice, resulting a total measurement time of three years.

The conducting of this INTELSAT measurements programme was combined with the EUT - ITS cooperation programme because of their great similarity. The EUT - ITS programme was performing a propagation research for satellite communications at 14/11 GHz and a propagation research for line-of-sight (LOS) communications at 11 GHz. Thus, the satellite signals propagation measurements in Surabaya were financed by INTELSAT and NUFFIC (Netherlands Universities Foundation For International Cooperation).

A site verification was conducted by INTELSAT on 15 February 1990 and the experiment was declared operational. The measurements were started 1 March 1990 which simultaneously used a beacon receiver and a radiometer to measure the propagation characteristics under tropical rainfall conditions.

2.3.2. The set up of the measurement

The EUT - ITS's radiowave propagation measurements at the Ku-band were conducted in Surabaya, the second biggest city after Jakarta in Indonesia. Surabaya is located on Java and very close to the Straits of Madura (see again fig 2.1). Surabaya and its surrounding have a rainy equatorial climate with wet monsoon from November until June and dry season from June until November. The Surabaya site coordinates are 7°15' South and 112°44' East.

The beacon receiver with an effective antenna diameter 3.6 m was installed on the top of the Electrical Engineering Department (EED) building of the Institute Technology of Surabaya (ITS). The antenna height was about 15 m above sea level. The antenna was pointed to receive the signals from the INTELSAT-508 satellite at 180°E longitude. The radiometer with diameter 1.8 m was pointed to the same direction. A raingauge of tipping bucket type was used and calibrated to measure rain intensities from 0.1 until 420 mm/h. This raingauge was located within 50 m from the beacon receiver on the roof of the EED building.

The first year of measurements was started in March 1990 and ended in February 1991. The second year was started in April 1991 because of radiometer modification. Starting on the second year, the beacon antenna was pointed to another satellite, i.e. INTELSAT-510 satellite at 174°E longitude. The pointing direction of radiometer was adjusted. The second year of measurements was extended for one year.

Accordingly the antenna elevation angle between the first and the second/third year were different. The antenna elevation angle of the first year was 14°07'15". The antenna elevation angle of the second year and the third are the same, that is 20°20'34". Further details are illustrated in table 2.1.

Table 2.1. Relevant data for the Surabaya earth station

INTELSAT satellites	508	510
satellite positions	180° E	174° E
frequency	11.198 GHz	
polarization	circular	
antenna elevation	14°07'15"	20°20'34"
antenna azimuth	86°58'23"	86°02'31"
coordinates site of Surabaya	7°15' S	112°44' E
antenna height	15 meters above sea level	
raingauge type	tipping bucket	
raingauge location	within 50 meters from antenna	
beacon antenna type	prime focus	
beacon antenna diameter	3.6 meters effective	
radiometer antenna diameter	1.8 meters offset	

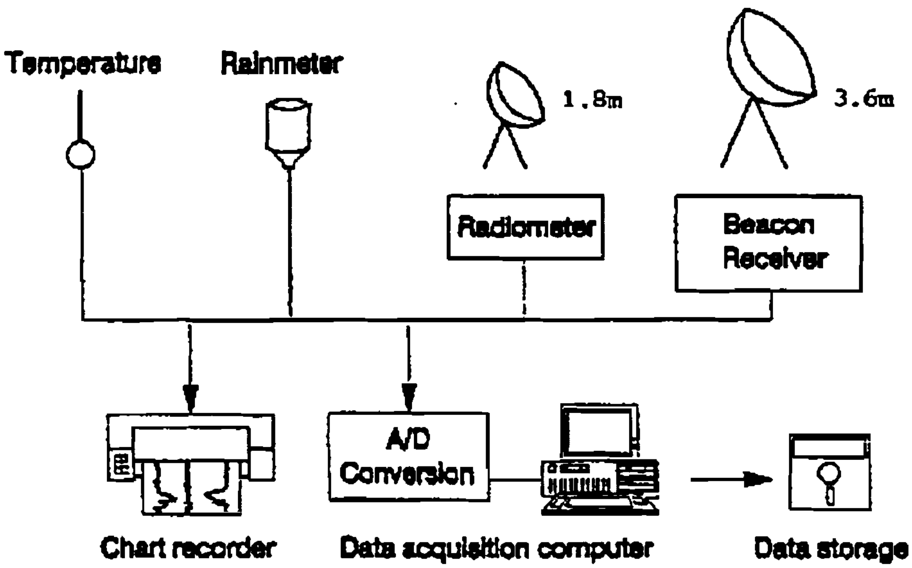


Fig. 2.2. Propagation experimental set-up at ITS [4]

Figure 2.2 gives a schematic of the experimental set-up which was installed at ITS and the complete measurement system consisted of :

a. A beacon receiver to measure attenuation of 11.198 GHz beacon signals (switchable between the two INTELSAT V beacon frequencies 11.198 and 11.452 GHz in the Pacific Ocean Region)

b. A radiometer to measure the sky noise temperature along the same path as the beacon antenna.

c. A rain meter to measure the rain intensity.

d. A data acquisition system.

e. A chart recorder to record all measured data on paper for a quick-look and back-up purposes.

f. Temperature sensors to measure the equipment room temperature and the outside temperature.

g. Humidity sensors to measure the inside humidity and the outside humidity. The data of these sensors were written down in the logbook on a daily routine basis.

h. Uninterruptable power supplies (UPS's), solar voltaic panels, an accumulator battery and a generator, to back-up the power of the experimental set-up.

i. A data processing system. Each month the data diskettes were sent to EUT to be processed with ASYST programmes. The data processing was also executed at ITS with PASCAL programmes, as a comparison to the conclusions to achieve optimal results.

The data acqusition system received 8 pre-filtered analog channels and converted the analog data to 12-bit digital data. The digital signals were collected by a personal computer at a sample rate of 40 Hz. The computer performed digital filtering on the data and stored the filtered data on 720 kB diskettes at a rate of 1 sample per second during the event mode. During off-event modes the data were stored at a lower rate of 1 sample per 10 seconds. The data recorded on floppy-diskettes were the values of the measured attenuation, the antenna noise temperature, the rain rate, the inside and outside temperature and three test signals. The system was in the event mode if the attenuation was larger than 1.5 dB and/or the rate change of the attenuation was larger than 0.2 dB/10 sec.

There were four drives available. One drive was used for running the main program to collect data and the other three were used for registrating the data measurements. If the data diskette in one drive was full, the main program controlling the operation looked for another drive with empty diskette and wrote down the data. Therefore it was possible to maintain the system continously 24 hours per day.

2.3.3. The results of the measurements

Some results from the radiowave propagation measurements in Surabaya are given. Figure 2.3 illustrates the cumulative distributions of excess attenuation for the three years of measurements. Figure 2.4 illustrates the sky noise temperature cumulative distributions.

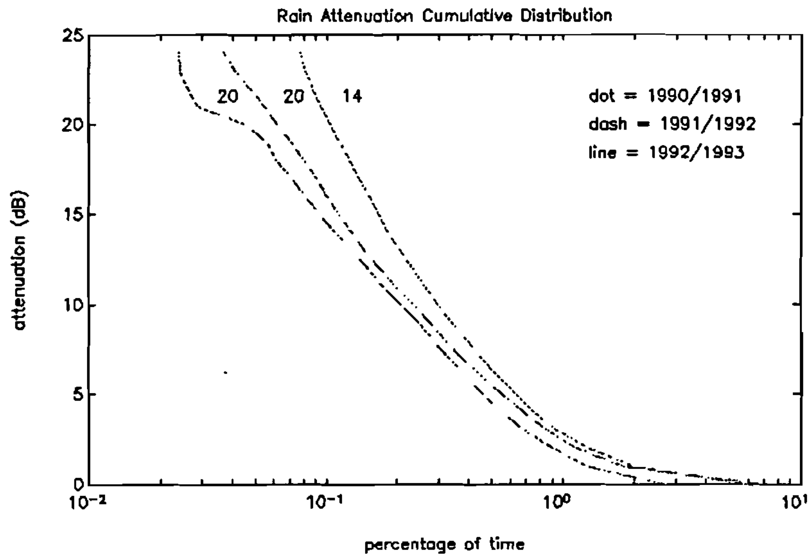


Fig.2.3. Rain attenuation cumulative distributions from the measurements in Surabaya during 1990 - 1993 in the INTELSAT campaign

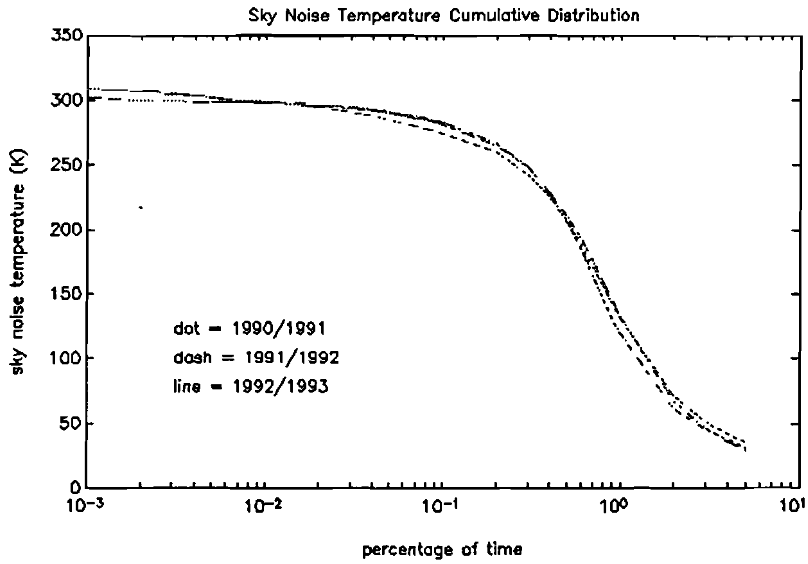


Fig.2.4. The cumulative distributions of the sky noise temperature from the same three year period of measurements in Surabaya

From the sky noise temperature measurements, the excess attenuation A_e can be derived by using the following expression

$$A_e = 10 \log \left(\frac{T_m - T_{cs}}{T_m - T_{sky}} \right)$$

The derived attenuation cumulative distributions from the sky noise temperature for the three years measurements are presented in [4]. By comparing the derived distributions with the measured ones, information on the medium temperature T_m for tropical countries was obtained. The most appropiate value was 290 K.

An accurate information on T_m enables other slant-path propagation measurements to be carried out in Indonesia without using a beacon receiver. It is possible to calculate the excess attenuation from radiometrically derived data for a satellite broadcast service up to 12 dB. Beyond 12 dB, the derived attenuation values are highly sensitive to the assumed medium temperature and therefore inaccurate.

Figure 2.5 illustrates a satellite path which suffers from rainfall. The rain shower, which has an effective medium temperature T_m, will attenuate the radiowaves by an excess or rain attenuation A_e. A beacon receiver can measure A_e directly by monitoring the power level of the beacon signal from the satellite, while a radiometer can detect T_{sky} from which A_e can be derived if T_m is known.

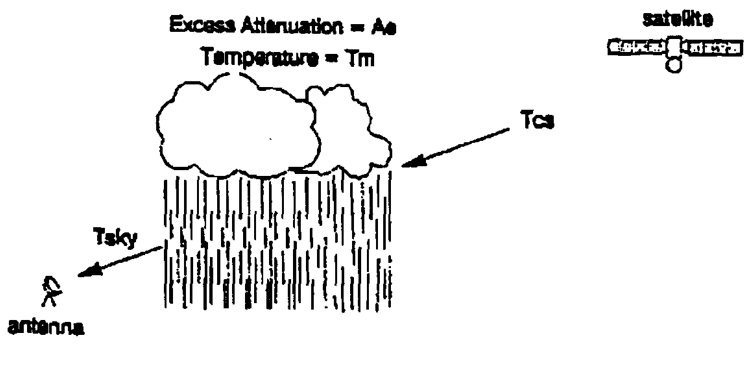


Fig. 2.5. Attenuation along a satellite path [4]

Finally, the rain intensity cumulative distributions of the same measurements are shown in Figure 2.6 and the availability of the measurements system of each year is given in Table 2.2.

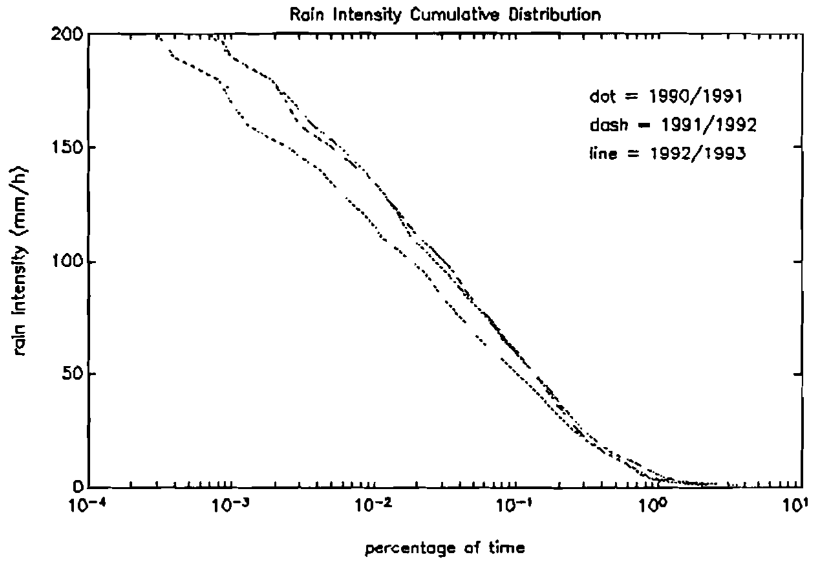


Fig. 2.6. The cumulative distributions of the rain intensity from the measurements in Surabaya during 1990 - 1993

Table 2.2. Availability of the measurement system

Period	Elapsed time	Availability of individual units			Concurrent availability
		beacon	radiometer	rainmeter	
year 1	365 days	99.05 %	98.81 %	99.13 %	98.74 %
year 2	366 days	96.93 %	96.94 %	97.40 %	96.94 %
year 3	365 days	98.63 %	98.50 %	99.81 %	98.50 %

A limitation of these radiowave propagation measurements is, that the dynamic range of the beacon receiver was 24 dB. During the first year, this level was reached for 0.03 % of the time. For the second year, it was 0.04 % of the time and for the third year, it was 0.02 % of the time. (See again Figure 2.3). As a consequence, the attenuation values for the 0.01% criterion could not be measured.

An important incident to be noticed is, when INTELSAT ceased to correct the N-S drift of the INTELSAT 510 in order to conserve fuel for E-W drift and orbit-raising manoeuvres from July 1992. As a consequence, the diurnal variation in the amplitude of the received beacon signal increased significantly by the end of the third year of measurements. The clear sky signal level showed a daily variation which steadily increased up to about 13 dB peak-to-peak because the antenna was not provided with tracking facilities.

2.3.4. Contribution to future satellite communications for tropical regions

The comparison of the measurements results with the ITU-R recommendations show great discrepancies. The ITU-R (formerly CCIR) rain intensity data from ITU-R Report 563-4 (1990) are significantly different from the measured rain intensity data. The predicted excess attenuation according ITU-R Report 564-4 (1990) shows a serious underestimation to the measured attenuation.

Many other measurements in the Ku-band which were executed in the tropical regions also reveal the inaccuracy of the ITU-R models. The data from those measurements and the radiowave propagation measurements in Surabaya, can be used to refine those models to give an accurate prediction. Consequently, the likely impairments to be encountered on a satellite communications link can be estimated in order to plan new services economically.

Another contribution is the delivery of the most appropiate value for the medium temperature T_m, i.e. 290 K. A slant-path propagation measurement is then possible to be performed in Indonesia without using a beacon antenna to receive the satellite signals, but only by pointing a radiometer to the sky.

3. Rain Characteristics in the Tropical Troposphere

Rainfall is a major cause of signal degradation for radiocommunication systems operating at centimetre and millimetre waves in the tropical environment. Attenuation due to rainfall plays a significant role in the design of earth satellite radio links especially at frequencies above 10 GHz.

As higher frequencies are used, rainfall becomes a serious source of attenuation for microwave communications. As the frequency increases, the wavelength approaches the size of raindrops, which therefore act as a screen of scatterers for the wave. Rainfall occurring over the links affects transmission quality and limits the system's performance. This phenomenon is more critical in the tropical regions, which are characterized by high intensity rainfall, enhanced frequency of rain occurrence, the increased presence of large raindrops, different shape of raindrops, and higher temperature, when compared with temperate climates.

3.1. Tropical precipitation

The average drop diameter in a non-precipitating cloud is about 0.02 mm in diameter [22]. In order to fall and not evaporate before reaching the ground, the drops must increase their average diameter almost a hundredfold. There are two principal mechanisms of increasing the drop diameter.

The first mechanism is through the formation of ice crystals which is also called the Bergeron process. Usually the upper part of the cloud exceeds the 0°C isotherm.

The 0°C isotherm is the height, where the decreasing temperature when the height increases, becomes 0°C. Therefore the ice crystals will present. However, the saturation vapour pressure above the water drops is larger than above the ice crystals. The ice crystals will grow. This effect is very dominant between -10°C and -20°C. As the ice crystals become large and heavy, they will fall down, and melt when they pass the 0°C isotherm. The size of one drop is only 250 μm. Bigger drops are formed because 10 up to 100 ice crystals melt together when they pass the 0°C isotherm and become raindrops.

The second mechanism is through the collision and coalescence of rain drops. There are always water drops with diameter between 20 - 30 μm in the clouds which will grow through collision and coalescence with other drops. The average rain-drop size will increase quite rapidly in turbulent conditions such as convective updraughts. The size of rain drops also depend on the thick of the clouds that diameter of 100 μm or more can be reached to induce rain.

Meteorologists classify rain into two groups : convective rain and stratiform rain. Stratiform rain event usually coincides with a passing warm front and typically produces low to moderate rainfall rates. Stratiform rain events can extend over several hundreds kilometres and last for many hours. Convective rain is caused by local instabilities of the atmosphere, due to the heating and cooling of the earth surface and due to the passage of cold front. This type of rain usually covers a limited area (a few kilometres) and has a short lifetime, from a few minutes up to one hour. Convective rain can exhibit a strong intensity.

Both of convective rain and stratiform rain are important in tropical precipitation. Stratiform precipitation typically occurs in direct association with deep intense convective rain, not as a separate phenomenon. The patterns of tropical precipitation are typically complicated in time and space.

3.2. The microstructure of precipitation

The microstructure of precipitation is determined by the size, shape, fall velocity, temperature, orientation and composition of the individual particles. A short description is presented in the following subsections.

3.2.1. Drop shapes

The exact shape of a rain drop at any instant of time is determined by a complex mix of surface tension and aerodynamic forces. Figure 3.1 illustrates the types of the rain drop shape. For very small drops (less than or equal to 170 μm in diameter), surface tension forces will dominate under almost any wind conditions and the drops will be almost exactly spherical. Between 170 μm and 500 μm, the drops become elliptical in cross-section. Above 500 μm, the drops become progressively flattened at the base. Ultimately, the bases of the drops are hollowed out to form the so-called Prupacher and Pitter rain-drop shape. Note that when reference is made to the diameter of a non-spherical rain drop, it is the diameter of the equivalent-volume spherical rain drop that is being referred to.

shape	drop	equivolumetric diameter (D) in μm
spherical	o	$D \le 170$
spheroidal		$170 \le D \le 500$
flattened spheroidal		$500 \le D \le 2000$
Pruppacher and Pitter		$2000 \le D$

Fig. 3.1. Schematic of rain drop shapes with approximate size ranges [38]

The larger the rain drop, the more it can be distorted from a spherical shape. Once it distorts out of the spherical form, it is not stationary in terms of its shape but it may oscillate between an oblate and prolate spheroid. A spheroid is formed by rotating an ellipse about its shortest axis which, in the case of an oblate spheroid, is vertical. A prolate spheroid is the one with the minor axis oriented horizontally. See Figure 3.2.

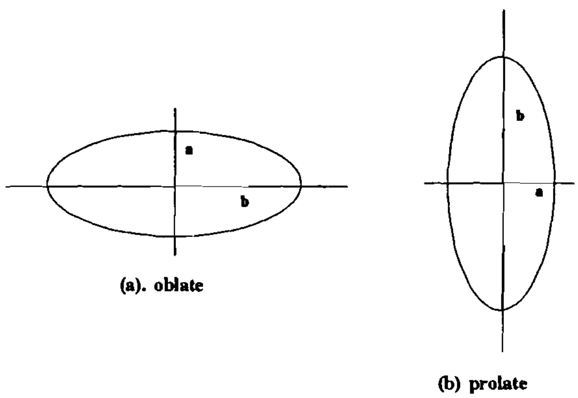


Fig. 3.2. Oblate and prolate spheroid

3.2.2. Drop fall velocity

When an object falls in a stationary fluid (e.g. air), it will at firts accelerate. As its speed increases, the drag force, the resistance of the fluid to motion of the object, will increase. Eventually when the drag force is just equal to the force due to gravity, terminal force is reached. There is no further increased in speed.

However, the case of the falling water drops is more complicated because they are not rigid but they are free to distort due to the aerodynamic forces. Internal fluid motions may be encountered. Another complication is that the drops undergo a number of interactions as they fall. Suppose a drop is repeatedly brought to rest by collisions. It would take time to reach terminal velocity after each collision. The average velocity would thus be reduced. If the collisions were sufficiently frequent, it would not have time to reach terminal velocity.

According Beard and Pruppacher [1969] and Wobus et.al. [1971], the observations of Gunn and Kinzer [1949] is the most complete useful formulation of terminal velocity as a function of drop diameter. Gunn and Kinzer's observations were made within stagnant air of 50% humidity. More details about drop fall velocity can be found in [56].

3.2.3. Drop-size distributions

The velocity depends on the size of raindrop and increases when the raindrop becomes larger. The relationship between terminal velocity and drop-size distribution is given by

$$N(D) = N'(D) \,/\, V(D) \qquad (3.1)$$

where N'(D) is the number of drops per unit time per unit increment in diameter D crossing a unit area of a measurement device;

V(D) is the terminal velocity;

N(D) is the drop-size distribution, i.e. the number of drops that exist between diameters D and D+dD per unit volume.

The Laws and Parsons' [1943] measurements of drop-size distribution that covered a range of drop sizes is currently adopted by ITU-R. Their results showed that the median drop diameter increased as the rainfall rate increased (see Figure 3.3). The mathematical description of the results was not given.

Later measurements by Marshall and Palmer [1948] proposed an exponential mathematical model to fit the results, that is

$$N(D) = N_0 \, e^{-\Lambda D} \qquad (3.2)$$

where $N_0 = 8000\ mm^{-1}m^{-3}$

$\Lambda = 4.1\ R^{-0.21}$ and R is the rain rate in mm/h

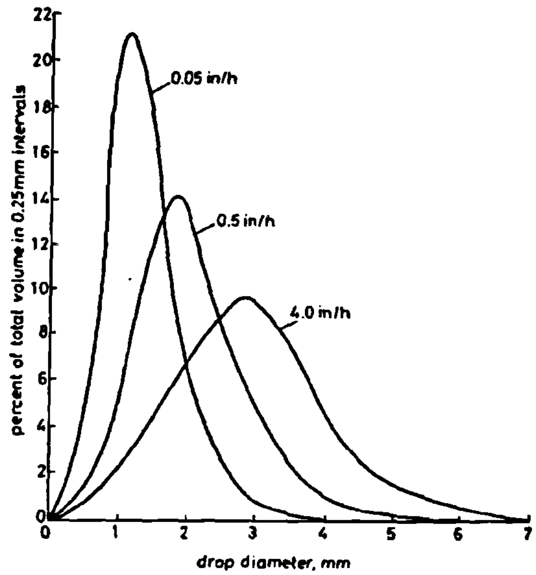


Fig. 3.3. The results of the drop size distribution measurements by Laws and Parsons [38]

Joss et.al. [1968] fitted the Marshall-Palmer (M-P) form of equation to the data measurement which was classified in three groups according to rain type. The mean values for N_0 and Λ were obtained and given in table 3.1. N_0 and Λ vary during the rainfall. The drop size distribution may vary with time and also depends on the rain type.

Ajayi and Olsen [1985] reported that the negative exponential distribution was not suited to model tropical rainfall and a lognormal model gave better fit. The Laws-Parsons (L-P) and M-P distributions overestimate the number of drops in the small and large diameter regions. The L-P and M-P distributions represent the temperate climate rainfall quite well, but not the tropical rainfall where thunderstorm and heavy-shower occur more often.

Table 3.1. Mean values for N_0 and Λ from Joss et.al.

Rain type	N_0 $m^{-3}mm^{-1}$	Λ mm^{-1} (R in mm/hr)
drizzle	3×10^4	$5.7\ R^{-0.21}$
stratiform	7×10^3	$4.1\ R^{-0.21}$
thunderstorm	1.4×10^3	$3.0\ R^{-0.21}$

The fitting of the lognormal model on tropical rainfall is still being investigated. However the general expression of lognormal drop size distribution can be written as

$$N(D)=\frac{N_T}{\sigma D\sqrt{2\pi}}\exp[-\frac{1}{2}(\frac{lnD-\mu}{\sigma})^2] \qquad (3.3)$$

where N_T is the total number of drops of all sizes

μ is the mean of ln D

σ is the standard deviation

The rain rate in mm/h is related to the drop size distribution and the terminal velocity by

$$R=6\pi.10^{-4}\int_0^\infty D^3N(D)V(D)dD \qquad (3.4)$$

Integrating the M-P drop size distribution in (3.4) is written in Appendix A. Another integration using the lognormal drop size distribution is also attached in that appendix.

3.2.4. Raindrop orientation

In a column of stagnant air, spheroidal raindrops will fall with their axis of symmetry along the vertical. There is no reason for any tilting. However in the atmosphere, local disturbances of the air density and wind variations may cause the mean orientation to be canted by a few degrees.

Brussaard [1976] developed a meteorological model of raindrop canting which relates the canting of an invidual raindrop to the variations with height in the horizontal wind field. The fall velocity of a raindrop plays a role in that relationship and because of the one-to-one relationship between fall velocity and drop size, the canting angle implicitly depends on the drop size. The model assumes a neutrally stable troposphere, it does not deal with the influence of turbulence. However, in a more realistic dynamic atmosphere larger canting angles can be encountered and turbulence will cause a random distribution of canting angles of an ensemble of raindrops. For more detail, see [14].

3.3. The spatial structure of precipitation

Rainfall rate is non-uniform both horizontally and vertically. In order to establish a model of rain rate profile, it is necessary to have a spatial distribution of rain rate and to determine the effective extent of rain. However, the interpretation of the rain intensity cumulative distribution will be described first in the following subsection.

3.3.1. Cumulative distribution of point rainfall intensity

Raindrops both absorb and scatter microwave power on earth-satellite links. Both may contribute to the attenuation on a radio path. Rainfall intensity measured at a point near the surface of the earth is a commonly used meteorological reference parameter in studies on the propagation effects due to rain.

In particular, the rainfall intensity pertaining to short integration times, even less than one minute, is of importance for tropical regions. Sharp intensity peaks during convective rain are often encountered in the tropical climate area.

The long-term behaviour of rainfall intensity is described by the so-called cumulative probability distribution or exceedance curve. It gives the percentage of time that the rainfall intensity exceeds a given value. The cumulative distribution of point rainfall intensity obtained from long term measurements are needed for prediction of rain attenuation.

Such distributions are available for a large number of locations and are presented in the ITU-R Report 563-4. However, the accurate mapping of the rain parameters for tropical regions is being questioned. It is desirable to use rain intensity data measured in the locality, when available.

At low and medium rainfall rates where accurate measurements can be obtained, it appears that the cumulative rainfall rate distribution can be well approximated by a log-normal law. The range over which this relationship may be assumed valid, depends on the climatic region, but typically it extends from 2 mm/h to about 50 mm/h. At medium and high rainfall rates, the Gamma distribution gives a good representation.

Moupfouma [1987] expressed this model by the equation

$$P(R \geq r) = a\frac{e^{-ur}}{r^{b}} \qquad r \geq 2 \text{ mm/h} \qquad (3.5)$$

where $P(R \geq r)$ is the probability of the rain rate R exceeding any given rain rate r and the parameters a, b, u depending on the integration time of the raingauges used as well as the climate and geographical features of the location.

Moupfouma obtained expressions for the parameters a and b in terms of the rain rate $R_{0.01}$ (mm/h) exceeded for 0.01% of the time for any given integration time.

$$a = 10^{-4} R_{0.01}{}^{b} \exp(u R_{0.01}) \qquad (3.6a)$$

$$b = 8.22 R_{0.01}{}^{-0.584} \qquad (3.6b)$$

$R_{0.01}$ and u determine the shape of the distribution and the slope of the curve respectively. For tropical zones, u was found to be 0.042 for coastal areas and 0.025 for average rolling terrain.

In the modified version of the model, Moupfouma expressed the parameter u as a function of the rain rate

$$u = \lambda\, r^{-s} \qquad (3.7)$$

where λ and s are parameters representing the ITU-R rain climatic zones in table 3.2.

Table 3.2. The value of parameters λ and s

climatic zones	λ	s
D	0.18	0.33
E	0.05	0.29
F	0.07	0.32
G	0.14	0.28
H	0.06	0.19
J	0.07	0.18
K	0.05	0.17
L	0.05	0.22
M	0.05	0.09
N	0.033	0.06
P	0.035	0.10

3.3.2. The horizontal structure of rain

Rainfall is inhomogeneous in the horizontal plane. In the last decade, numerous models and approaches have been developed by many researchers in order to quantify the properties of the horizontal structure of rain relevant for propagation applications.

Raingauge records show short intervals of high rain rate embedded in longer periods of lighter rain. Weather radar observations show small areas of high rain rate embedded in larger regions of lighter rain. The results of many measurements show that the size of rain cell is a function of rain rate and reduces as the rain rate increases. The horizontal structure of rainfall varies from one locality to another depending on climate, topography and the rainfall type.

In the modelling of rain cells, rain is assumed to be a collection of cells and regions with well-defined spatial profiles of rainfall intensity having certain probability of occurrences. In the experimental approach, the parameters related to the spatial structure of rain are directly extracted from rainfall data measured by radar or network of raingauges. The reduction factor is a well known example of such parameters and is used in particular for prediction of rain attenuation.

The reduction factor r_A is a conversion factor used to relate the rain attenuation value A_p (dB) exceeded for a given time percentage p on a link of length L (km) at frequency f (GHz) to the value of the point rainfall intensity R_p (mm/h) exceeded for the same percentage of time. The defining equation for r_A is given by

$$A_p = \gamma(R_p)\ L\ r_A \qquad (3.8)$$

where γ (dB/km) is the specific attenuation value for a rainfall intensity R_p assuming certain representative raindrop size distribution. If the correct raindrop size distribution is used, then the values of r_A are very close to that of the rainfall intensity reduction factor as is explained in the following.

As mentioned in [48], the form of the relationship between specific attenuation and rainfall intensity is accurately expressed by a power law for many different raindrop size distributions :

$$\gamma = k R^{\alpha} \qquad (3.9)$$

where k and α are strongly frequency and polarization dependent quantities. By introducing this expression in equation (3.8) and using the fact that the attenuation is the integral of the specific attenuation along the link, the following expression is derived :

$$r_A(R_p,L,\alpha) = R_{L,p}^{\alpha} / R_p^{\alpha} \qquad (3.10)$$

where $R_{L,p}^{\alpha}$ is the value exceeded for the percentage of time p by the extended path-averaged rainfall intensity R_L^{α} defined as :

$$R_L^{\alpha} = \frac{1}{L}\int_0^L R^{\alpha}(x)dx \qquad (3.11)$$

For $\alpha = 1$ equation (3.11) represents the well-known path-averaged rainfall intensity, while equation (3.10) reduces to that of the rainfall intensity reduction factor :

$$r(R_p,L) = r_A(R_p,L,1) \qquad (3.12)$$

r_A is only slightly dependent on the frequency and to a first order of accuracy can be approximated by the rainfall intensity reduction factor r. The function r depends only on R_p and L and can be directly derived from rainfall intensity measurements along a line using radar or raingauge network.

3.3.3. The vertical structure of rain

The observed vertical structure of rain shows a large degree of complexity, including the possible presence of other precipitation particles such as melting snow and hail. Radar observations provide the only direct measurement of the vertical structure of precipitation. Usually, vertical homogeneity is assumed up to a certain height, which is called rain height and correlated to the 0°C isotherm height H_0 of the atmosphere (freezing height).

The observation on the melting layer will improve the accuracy of the rain height estimation for stratiform rain type. For convective type of rain, additional information on the presence of other types of hydrometeor above the freezing height is needed.

Initially, the physical rain height was assumed to be equal to the 0°C isotherm height, according to the intuitive concept that liquid rain can only exist below that level. Unsatisfactory results were obtained when it was applied to predict rain attenuation for tropical regions. An empirical vertical reduction factor was suggested for the 0°C isotherm height, leading to the concept of effective rain height.

The effective rain height h_R, was tentatively equated to the 0°C isotherm height during rainy conditions h_{FR}. This assumption seems to be adequate for stratiform rain. However other types of rain may occur, such as "warm" convective rain, where rain is generated well below h_{FR} and the thunderstorms, where "tower" shaped clouds contain supercooled rain droplets far above the h_{FR} level. In these cases h_R is not well approximated by the measured h_{FR}. These two latest types of rain, convective rain and thunderstorm, are more often encountered in tropical regions and thus the accuracy of rain attenuation model prediction is questionable for these regions.

4. Rain Attenuation Prediction Models

Heavy rain causes serious degradation of satellite-earth communication operating at frequencies above 10 GHz. The statistical distribution of rain attenuation is therefore essential for the reliable planning of such links. Unfortunately, many years of recording with complicated equipment are necessary to obtain long-term rain attenuation statistics. Consequently measurements are only available for a limited number of places. However, rain rate measurements have been performed for many years in many countries and therefore rain rate statistics are available for most places.

Models that can predict rain attenuation statistics from known rain rate statistics are desirable. A number of such models have been proposed; the most popular one is the ITU-R model. Unfortunately, this model is not accurate to predict rain attenuation in the tropical climate area. Refinement of the model is necessary.

Many attempts to improve the prediction accuracy by introducing new methods have been done. Some of them will be presented in this chapter, however the concept of attenuation signals induced by rain will be first introduced.

4.1. Attenuation due to rain

The characteristics of rain vary both in space and time. It is difficult to design the attenuation calculation procedures. Simple procedures, while not always absolutely accurate, can sometimes produce satisfying results within the achievable accuracy. One such simplification is the power law relationship [Olsen et al.,1978] as expressed in equation (3.9).

The ITU-R adopted this relationship in the Report 721-3. k and α strongly depend on the frequency and polarization. The calculation of these coefficients are presented in Appendix B.

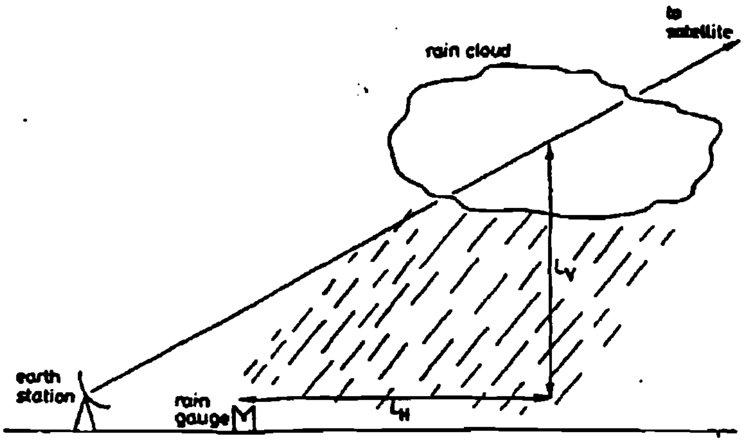


Fig. 4.1. Schematic representation of an earth-space path [38]

Figure 4.1 shows an earth-satellite radio path. If the rain rate R uniform over a radio path L km, the path attenuation A caused by the rain is given by

$$A = \gamma L \qquad \text{(in dB)} \qquad (4.1)$$

In practice the rain rate changes with position and time. The length of the portion of the path that contains rain, varies as well. If this length is L(t), and R(y,t) is the rain in mm/h at time t at a distance y km measured from the ground along the path, then the attenuation A(t) is given by

$$A(t) = \int_0^{L(t)} k[R(y,t)]^{\alpha} dy \qquad (4.2)$$

The link to a satellite can intercept rain at many heights along the slant path. A raingauge on the ground, usually will not measure at any given instant the same rainfall encountered at a point along the path. Therefore in general no instantaneous correlation will be found between attenuation A(t) along the slant path and the point rain rate R(t) measured on the ground near a receiving antenna.

Raindrops, particularly those caught in updrafts, require a surprisingly long time to fall from the upper part of a storm to a ground-based rain gauge. Typically the behaviour of the attenuation at time t resembles the behaviour of the ground rain rate of time t+T, where the delay T is variable and may be as long as 4 to 8 min. For this reason, predictive models for rain attenuation are statistical rather than instantaneous.

A path-average rain rate $\overline{R_L(t)}$ is defined and A(t) from equation (4.3) can be written as

$$A(t) = k\,[\overline{R_L(t)}]^{\alpha}\,L(t) \qquad (4.3)$$

The rain that passes through the propagation path is assumed to reach the ground. Hence the exceedance curve of the path average rain rate should be the same as the exceedance curve of the point rain rate. Since attenuation is caused by rain, it exhibits the same kind of statistical behaviour and can be described by exceedance plots. The attenuation value A_p equalled or exceeded p percent of the time is interpreted to be proportional to the value of point rain rate R_p equalled or exceeded for the same p percentage of time. The proportionality factor between A_p and $k\,[R_p]^{\alpha}$ is called effective path length, L_e

$$A_p = k\,[R_p]^{\alpha}\,L_e \qquad (4.4)$$

The critical feature of a slant path attenuation prediction model is how to create the effective path length over which the rainfall rate can be quantified and the attenuation can be calculated. Some models assume a constant rainfall rate along the path and vary the path length to achieve the correct value of attenuation. This variation is done by means of reduction factors.

The variation of precipitation in both horizontal and vertical directions makes the calculation of attenuation a complex matter. Many competing models have been introduced to obtain slant path attenuation statistics from point rainfall rate statistics. Some of them will be presented in the following section.

4.2. Developing rain attenuation models for tropical regions

Several methods are available for calculation of long-term rain attenuation statistics from the point rainfall rate statistics. The prediction method recommended by the ITU-R appears to give good accuracy in predicting rain attenuation for temperate climate areas, but not for tropical regions.

However, the ITU-R method remains successful because it is simple and its empirical nature makes this method easier to be modified as new data are made available. From this point of view it may be useful to continue such empirical approach. In this section, the ITU-R model will be presented and followed by other models which has been proposed to refine the ITU-R model.

4.2.1. The ITU-R method

The ITU-R method in Report 564-4 uses the concept of effective path length by means of a reduction factor. The method consists of the following procedure which is proposed to calculate the long-term statistics of the slant path rain attenuation at a given location for frequency up to 30 GHz (and provisionally for higher frequencies). This method consists of eight steps.

Step 1 : The effective rain height, h_R (km) is calculated from the latitude of the earth station ϕ,

$h_R = 3.0 + 0.028\,\phi \qquad 0 \le \phi \le 36°$ (4.5)

$h_R = 4.0 - 0.075\,(\phi - 36) \qquad \phi \ge 36°$

Step 2 : For an elevation angle $\theta \ge 5°$ the slant-path length L_s (km) below the rain height is obtained from,

$$L_s = \frac{(h_R - h_s)}{\sin\theta} \qquad (4.6)$$

with h_s is the height above mean sea level of the earth station (km).

For $\theta < 5°$ a more accurate formula should be used,

$$L_s = \frac{2(h_R - h_s)}{\left(\sin^2\theta + \frac{2(h_R - h_s)}{R_e}\right)^{½} + \sin\theta} \qquad (4.7)$$

with R_e is the effective radius of the earth (8500 km).

Step 3 : The horizontal projection L_G of the slant path length is found from (see fig. 4.2),

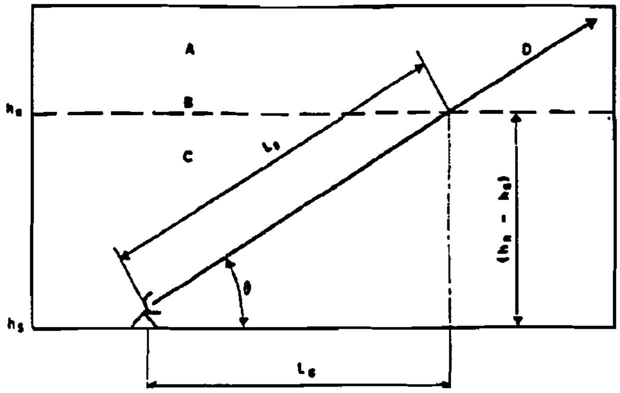
$$L_G = L_s \cos\theta \qquad \text{km} \qquad (4.8)$$

Step 4 : Obtain the rain intensity $R_{0.01}$ exceeded for 0.01% of an average year (with an integration time of 1 min). If this information cannot be obtained from local data sources, an estimate can be obtained from the maps of rain climates given in § 4.2 of ITU-R Report 563.

Step 5 : The reduction factor $r_{0.01}$ for 0.01% of the time can be calculated from,

$$r_{0.01} = \frac{1}{1 + L_G/L_O} \qquad (4.9)$$

where $L_O = 35 \exp(-0.015\, R_{0.01})$ is the characteristic length of a rain cell.



A : Precipitation
B : Rain height
C : Liquid precipitation
D : Earth-space path

Fig. 4.2. Schematic presentation of an earth-space path giving the parameters to be input into the attenuation prediction process[22]

Step 6 : Obtain the specific attenuation γ_R using the ITU-R Report 721 and the rainfall rate $R_{0.01}$ determined from step 4,

$$\gamma_R = k\,(R_{0.01})^{\alpha} \qquad \text{dB/km} \qquad (4.10)$$

Step 7 : The attenuation exceeded for 0.01% of an average year may then be obtained from,

$$A_{0.01} = \gamma_R\, L_s\, r_{0.01} \qquad \text{dB} \qquad (4.11)$$

Step 8 : The attenuation to be exceeded for other percentages of an average year, in the range 0.001% to 1.0% may be estimated from the attenuation to be exceeded for 0.01% of an average year by using,

$$A_p = A_{0.01}\, 0.12\, p^{-(0.546+0.043 \log p)} \quad (4.12)$$

4.2.2. Ajayi method

The path reduction factor in the ITU-R prediction method, converts a physical path length to an equivalent length along which the rain rate can be assumed constant. It turns out that the conversion process does not always lead to a reduction in path length. Hence, Ajayi has modified the ITU-R method by introducing two reduction factors, the horizontal reduction factor and the vertical reduction factor.

Figure 4.3 is used for that modification and the procedure to calculate rain attenuation from rain rate statistics in Ajayi method is as follows,

Step 1 : The height of the freezing level during the rain, h_{FR} (km) is calculated using

$$h_{FR} = 5.0 \qquad 0° \leq \phi < 23° \quad (4.13)$$

$$h_{FR} = 5.0 - 0.075\,(\phi - 23) \qquad \phi \geq 23°$$

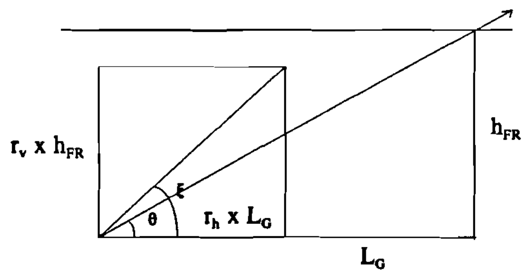


Fig. 4.3. Slant-path geometry for Ajayi method[7]

Step 2, 3, 4 and 5 remain unchanged

Step 6 : The horizontal reduction factor, $rh_{0.01}$ for 0.01% of the time can be calculated from

$$rh_{0.01}=\frac{1}{1+L_G^{0.002}(R_{0.01})^{1.01}} \tag{4.14}$$

Step 7 : The vertical reduction factor, $rv_{0.01}$ for 0.01% of the time can be calculated from

$$rv_{0.01}=\frac{1}{1+\frac{h_{FR}}{5+0.4\phi^{1.5}}} \tag{4.15}$$

Step 8 : The effective path length through the rain L_e can be calculated from

$$L_e=\frac{L_G rh_{0.01}}{\cos\theta} \qquad \xi > \theta \tag{4.16a}$$

$$L_e=\frac{h_{FR} rv_{0.01}}{\sin\theta} \qquad \xi \le \theta \tag{4.16b}$$

where

$$\xi=\tan^{-1}\left(\frac{h_{FR} rv_{0.01}}{L_G rh_{0.01}}\right) \tag{4.17}$$

Step 9 is the same as the step 6 of the ITU-R method.

Step 10 : The attenuation exceeded for 0.01% of an average year, $A_{0.01}$, is obtained from,

$$A_{0.01} = \gamma_R \, L_e \, r_{0.01} \qquad \text{dB} \tag{4.18}$$

Step 11 is the same as the step 8 of the ITU-R method.

4.2.3. Dissanayake-Allnutt method

The conversion of the physical path length to the effective path length as implemented in the ITU-R method does not always lead to an accurate reduction in path length. Therefore in the Dissanayake-Allnutt method, the conversion factor is called the adjustment factor instead of the reduction factor.

Dissanayake and Allnutt include two adjustment factors in their proposed method, namely horizontal path adjustment factor and vertical adjustment factor. The horizontal path adjustment factor takes into account the inhomogeneity of rain along the propagation path horizontally, while the vertical adjustment factor takes into consideration the vertical inhomogeneity of the rain. These two adjustments factors were devised by using the available slant path attenuation measurement data. The derivation of these adjustment factors is beyond the scope of this text, thus only the end results of that derivation will be included.

Figure 4.4 shows the modification of slant path geometry, while the procedure to calculate the prediction of slant path attenuation according this method is as follows,

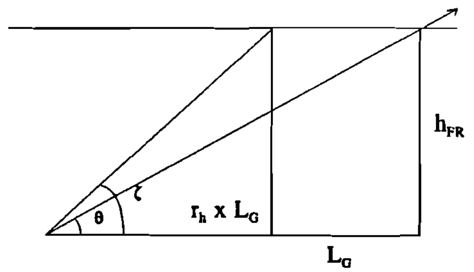


Fig. 4.4. Slant path geometry of Dissanayake-Allnutt method

Step 1 : The freezing height h_{FR} (km) is given by

$$h_{FR} = 5.0 \qquad 0° \leq \phi < 23° \qquad (4.13)$$

$$h_{FR} = 5.0 - 0.075\ (\phi - 23) \qquad \phi \geq 23°$$

Step 2 : The slant path length for elevation angle greater than 5°, is

$$L_s = \frac{(h_{FR} - h_s)}{\sin\theta} \qquad \text{km} \qquad (4.19)$$

Step 3 : Obtain the rain intensity $R_{0.01}$ (mm/h) exceeded for 0.01% of an average year, and hence the specific attenuation γ_R

$$\gamma_R = k\ (R_{0.01})^{\alpha} \qquad \text{dB/km} \qquad (4.10)$$

as adopted from the ITU-R method.

Step 4 : The horizontal path adjustment factor $rh_{0.01}$ is calculated by using

$$rh_{0.01} = \frac{1}{0.628 + 0.194\sqrt{\gamma_R L_s}} \qquad (4.20)$$

Step 5 : Calculate the vertical adjustment factor $rv_{0.01}$

$$rv_{0.01} = \frac{1}{1 + \sin\theta(1.282\sqrt{L_s} - 2.871)} \qquad \text{for } \phi > 23° \qquad (4.21a)$$

$$rv_{0.01} = 1 - 0.5\sin\theta \qquad \text{for } \phi = 0° \qquad (4.21b)$$

For latitude between 0° and 23°, a linear interpolation between (4.21a) and (4.21b) is suggested. This adjustment factor is also applicable only for 0.01% of the time.

Step 6 : Calculate the horizontal projection L_G of the slant path as in the ITU-R method

$$L_G = L_s \cos\theta \qquad \text{km} \qquad (4.22)$$

Step 7 : Calculate the effective horizontal extent of rain $L_{0.01}$ for 0.01% of the time

$$L_{0.01} = rh_{0.01}\ L_G \qquad \text{km} \qquad (4.23)$$

Step 8 : Calculate the effective path length L_e (km) through rain

$$L_e = L_{0.01} / \cos\theta \qquad \text{for } \zeta > \theta \qquad (4.24)$$

$$L_e = h_{FR} / \sin\theta \qquad \text{for } \zeta \leq \theta$$

where $\zeta = \tan^{-1} (h_{FR} / L_{0.01})$

Step 9 : The attenuation exceeded for 0.01% of an average year may then be obtained from

$$A_{0.01} = \gamma_R \, L_e \, rv_{0.01} \qquad \text{dB} \qquad (4.25)$$

Step 10 : The attenuation to be exceeded for other percentages of an average year, in the range 0.01% to 1.0%, may be estimated from the attenuation to be exceeded for 0.01% for an average year by using

$$A_p = A_{0.01} \left(\frac{p}{0.01} \right)^y \qquad \text{dB} \qquad (4.26)$$

where $y = 0.05 \ln(A_{0.01}) - 0.04 \ln(p) - 0.7 + z(\theta)$ (4.27a)

with

$$z(\theta) = q \sqrt{\sin\theta} \;\; e^{(-8.5 \sin\theta)} \qquad \text{for } \theta \leq 20° \qquad (4.27b)$$

$$z(\theta) = z(20°) \qquad \text{for } \theta > 20°$$

and $q = 1.72 - 0.5 (\log p + 1)^2$ (4.27c)

4.2.4. Pontes-Silva-Souza Method

The ITU-R rain attenuation prediction method is based on the estimation of the attenuation exceeded at 0.01% of the time ($A_{0.01}$), using the rain rate exceeded at the same percentage of time ($R_{0.01}$). An empirical expression is then used for scaling to other time percentages, in order to generate the complete attenuation distribution.

For low latitude regions, the estimation of $A_{0.01}$ shows inaccuracy, mainly because the values of rain height used in the calculation are too small. The expression for time percentage scaling also does not produce the proper slope of the distribution for tropical regions.

The Pontes-Silva-Souza method uses the complete rainfall rate distribution to predict the attenuation distribution in a point-to-point equiprobability basis. The slant path attenuation A_p exceeded for a percentage of time p is given by

$$A_p = \gamma(R_p)\, L_e(R_p) \qquad \text{dB} \qquad (4.28)$$

with the specific attenuation $\gamma(R_p)$,

$$\gamma(R_p) = k\, R_p^{\alpha} \qquad \text{dB/km} \qquad (4.29)$$

and the effective path length L_e,

$$L_e(R_p) = L_s(R_p)\, r(R_p) \qquad \text{km} \qquad (4.30)$$

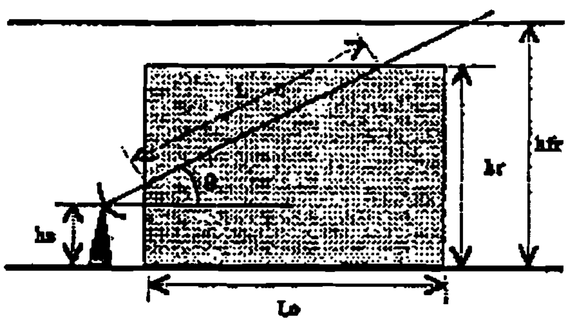


Fig. 4.4. Slant path geometry for the Pontes-Silva-Souza method

The effective path length L_e is the average value of the path length L inside the equivalent rain cell. Figure 4.4 shows that the L_e is a function of the effective rain height h_R, the antenna altitude h_s, the effective horizontal rain length L_0 and the elevation angle θ. The expression for L_s as the function of rainfall rate is given by

$$L_s(R_p) = \frac{h_R(R_p) - h_s}{\sin\theta} \quad \text{km} \qquad (4.31)$$

The reduction factor r is also expressed as the function of rain rate

$$r(R_p) = \frac{1}{1 + L_G(R_p)/L_0(R_p)} \qquad (4.32)$$

with $L_G(R_p) = L_s(R_p) \cos\theta$ km

$L_0(R_p) = 35 \exp(-0.015\ R_p)$ km

The behaviour of the effective rain height h_R was investigated by using the data from the radiometric measurements at 12 GHz, which were performed in Brazil. The derivation of the empirical expression for h_R as the function of rain rate is beyond the scope of this report. However the preliminary result of that derivation is introduced here as,

$$h_R(R_p) = 3.8\ [\ 1 + \exp(-0.1R_p)\ ] \quad \text{km} \qquad (4.33)$$

4.3. Model comparison

The methods given in the previous section will be compared in this section and presented in the form of table. Table 4.1 gives an overview of the four methods. The Ajayi method and the Dissanayake-Allnutt method modify the ITU-R method by implementing the reduction factors horizontally and vertically, to convert a physical path length to an equivalent path length. Ajayi uses the same expression as the ITU-R method to calculate the A_p from the $A_{0.01}$, while Dissanayake and Allnutt use completely different expression.

Pontes, Silva and Souza use different approach in calculating the rain attenuation cumulative distribution. The expressions from the ITU-R method are implemented as a function of point rainfall rate with different expression to calculate the rain height h_R.

Table 4.1. Model comparison

	ITU-R	Ajayi	Dissanayake-Allnutt	Pontes-Silva-Souza
h_R / $h_R(R_p)$	$3.0 + 0.028\,\phi$ $4.0 - 0.075(\phi - 36)$	see ITUR	not used	$3.8\,[1+\exp(-0.1\,R_p)]$
h_{FR}	not used	5.0 $5.0 - 0.075(\phi - 23)$	see Ajayi	not used
L_s / $L_s(R_p)$	$(h_R-h_s)/\sin\theta$ $\dfrac{2(h_R-h_s)}{(\sin^2\theta+2(h_R-h_s)/R_e)^{1/2}+\sin\theta}$	see ITUR	$(h_{FR}-h_s)/\sin\theta$	$[h_R(R_p) - h_s]/\sin\theta$
$L_G/L_G(R_p)$	$L_s\cos\theta$	see ITUR	see ITUR	$L_s(R_p)\cos\theta$
$r_{0.01}$ / $r(R_p)$	$1/(1 + L_G/L_0)$	see ITUR	not used	$1/[1+L_G(R_p)/L_0(R_p)]$
$rh_{0.01}$	not used	$1/(1+L_G^{0.002}\,R_{0.01}^{1.01})$	$1/(0.628+0.194\sqrt{\gamma_R L_s})$	not used
$rv_{0.01}$	not used	$\dfrac{1}{1+h_{FR}/(5+0.4\phi^{1.5})}$	$1/[1+\sin\theta(1.282\sqrt{L_s}-2.871)]$ $1 - 0.5\sin\theta$	not used
L_e / $L_e(R_p)$	not used	$L_G\,rh_{0.01} / \cos\theta$ $h_{FR}\,rv_{0.01} / \sin\theta$	$L_G\,rh_{0.01} / \cos\theta$ $h_{FR} / \sin\theta$	$L_s(R_p)\,r(R_p)$
γ_R / $\gamma(R_p)$	$k\,(R_{0.01})^{\alpha}$	see ITUR	see ITUR	$k\,R_p^{\alpha}$
$A_{0.01}$	$\gamma_R\,L_s\,r_{0.01}$	$\gamma_R\,L_e\,r_{0.01}$	$\gamma_R\,L_e\,rv_{0.01}$	not used
A_p	$A_{0.01}\,0.12\,p^{-(0.546+0.043\log p)}$	see ITUR	$A_{0.01}\,(p/0.01)^y$	$\gamma(R_p)\,L_e(R_p)$

5. Rain Attenuation Prediction in the K_u-band for the Palapa B4 Satellite

In the previous chapter some methods, indicated as the ITU-R method, the Ajayi method, the Dissanayake-Allnutt method and the Pontes et.al method, to predict the rain attenuation along a satellite path have been introduced. In this chapter those methods will be applied to the data which were collected in Surabaya for the INTELSAT telecommunications research project as mentioned already in Chapter 2. The predicted rain attenuation according those methods will be compared with the measured one.

Also in Chapter 2, the present Indonesian telecommunication services have been illustrated. The telecommunication services are operated in the C-band. The use of higher frequency bands, for instance the K_u-band, is hindered by the ambiguity of the effects of rain on the satellite signals in those frequency bands. The existing methods to predict the impairments on the satellite signals caused by rain are not accurate for tropical regions.

Based on the comparisons between the predicted rain attenuation using the methods in Chapter 4 with the measured rain attenuation in the K_u-band for Surabaya earth station, the predicted rain attenuation in the same frequency along a satellite path from Surabaya to the Palapa B4 satellite will be derived.

Elevation angle scaling technique will also be introduced. The rain attenuation as a function of antenna elevation angle will be investigated. From this approach, the predicted rain attenuation in the K_u-band along a satellite path from Surabaya to the Palapa B4 satellite will be presented.

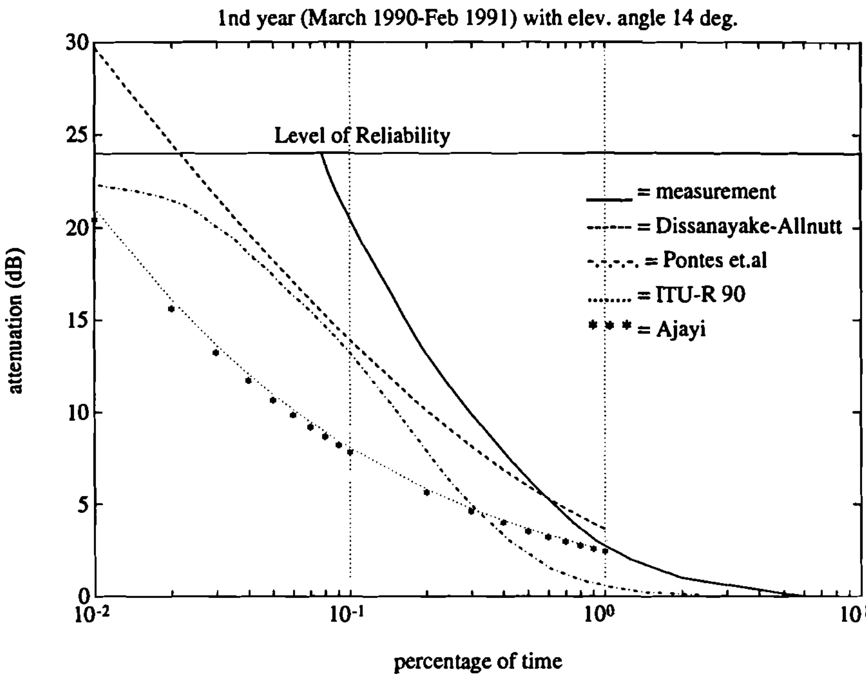
5.1. Implementation of the methods and its analysis

5.1.1. Calculating predicted rain attenuation

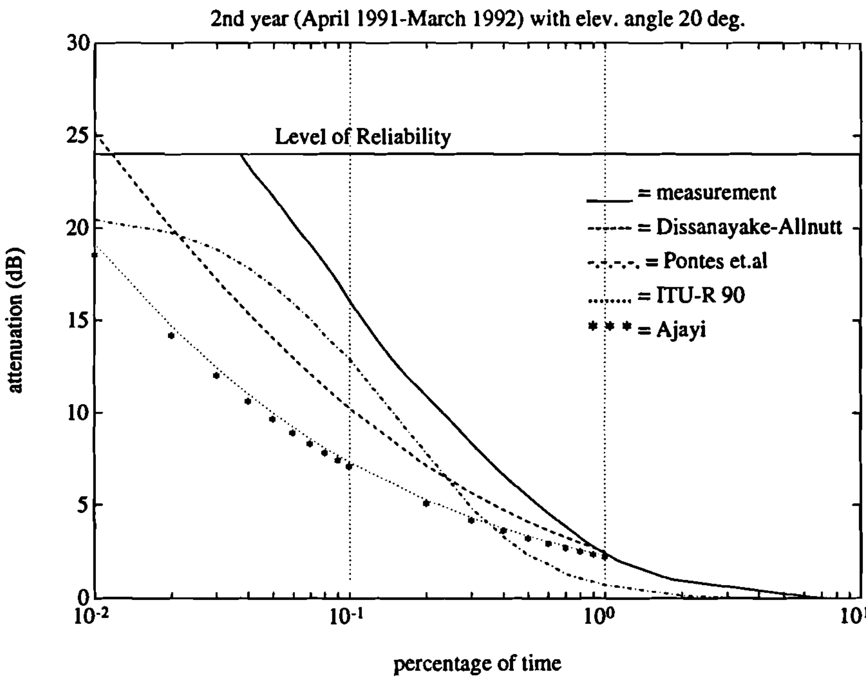
The four methods in the previous chapter to predict the rain attenuation strongly depend on the statistical distribution of the rain intensity. Using the collected rain intensity data from the INTELSAT telecommunications research project at ITS, Surabaya, the rain attenuation in the K_u-band along a satellite path to the INTELSAT V from the Surabaya earth station is calculated. Remember that in the first year the antenna was pointed to the INTELSAT-508 with an antenna elevation angle of 14°07'15", while in the second and the third year it was pointed to the INTELSAT-510 with an angle of 20°20'34".

Table 5.1. Model parameters for each year

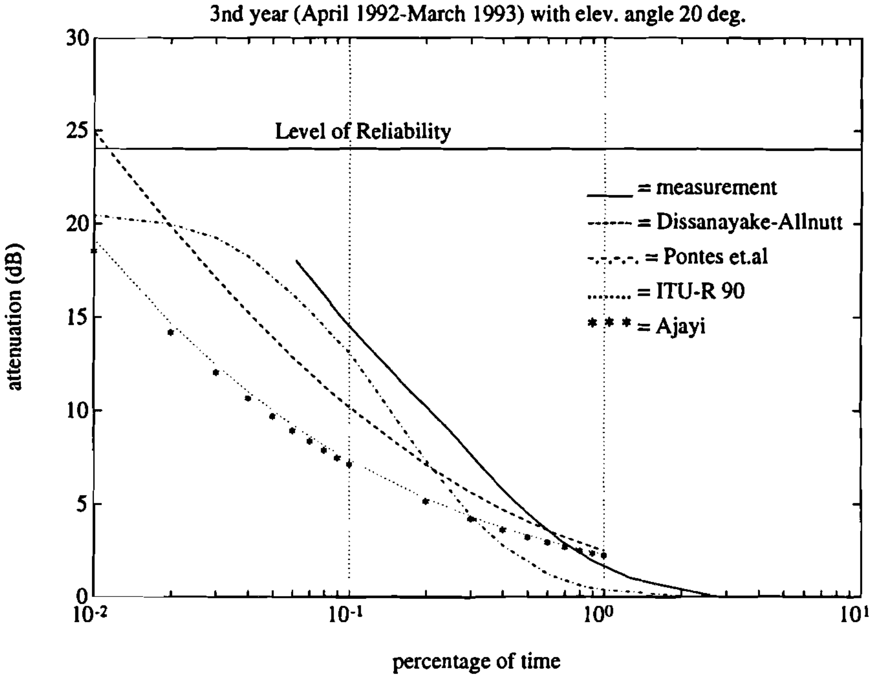
	ITU-R			Ajayi			Dissanayake - Allnutt		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
h_R	3.20			see ITU-R			not used		
h_{FR}	not used			5			see Ajayi		
L_s	13.07	9.17		see ITU-R			20.43	14.34	
L_G	12.67	8.60		see ITU-R			19.81	13.45	
$R_{0.01}$	110	125.1	123.8	see ITU-R			see ITU-R		
L_0	6.72	5.36	5.47	see ITU-R			not used		
$r_{0.01}$	0.35	0.38	0.39	see ITU-R			not used		
γ_R	4.66	5.46	5.39	see ITU-R			see ITU-R		
$rh_{0.01}$	not used			0.97	0.97	0.97	0.40	0.43	0.43
$rv_{0.01}$	not used			0.719			0.787	0.753	
L_e	not used			12.69	8.87	8.87	8.11	6.12	6.15
$A_{0.01}$	21.09	19.21	19.20	20.48	18.6	18.6	29.71	25.14	24.93



(a) first year



(b) second year



(c) third year

Fig. 5.1. The measured rain attenuation and the predicted rain attenuation

Every step in each method has been followed by using the data in Table 2.1 and Matlab has been used as a tool for the calculation. The results are presented in Table 5.1 except the ones which were obtained by using the Pontes-Silva-Souza method. The latest step of each method and the calculation results of the Pontes et.al. method can be noticed in Figure 5.1. The statistical distributions of the measured rain attenuation are also presented in the same figure.

Figure 5.1 shows that there are big discrepancies between the measurement results and the calculation results using all those four methods. Those discrepancies can be observed from their r.m.s. values in Table 5.2. All of those methods give the predicted rain attenuation which is lower than the measured attenuation at small percentages of the time. This phenomenon is very critical regarding the system availability of the telecommunication services which consider the rain attenuation at small percentages of the time important.

Another phenomenon which must be noticed is that a saturation occurs in the predicted rain attenuation cumulative distribution of Pontes et.al. It occurs above 16 dB at small percentages of the time. This occurrence will be discussed later in a special subsection.

Notice that the comparison for the third year is considered until 18 dB instead of 24 dB. The INTELSAT had ceased to correct the N-S drift of the INTELSAT 510 in order to conserve fuel for E-W drift and orbit-raising manoeuvres since July 1992. The antenna was not provided with tracking facilities. As a consequence, the diurnal variation in the amplitude of the received beacon signal was steadily increased up to about 13 dB peak-to-peak by the end of the third year of measurements.

Table 5.2. R.m.s. values for each year

	r.m.s. values		
	1st	2nd	3rd
ITU-R	7.3721	7.2768	5.1336
Ajayi	7.5190	7.4838	5.3065
Dissanayake - Allnutt	3.8514	4.8112	3.1141
Pontes - Silva - Souza	5.0373	3.2148	4.8232

5.1.2. Discrepancies analysis

Calculating the predicted rain attenuation by using the Dissanayake-Allnutt method and the Pontes et.al. method give the smallest r.m.s values. The implementation of the Ajayi method shows the biggest discrepancies. The implementation of the ITU-R method shows almost the same discrepancies as the Ajayi method.

From the previous chapters, the difficulties in predicting the rain attenuation have been illustrated. The overall structure of the rain shower must be well understood. The knowledge of the rain height and the horizontal structure of rain are some of the major problems.

In Table 5.1, the value of L_G has a factor two to three times greater than the value of L_0. It implies that the slant path may pass through more than one rain cell which complicates the calculation of the reduction factor. Significant discrepancies between the calculation and the measurement results may occur.

Another reason which may explain those discrepancies is the chosen rainfall drop-size distribution. Ajayi, Dissanayake-Allnutt and Pontes et.al. follow the ITU-R method in calculating the specific attenuation which uses the Laws-Parsons drop-size distribution. As mentioned in Chapter 3 this type of distribution is not appropriate for tropical regions. The lognormal drop-size distribution is considered more suitable, but its implementation is still under study.

For the discrepancies in using the ITU-R method, two possible reasons can be added. The first is that the value of the rain height h_R is too small which effects the value of $A_{0.01}$. The second is that the expression for time percentage scaling does not produce the proper slope of the rain attenuation cumulative distribution.

Ajayi reduces the slant path length horizontally and vertically to determine the effective path length. The horizontal reduction factor $rh_{0.01}$ depends on the horizontal projection L_G and the rain intensity $R_{0.01}$. The vertical reduction factor $rv_{0.01}$ is determined by the height of the freezing level during the rain h_{FR} and the latitude of the earth station. The effective path length through the rain L_e is used to calculate the attenuation $A_{0.01}$. The idea of Ajayi of these reduction factors as the modification on the ITU-R method is a possible reason which cause significant discrepancies between the prediction and the measurement. Since the same expression for time percentage scaling as the ITU-R is used, the slope of the distribution is not satisfying either.

Figure 5.1 and Table 5.2 create an interest in further improving the Dissanayake-Allnutt method. Dissanayake and Allnutt involve the freezing height h_{FR} instead of the effective rain height h_R, to calculate the slant path length L_s. It gives a larger value of

$A_{0.01}$. A better slope of distribution is shown, while the differences between the prediction and the measurement are possibly caused by the adjustment factor calculation.

The Pontes et.al. method gives a similar curve pattern of distribution with the measured one until about 16 dB before the saturation appears. However the demonstrated discrepancies are probably caused by the expression of the effective rain height h_R. That expression is derived from the radiometric measurements in Brazil, which may not be suitable for Surabaya. The radiometric measurements were also conducted at 12 GHz which is slightly different from the chosen frequency for Surabaya, that is 11.198 GHz.

Based on their smallest r.m.s. values, the latest two methods will be further analyzed. A modification will be performed using the curve fitting method. The best fit will then be applied to derive the rain attenuation along a satellite path from the Surabaya earth station to the Palapa B4 satellite.

5.2. Modification of the Pontes-Silva-Souza method.

In the previous section the occurrence of a saturation in the predicted rain attenuation cumulative distribution according Pontes et.al. has been mentioned. This will be discussed in the first subsection.

5.2.1. The saturation phenomenon

Pontes, Silva and Souza derived an empirical expression for the effective rain height h_R from their radiometric measurements at 12 GHz, performed at six sites in Brazil. The effective rain height h_R, associated to the rain rate exceeding p% of the time, was estimated by the following equation which were derived from expressions (4.28) to (4.32) :

$$h_R(R_p) = \frac{L_0(R_p)\sin\theta}{\frac{\gamma(R_p)}{A_p}L_0(R_p) - \cos\theta} + h_s \qquad (5.1)$$

The derivation of this expression is given in Appendix C.

Using Equation (5.1), h_R for each site was calculated. From those results, an empirical expression for h_R was produced by using the least square fitting method. Pontes et.al. wrote that expression in Equation (4.33).

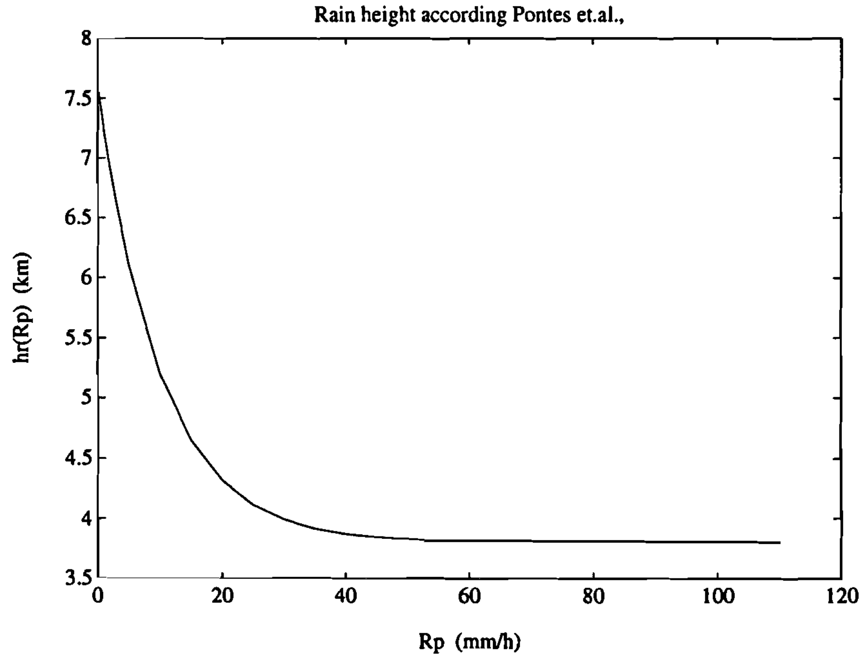


Fig. 5.2. Effective rain height for Surabaya using the Brazil empirical expression

Equation (4.33) has been applied to the collected rain intensity data at ITS, Surabaya. The result is presented in Figure 5.2. The effective rain height h_R is towards constant at high rain rates.

From Figure 5.2 the explanation of the saturation phenomenon on the rain attenuation according Pontes et.al can be derived. The constant values of h_R affect the slant path length L_s in Equation (4.31) which become constant as well. L_G depends on L_s, therefore it also becomes constant. As the rain rate increases, L_0 decreases. Since L_G is constant and L_0 is decreasing at high rain rates, the nominator in Equation (4.32) is increasing. Thus, the reduction factor $r(R_p)$ is decreasing. Consequently, the effective path length L_e in Equation (4.30) is also decreasing. The increase of $\gamma(R_p)$ at high rain rates is compensated by the decrease of $r(R_p)$. It makes the rain attenuation A_p becoming nearly constant. The saturation occurs above 16 dB and please notice that it happens at small percentages of the time.

5.2.2. Empirical expression of the rain height for Surabaya

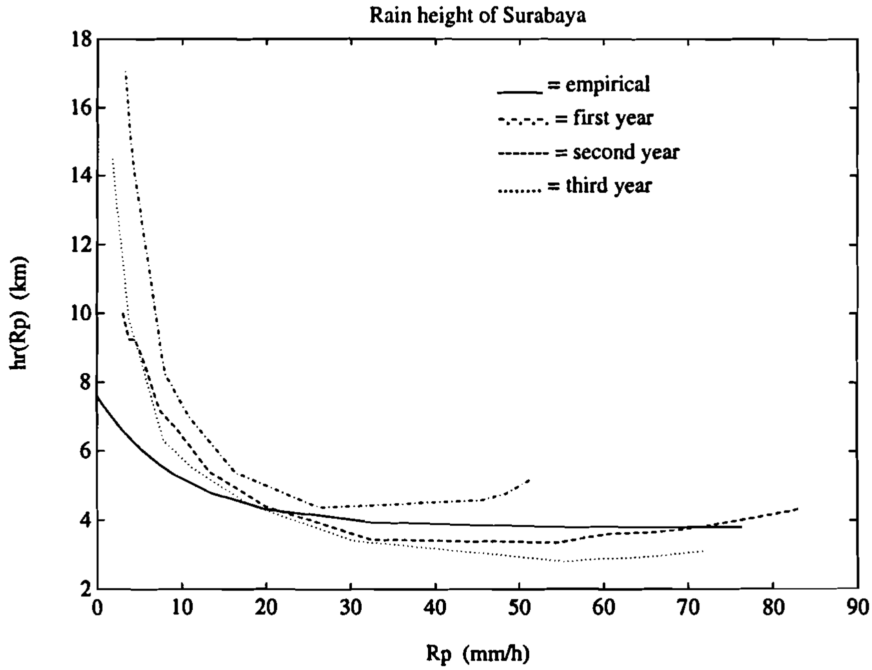


Fig. 5.3. h_R of Surabaya with the Pontes et.al. empirical expression

Using Equation (5.1), the rain height for Surabaya is also derived. For each year, it is calculated separately and the result is presented in Figure 5.3. Apparently, the rain height h_R is nearly constant at high rain rates. The rain height of the first year with antenna elevation angle of 14°07'15" is higher than the one from the second and the third year with antenna elevation angle of 20°20'34".

The empirical expression according Pontes et.al. is implemented to the rain intensity data of the second year. Figure 5.3 also shows the result of this implementation. From that illustration it can be concluded that the empirical expression of the rain height h_R from Pontes et.al. does not represent the rain height expression for Surabaya. This interpretation may explain the differences between the predicted attenuation and the measured one in Figure 5.1.

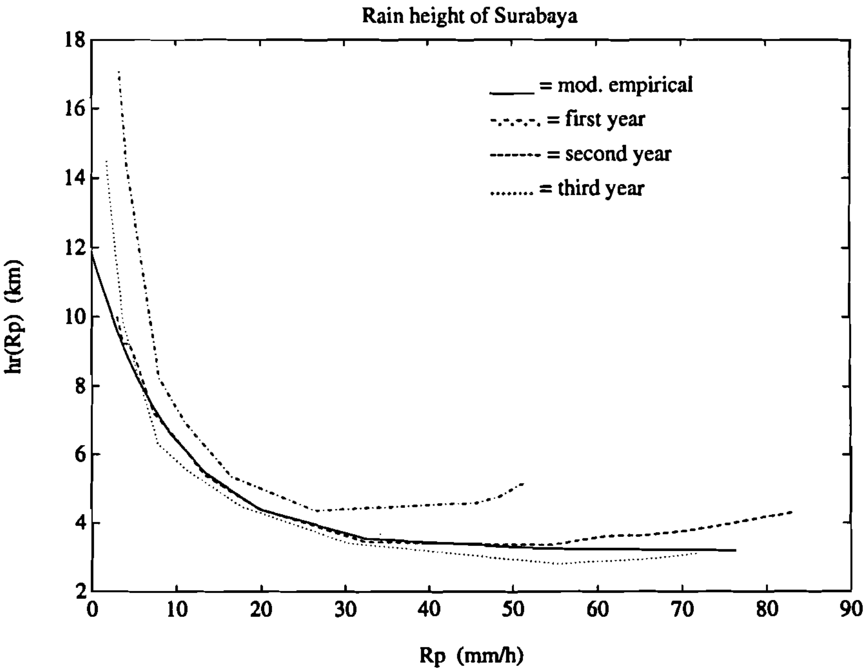


Fig. 5.4. h_R with the modified Pontes et.al. empirical expression

The empirical expression according Pontes et.al. is slightly modified. A representative empirical expression of the rain height for Surabaya is obtained and the result is shown in Figure 5.4. The empirical expression which represents the rain height for Surabaya is :

$$h_R = 3.2\ [\ 1+exp(-0.1R_p+1)\ ] \qquad (5.2)$$

5.2.3. Curve fitting for the Pontes et.al. method

A curve fitting method with one variable is applied to the Pontes-Silva-Souza method. Analyzing the decrease of its r.m.s. values and the results of the choosing variable, this method may be used later to reveal the impairments characteristics of the Palapa B4 satellite signals in the K_u-band.

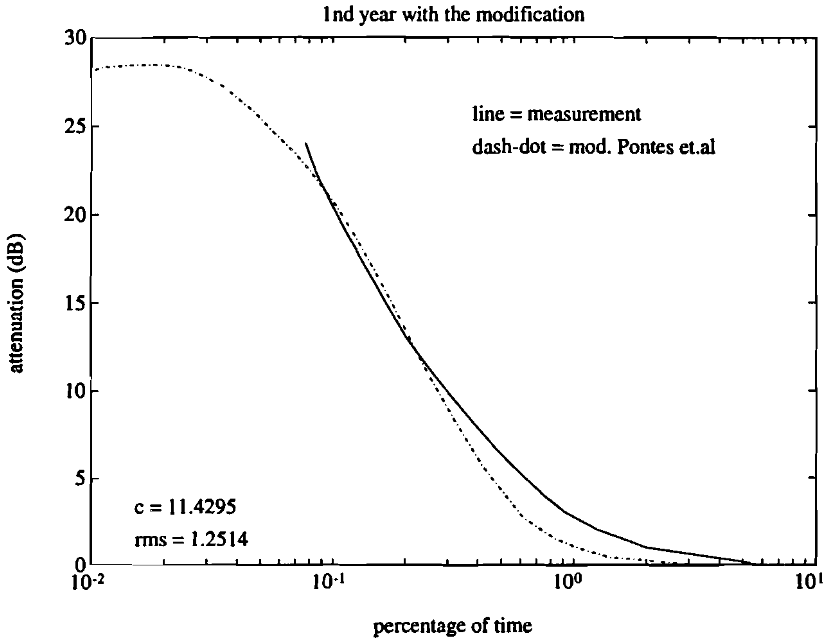
By keeping the exponential term of equation (5.2), the first factor is chosen as the variable. Thus, Equation (5.2) can be written as :

$$h_R = c\ [\ 1+exp(-0.1R_p+1)\ ] \qquad (5.3)$$

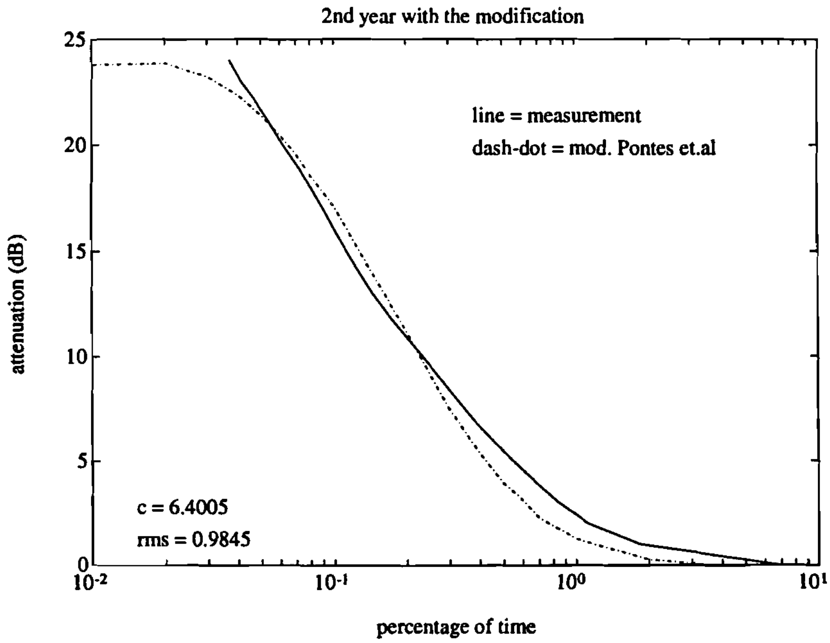
Equation (5.3) is applied to the yearly rain intensity statistics of the INTELSAT measurements in Surabaya. The produced results of variable c and the related r.m.s. values of the curve fit are presented in Table 5.3. The curve fitting between the measurement and the modified Pontes et.al. is shown in Figure 5.5.

Table 5.3. The variable c values and the related r.m.s. values

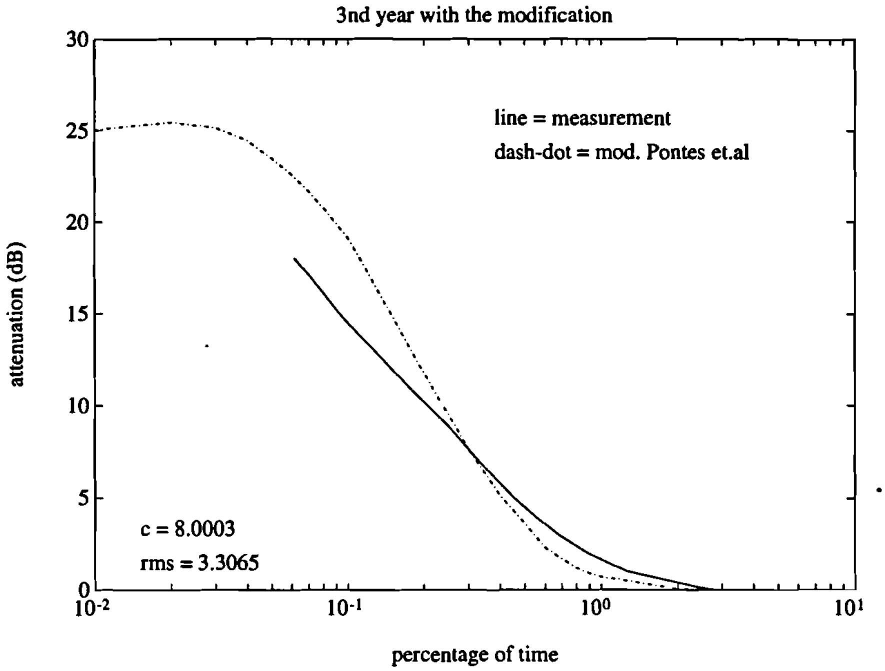
	1st	2nd	3rd
c	11.4295	6.4005	8.0003
r.m.s.	1.2514	0.9845	3.3065



(a) first year



(b) second year



(c) third year

Fig. 5.5. Curve fitting on the Pontes et.al. method

Figure 5.5 illustrates that the saturation is more obvious. Table 5.3 and Figure 5.5 show that the implementation on the second year measurement gives the best fit, while the one on the third year measurement gives the worst fit. The fitting results of variable c vary from 6.4 to 11.43. The r.m.s. values vary from 0.9 to 3.3.

The saturation shows up already at percentage of the time which is larger than 0.01%. For instance, the outage time of data communication services is 0.01% of the time. To design a system for this services means using the information in the saturation part which implies that the system design will not be accurate.

The large variation of variable c gives difficulty in choosing a suitable value to be implemented in Equation (5.3). A representative effective rain height expression to predict rain attenuation can not be defined.

The occurrence of the saturation phenomenon and the large variation of variable c give consideration that this method is not acceptable for predicting the rain attenuation along a satellite path from Surabaya earth station to the Palapa B4. Another comment is that the rain height expression is derived empirically. Therefore it can not provide a physical explanation of the rain characteristics.

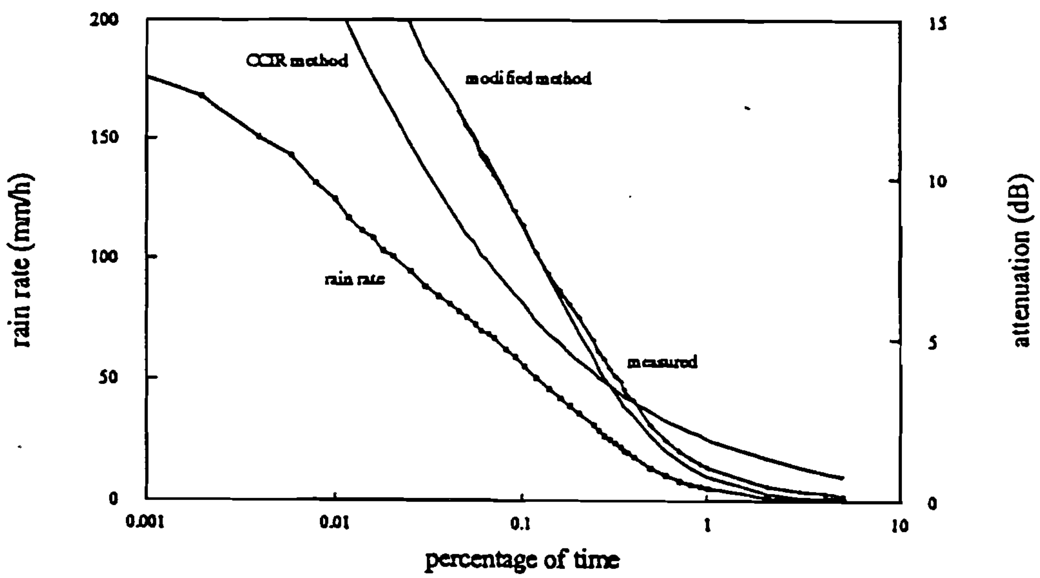


Fig. 5.6. The results of the measurements in Belém from Pontes et.al. [16]

An original illustration of the Pontes et.al. method is presented in Figure 5.6. It shows the comparison between the measured and the predicted attenuation for Belém earth station in Brazil. The comparison is performed up to 12 dB. The comparison above 12 dB can not be provided with respect to the limitation of the radiometer accuracy. Thus, the saturation phenomenon can not be detected. See again Figure 5.1 which shows that saturation occurs above 16 dB. This caution of using the Pontes et.al. method to predict rain attenuation must be noticed.

5.3. Modification of the Dissanayake-Allnutt method

As implied in Subsection 5.1.2, an attention would be given to the adjustment factor calculation. Dissanayake and Allnutt include two types of adjustment factor in their method, namely horizontal path adjustment factor and vertical path adjustment factor.

5.3.1. Vertical path adjustment factor

Step 5 in the Dissanayake-Allnutt method describes the calculation of the vertical adjustment factor $rv_{0.01}$. The location site for Surabaya earth station is 7°15'. A vertical adjustment factor for Surabaya earth station is obtained from the linear interpolation between (4.21a) and (4.21b). The value of $rv_{0.01}$ depends on the latitude of the earth station and the antenna elevation angle.

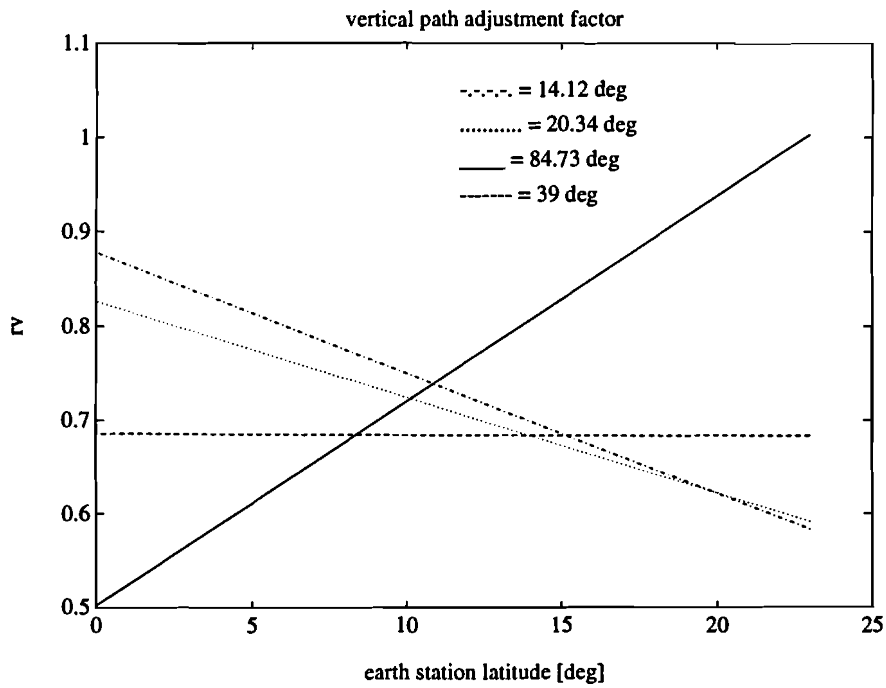


Fig. 5.7. An illustration of the vertical path adjustment factor

Figure 5.7 shows that different antenna elevation angles produce different lines. For small antenna elevation angle, the vertical adjustment factor reduces as the latitude of the earth station increases. The larger the antenna elevation angle, the slope of $rv_{0.01}$ becomes smaller. When the antenna elevation angle reaches 39°, $rv_{0.01}$ becomes constant. For an antenna elevation angle larger than 39°, $rv_{0.01}$ increases as the latitude of the earth station increases.

For Surabaya earth station, the larger its antenna elevation angle, the smaller is its $rv_{0.01}$. In other locations at high latitude, $rv_{0.01}$ increases as the antenna elevation angle increases.

The vertical path adjustment factor is chosen not to be modified considering its complexity. The modification is considered to be applied to the horizontal path adjustment factor.

5.3.2. Curve fitting with one variable

The horizontal path adjustment factor $rh_{0.01}$ is calculated by using Equation (4.21). Keeping the factor 0.194 fixed and changing the factor 0.628 by a variable **s**, a curve fitting method is applied to the second year data of the measurements which were performed at ITS. The result for **s** that gives the best fitting is -0.1205 with a r.m.s. value of 0.9410. Assuming the factor 0.628 is fixed and the factor 0.194 is changed by a variable **t**, a curve fitting method is applied to the same data. The produced result for **t** is 0.109 with a r.m.s. value of 0.9414.

Figure 5.8 gives an illustration of the implementation of the curve fitting with **t** as the variable. The rain attenuation is overestimated at big percentages of the time. However, a better fit may be gained by involving one more variable. The second variable must be implemented to the expression for time percentage scaling in Equation (4.27a). The parameter z depends on q. It means the second variable implementation may also be in Equation (4.27c).

A curve fitting procedure is performed by replacing the factor 0.05 in Equation (4.27a) with a variable $\mathbf{a_1}$ and keeping the others fixed. This procedure is executed twice for the condition when **s**=-0.1205 and when **t**=0.109. The change of the r.m.s. values is observed. The same approach is also conducted by replacing the factor 0.041 with $\mathbf{a_2}$, the factor 0.7 with $\mathbf{a_3}$, the factor 1.72 in Equation (4.27c) with $\mathbf{a_4}$ and the factor 0.5 with **b**. The results are written in Table 5.4.

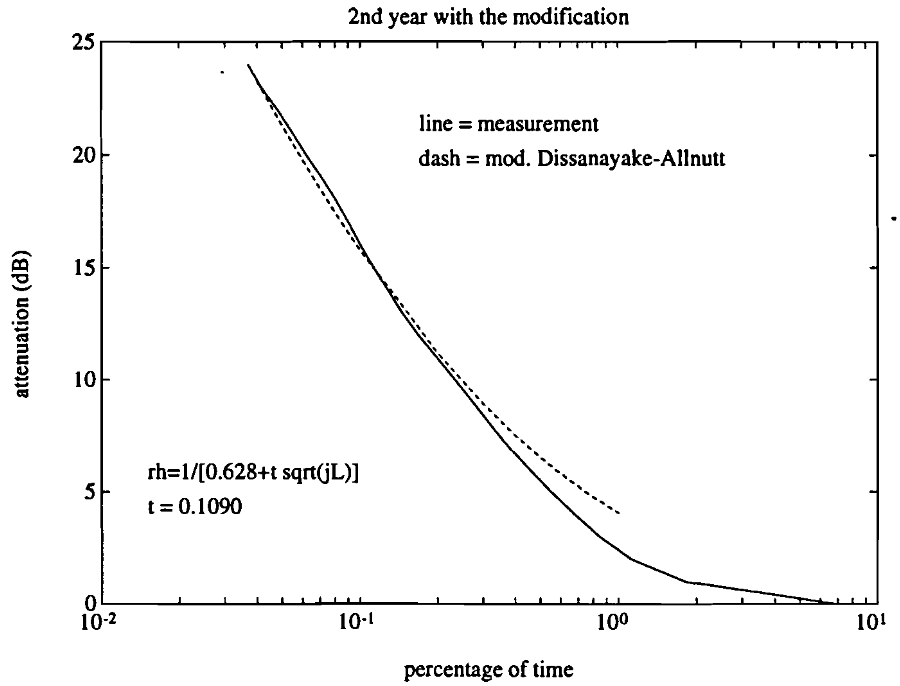


Fig. 5.8. Curve fitting with one variable on the Dissanayake-Allnutt method

The curve fitting results in Table 5.4 show that choosing **b** as the second variable produces the largest improvement on the r.m.s. value. From 0.9410 for **s** variable, becomes 0.423. For **t** variable, 0.9414 becomes 0.3954. Observing other second variables $\mathbf{a_1}$, $\mathbf{a_2}$, $\mathbf{a_3}$ and $\mathbf{a_4}$, the decrease of the r.m.s. values is not satisfying. Therefore **b** is chosen as the second variable to be implemented in the curve fitting method with two variables and other parameters are kept the same as the original.

Table 5.4. Choosing the second variable

	s = -0.1205 rms = 0.9410	t = 0.109 rms = 0.9414
a_1	0.0481, rms = 0.9166	0.0477, rms = 0.9095
a_2	0.0439, rms = 0.9210	0.0435, rms = 0.9275
a_3	0.7072, rms = 0.9166	0.7079, rms = 0.9095
a_4	1.7207, rms = 0.9305	1.7203, rms = 0.9300
b	3.3555, rms = 0.4230	3.4055, rms = 0.3954

5.3.3. Curve fitting method with two variables

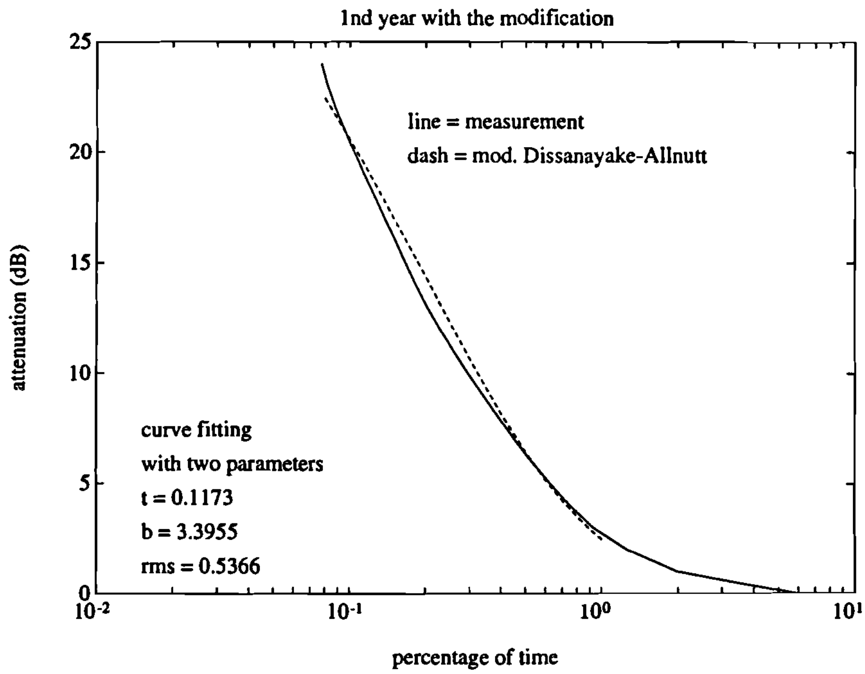
Two types of curve fitting method with two variables are conducted. The one with **s** and **b** as the variables and the other one with **t** and **b** as the variables. This method is applied to the yearly statistics collected from the INTELSAT measurements in Surabaya.

The results are written in Table 5.5. Figure 5.9 illustrates the good fit of this method. Comparing the implementation to the second year data with the one variable curve fitting results as depicted in Figure 5.8, the improvement of curve fitting method with two variables is very obvious. Notice the decrease of their r.m.s. values.

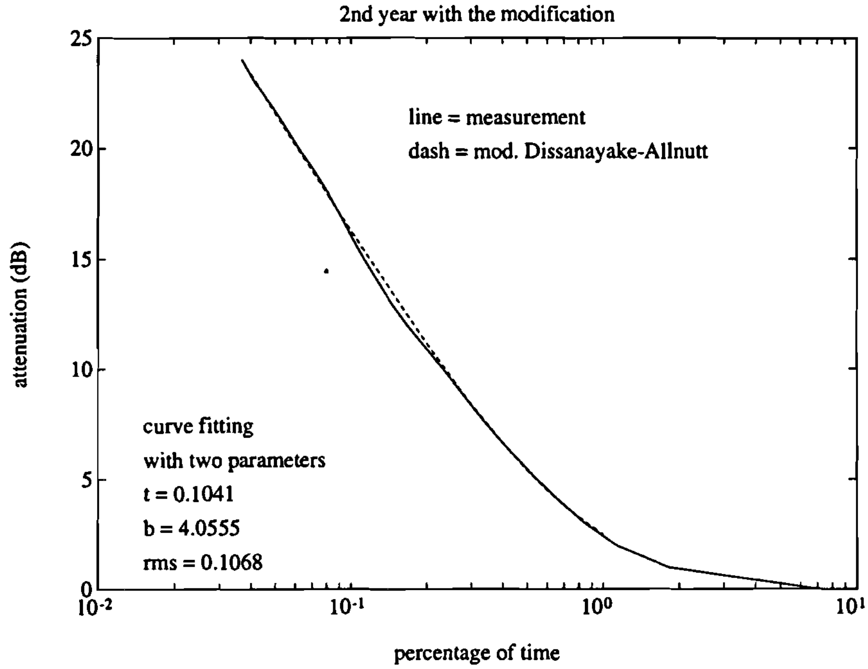
The implementation to the first year data produces the largest r.m.s value. However, the implementation of curve fitting method with two variables still gives satisfying results.

Table 5.5. The results of curve fitting with two variables

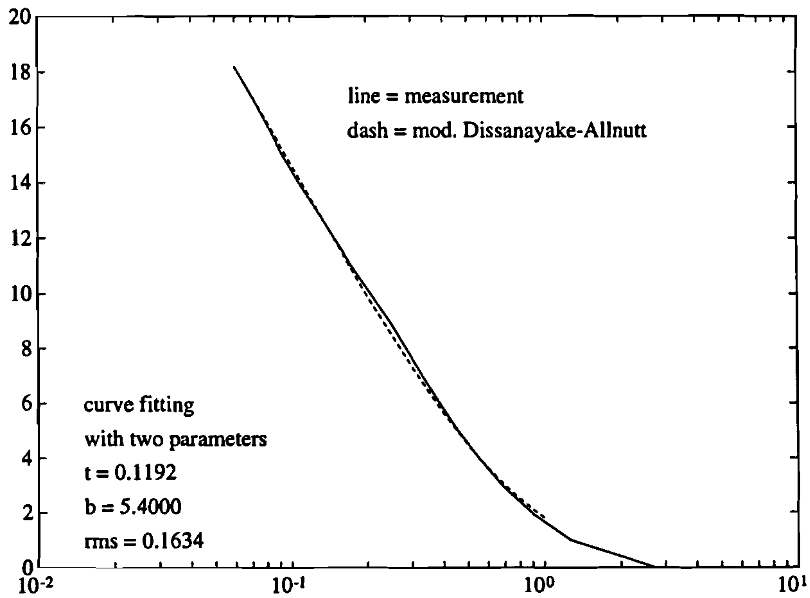
	1st	2nd	3rd
s	-0.1205	-0.1674	-0.0295
b	3.4050	4.0445	5.4005
rms	0.5366	0.1068	0.1634
t	0.1173	0.1041	0.1192
b	3.3955	4.0555	5.4000
rms	0.5366	0.1068	0.1634



(a) first year



(b) second year



(c) third year

Fig. 5.9. Curve fitting method with two variables

Those implementation results show that the variable **s** varies more than the variable **t**, while the presented r.m.s. values are the same. The larger variation of **s** will give larger differences between **s** and its average value. Therefore **t** is chosen as the first variable and **b** as the second variable.

The average value of **t** obtained from the **t**'s results of the three years is 0.1135. The results for **b** from Table 5.5 which relate to the variable **t** are added and then divided by three. The average value of **b** is 4.2837. The modified equation of the Dissanayake-Allnutt method can then be written as

$$rh_{0.01} = \frac{1}{0.628 + 0.1135\sqrt{\gamma_R L_s}} \qquad (5.4)$$

and

$$q = 1.72 - 4.2837\,(\log p + 1)^2 \qquad (5.5)$$

These modified expressions are fed back into the data measurement of the INTELSAT project in Surabaya. The r.m.s. value of each year measurement is recalculated. Table 5.6 gives the results. The r.m.s. values become slightly higher.

Table 5.6. The given r.m.s. values from the modified Dissanayake-Allnutt method

	1st	2nd	3rd
rms	0.7001	0.7993	0.5337

5.3.4. Using the modified Dissanayake-Allnutt method to predict rain attenuation for the Palapa B4

Detecting satellite signals from ITS, Surabaya to the INTELSAT 508 and INTELSAT 510 can be performed with antenna elevation angles of 14°07'15" and 20°20'34" respectively. If the signals from the Palapa B4 are chosen to be detected, then the antenna alevation angle will be 84°44'.

Using the modified Dissanayake-Allnutt method, the predicted rain atttenuation along a satellite path from the Surabaya earth station to the Palapa B4 is calculated. Equations (5.4) and (5.5) replace Equations (4.20) and (4.27c). The results of these calculations are presented in Figure 5.10.

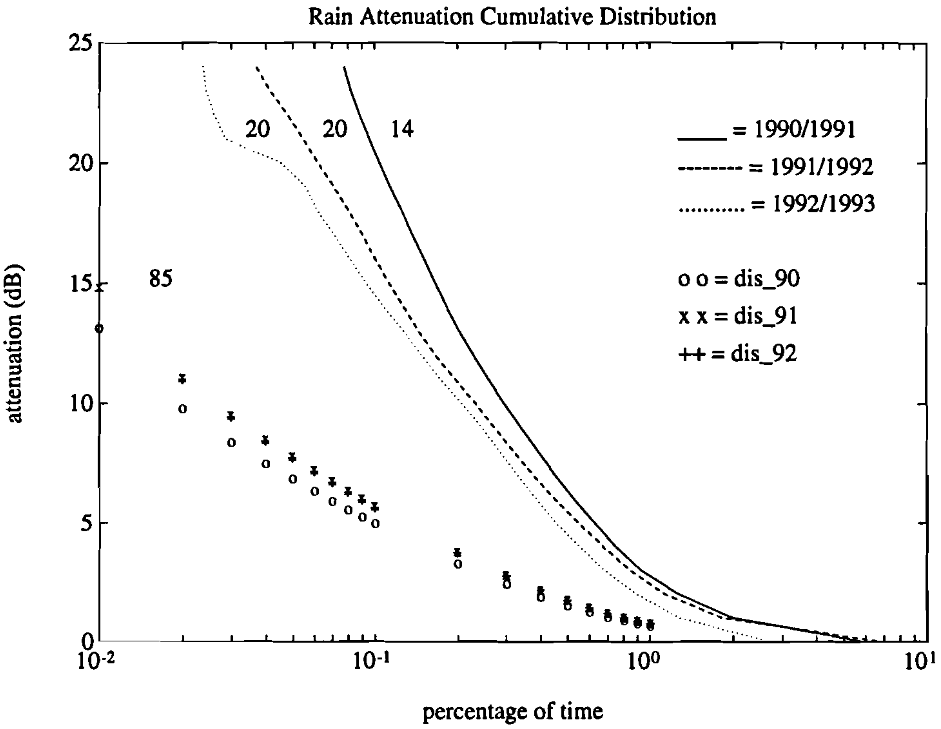


Fig. 5.10. Predicted rain attenuation cumulative distribution for the Palapa B4 by using the modified Dissanayake-Allnutt method

Dis_90 shows the result of calculation by using $R_{0.01}$ which is retrieved from the first year of the measurements. Dis_91 relates to $R_{0.01}$ of the second year and Dis_92 relates to the one from the third year. The measurement results obtained from the INTELSAT research project at ITS are also presented in the same figure. The decrease of the rain attenuation is very obvious. As the antenna elevation angle increases, the attenuation signal impairment due to rain decreases.

5.4. Elevation scaling techniques

Another approach will be introduced, that is the elevation scaling technique. This technique can be used if a rain attenuation cumulative distribution is available. In the next subsections three elevation scaling formulas will be derived. These formulas estimate the scaling to be applied to an attenuation cumulative distribution when the elevation angle is changed.

5.4.1. Fundamental formulae

Figure 5.11 shows two satellite radio paths with different antenna elevation angles, θ_1 and θ_2 respectively. θ_1 is smaller than θ_2, therefore the path length $L(\theta_1)$ is longer than the path length $L(\theta_2)$.

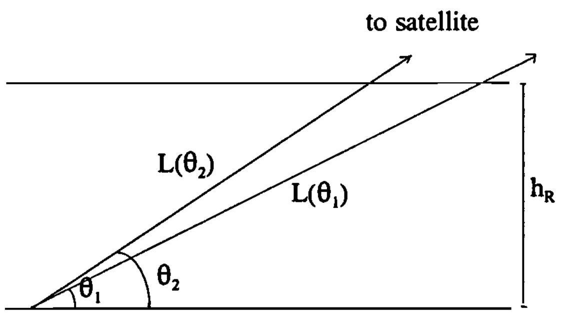


Fig. 5.11. Two satellite radio paths with different antenna elevation angle

The path length L as a function of θ is written as

$$L(\theta) = h_R/\sin\theta \qquad (5.6)$$

Equation (4.1) gives the path attenuation caused by rain. Then the elevation scaling formula is derived as follow

$$\frac{A(\theta_1)}{A(\theta_2)}=\frac{\gamma_1 L(\theta_1)}{\gamma_2 L(\theta_2)}$$

where $\gamma_1 \approx \gamma_2$. This assumption is valid if :

a. the using frequencies are the same

b. $R_1 \approx R_2$, since both radio paths are at the same location.

c. circulair polarizations are chosen for both of them

Therefore,

$$\frac{A(\theta_1)}{A(\theta_2)} \approx \frac{h_R \sin\theta_2}{h_R \sin\theta_1}=\frac{\sin\theta_2}{\sin\theta_1} \qquad (5.7)$$

Equation (5.7) gives the fundamental scaling ratio. It allows transforming on an equaprobability basis, a given cumulative distribution into another one which will be obtained at different elevation.

5.4.2. Elevation scaling ratio derived from the ITU-R method

A scaling ratio based on the ITU-R method is considered. The ITU-R method includes the concept of effective path length which is obtained by multiplying the physical path length with a reduction factor.

From Equation (4.11), the scaling ratio can be derived as follow

$$\frac{A(\theta_1)}{A(\theta_2)}=\frac{\gamma_1 L_{s1} r_1}{\gamma_2 L_{s2} r_2}$$

again $\gamma_1 \approx \gamma_2$. By inserting Equations (4.6) and (4.9),

$$\frac{A(\theta_1)}{A(\theta_2)} \approx \frac{\dfrac{h_R - h_s}{\sin\theta_1} \dfrac{1}{1 + \dfrac{L_{s1}\cos\theta_1}{L_{01}}}}{\dfrac{h_R - h_s}{\sin\theta_2} \dfrac{1}{1 + \dfrac{L_{s2}\cos\theta_2}{L_{02}}}}$$

The rain cell length L_0 depends on the rain intensity $R_{0.01}$. Assuming $R_1 \approx R_2$, yield $L_{01} \approx L_{02}$.

The scaling ratio according the ITU-R method is written as

$$\frac{A(\theta_1)}{A(\theta_2)} \approx \frac{\sin\theta_2}{\sin\theta_1} \frac{L_{01} + L_{s2}\cos\theta_2}{L_{01} + L_{s1}\cos\theta_1} \qquad (5.8)$$

The first factor is the same as the fundamental scaling ratio. The second factor shows up because the reduction factor $r_{0.01}$ is included.

5.4.3. Elevation scaling ratio derived from the Dissanayake-Allnutt method

Another scaling formula will be derived, that is from the Dissanayake-Allnutt method. This method includes the concept of effective path length by involving two reduction coefficients, horizontally and vertically to the physical path length.

The scaling ratio is derived from (4.25),

$$\frac{A(\theta_1)}{A(\theta_2)} = \frac{\gamma_1 L_{e1} rv_1}{\gamma_2 L_{e2} rv_2}$$

again $\gamma_1 \approx \gamma_2$. For $\zeta > \theta$, $L_e = L_{0.01} / \cos\theta$. Inserting (4.24), the scaling ratio is further derived as follow,

$$\frac{A(\theta_1)}{A(\theta_2)}=\frac{\frac{L_{G1}rh_1}{\cos\theta_1}rv_1}{\frac{L_{G2}rh_2}{\cos\theta_2}rv_2}$$

$$\frac{A(\theta_1)}{A(\theta_2)}=\frac{\frac{L_{s1}\cos\theta_1 rh_1}{\cos\theta_1}rv_1}{\frac{L_{s2}\cos\theta_2 rh_2}{\cos\theta_2}rv_2}$$

$$\frac{A(\theta_1)}{A(\theta_2)}=\frac{\frac{h_{FR}-h_s}{\sin\theta_1}rh_1 rv_1}{\frac{h_{FR}-h_s}{\sin\theta_2}rh_2 rv_2}$$

Therefore, the scaling ratio according this method is

$$\frac{A(\theta_1)}{A(\theta_2)}=\frac{\sin\theta_2}{\sin\theta_1}\frac{rh_1}{rh_2}\frac{rv_1}{rv_2} \qquad (5.9)$$

This scaling ratio includes the fundamental scaling ratio which is followed by the horizontal path adjusment factor ratio and the vertical path adjustment factor ratio.

5.4.4. Application of the elevation scaling techniques

Those scaling ratio formulas are applied to the rain attenuation cumulative distribution of the first year. Its antenna elevation angle is 14°07'15". Three transformations on equaprobability basis give other rain attenuation cumulative distributions at elevation angle of 20°20'34".

These three estimated cumulative distributions are compared with the measured cumulative distributions of the second year and the third year. Figure 5.12 shows this comparison. The attenuation cumulative distribution which is generated by using the scaling ratio derived from the Dissanayake-Allnutt method gives the best estimation.

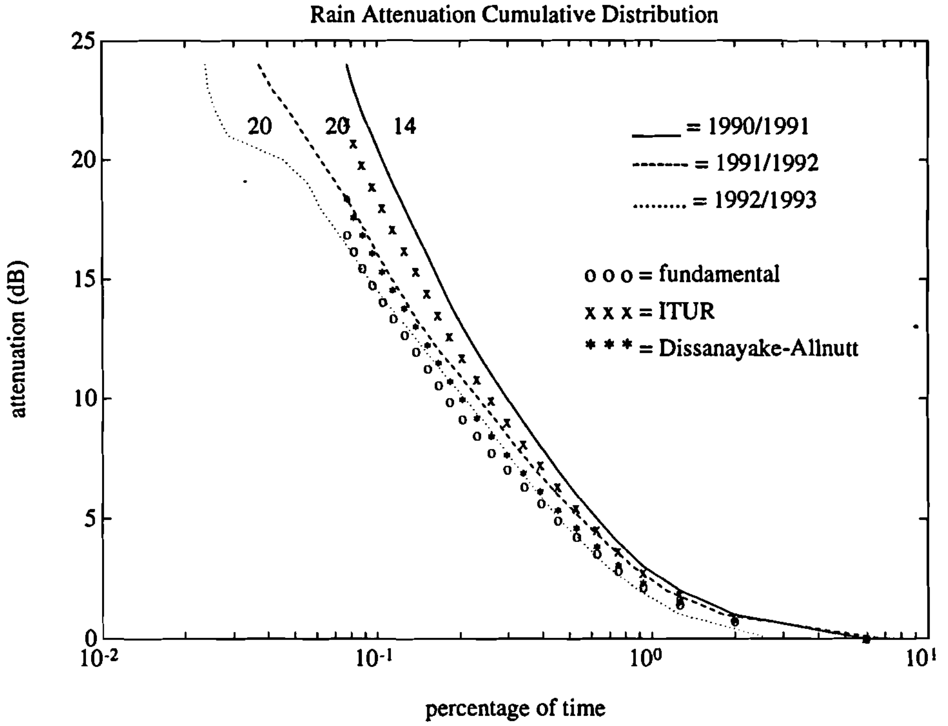


Fig. 5.12. Application of the elevation scaling techniques to the data measurement which was collected in Surabaya

A radiometric measurement in Singapore which has been conducted by McCormick et.al. will be taken as another reference. McCormick et. al. has conducted a series of measurements using radiometers and raingauges at four different places in South East Asia since March 1992. The radiometers are operated at a frequency of 12 GHz and are installed at Bangkok and Si Racha, Thailand, at Bukit Timah, Singapore and at Bandung, Indonesia. A tipping-bucket raingauge is mounted near each radiometer.

The satellite position chosen is 174°E longitude except for Singapore, where the radiometer antenna is pointed in the direction of a satellite at 60°E. Therefore the elevation angle for Singapore is 39.4°, while it is around 7° for Thailand and is 15° for Indonesia. The radiometric measurements of sky noise temperature are converted to path attenuation.

The rain attenuation cumulative distribution of Surabaya will be transformed into another cumulative distribution with an angle of 39.4°. The transformation result will be compared with the cumulative distribution of the converted path attenuation of Bukit Timah, Singapore. The coordinate site of Bukit Timah is 103.9° E and 1.3° N.

Equations (5.7), (5.8) and (5.9) must be adjusted considering :

a. measurements are operated in different frequency

b. measurements are conducted at different location

The fundamental scaling ratio in Equation (5.7) becomes

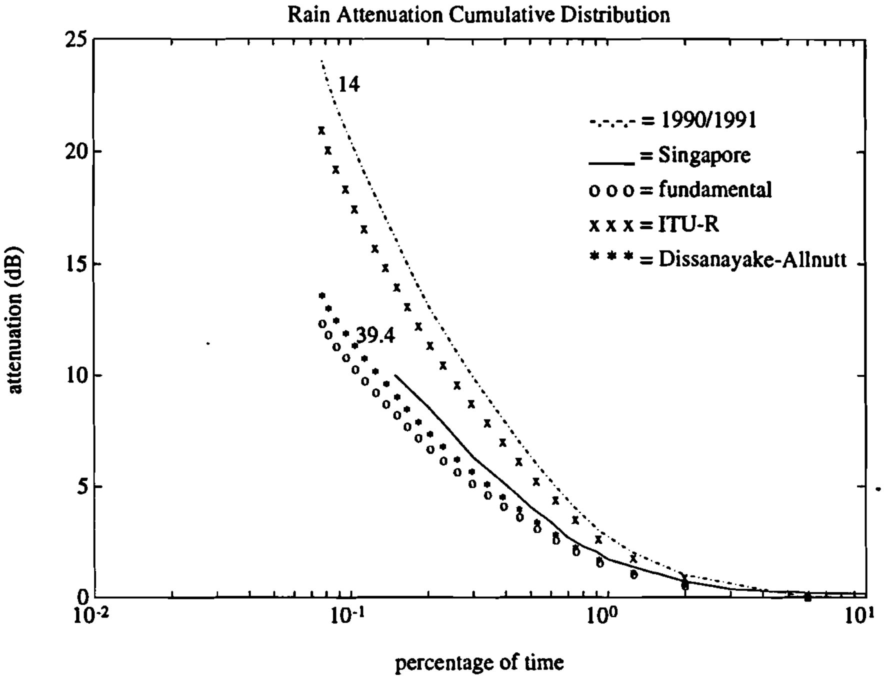
$$\frac{A_1(\theta_1)}{A_2(\theta_2)} = \frac{\gamma_1}{\gamma_2}\frac{\sin\theta_2}{\sin\theta_1} \qquad (5.10)$$

γ_1 can not be assumed to be the same as γ_2. The scaling ratio derived from the ITU-R method in Equation (5.8) becomes

$$\frac{A_1(\theta_1)}{A_2(\theta_2)} = \frac{\gamma_1}{\gamma_2}\frac{\sin\theta_2}{\sin\theta_1}\frac{L_{01}}{L_{02}}\frac{L_{02}+L_{s2}\cos\theta_2}{L_{01}+L_{s1}\cos\theta_1} \qquad (5.11)$$

Notice that the antenna height at Bukit Timah is 20 meter which is only 5 m higher than the one at Surabaya, thus $h_{s1} \approx h_{s2}$. However, R_1 is not equal with R_2. The scaling ratio derived from the Dissanayake-Allnutt method which is written in Equation (5.9) becomes

$$\frac{A_1(\theta_1)}{A_2(\theta_2)} = \frac{\gamma_1}{\gamma_2}\frac{\sin\theta_2}{\sin\theta_1}\frac{rh_1}{rh_2}\frac{rv_1}{rv_2} \qquad (5.12)$$



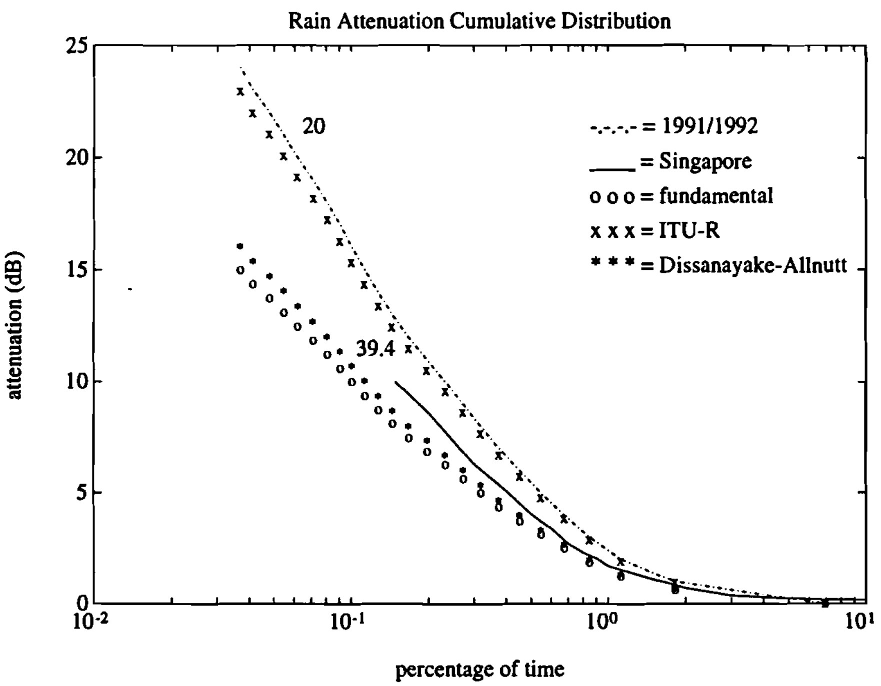


Fig. 15.13. Comparison of the scaled attenuation of Surabaya with the converted path attenuation of Bukit Timah

Using Equations (5.10), (5.11) and (5.12), Figure 5.13 is produced. The converted path attenuation distribution of Singapore with T_m equal to 290 K is also given in Figure 5.13. The first year of the measurement in Singapore was started from March 1992 - February 1993 and the second year was started from March 1993 - February 1994. Again, the scaling ratio derived from the Dissanayake-Allnutt gives the best result. The scaling ratio derived from the ITU-R method gives significant discrepancies between the scaled attenuation and the measured one.

It can be concluded that the scaling ratio derived from the Dissanayake-Allnutt method gives the best result in transforming a rain attenuation cumulative distribution into another one with different antenna elevation angle. Using this scaling ratio, the rain attenuation cumulative distribution of a satellite path from Surabaya to the Palapa B4 is obtained from the cumulative distributions of the measured rain attenuation. The antenna elevation angle for this path is 84°44'.

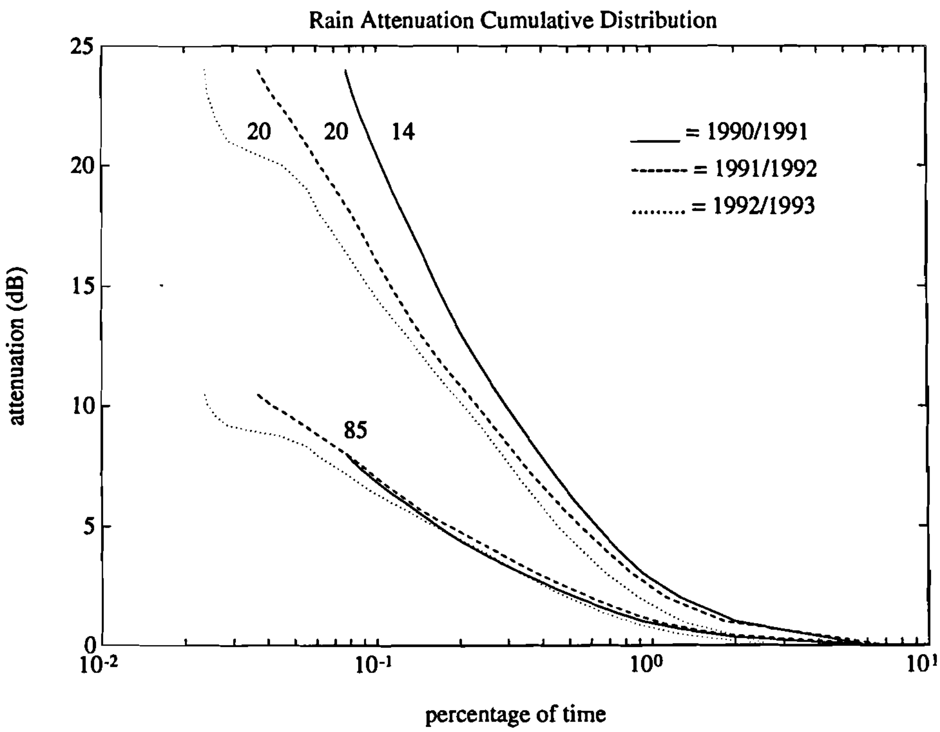


Fig. 5.14. Estimated rain attenuation cumulative distribution for the Palapa B4 obtained from the elevation scaling technique

The rain attenuation cumulative distribution of the first year with an angle of 14°07'15" is tranformed into another cumulative distribution with an angle of 84°44'. The rain attenuation cumulative distribution of the second and the third year are transformed as well. Figure 5.14 gives these results.

The estimated cumulative distributions from those transformations are almost indistinguishable. It is also obvious that the rain attenuation decreases as the antenna elevation angle increases. The slant path is shorter which causes less impairments on the satellite signals.

5.5. Discussion on predicting rain attenuation along a satellite path to the Palapa B4

Figure 5.10 is obtained by using the modified Dissanayake-Allnutt method. An important parameter in this method is the rain intensity exceeding 0.01% of the time $R_{0.01}$. Therefore an accurate information about the rain intensity cumulative distribution is necessary.

Figure 5.14 is obtained from the application of the elevation scaling technique. A scaling ratio is applied to transform a rain attenuation cumulative distribution into another one with different antenna elevation angle. An accurate information about the rain attenuation cumulative distribution is needed.

It is very interesting in investigating Figure 5.10 and Figure 5.14. Those figures show that both techniques produce nearly the same results. The results are presented together in Figure 5.15. Based on this, the predicted rain attenuation cumulative distribution for a slant path satellite from Surabaya to the Palapa B4 is revealed.

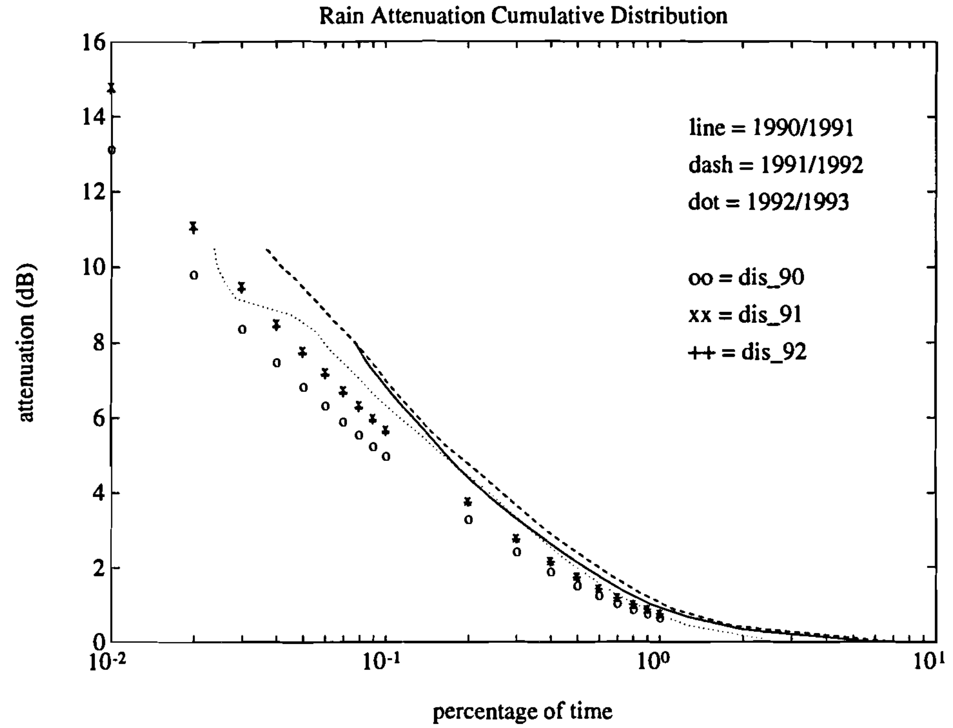


Fig. 5.15. Rain attenuation cumulative distribution for the Palapa B4

6. The Feasibility of K_u-band Satellite Telecommunication Services for Indonesia

In Chapter 5, the statistical distributions of the rain attenuation along a satellite path from Surabaya to the Palapa B4 have been revealed. Based on those distributions the feasibility of K_u-band satellite telecommunication services will be discussed in this chapter.

Some types of services have a fluctuating demand during the day, therefore the diurnal variation of the rain attenuation and the rain intensity will be investigated. Both of the yearly cumulative distributions of the rain attenuation and the rain intensity will also be illustrated differently. The 24-hours of one day will be divided into four groups of 6-hours. The statistical distributions are then presented according the clasification of these four groups. The feasibility of K_u-band satellite telecommunication services can be observed more accurately.

6.1. Advantages and disadvantages of using K_u-band

A demand for more transponder capacity to offer the satellite telecommunication services in Indonesia is increasing. It is not possible to increase the number of transponders of the Palapa B4 which is still operated in the C-band. However, more transponder capacity can be offered in the K_u-band.

As the frequency increases and the same antenna gain is chosen, the size of the antenna reflectors to receive the satellite signals decreases. The size of the antenna is inversely proportional with the frequency [61]. Therefore the cost for the ground stations can be reduced. Since the size is smaller, it is also easier for a user to install the antenna.

The interferences from the terrestrial microwave links can be prevented. The terrestrial microwave links are usually operated in the C-band. Since the satellite telecommunication is operated in a higher frequency band those interferences may be avoided.

The disadvantage of using K_u-band is that the satellite signals will suffer higher atttenuation due to rainfall. The feasibility of using K_u-band for the satellite telecommunication services in Indonesia, especially in Surabaya, will be discussed based on the results in the previous chapter.

6.2. The conventional feasibility study

Figure 5.15 in Chapter 5, illustrates the predicted cumulative distributions of the rain attenuation along a satellite path from Surabaya to the Palapa B4 in the K_u-band. Designing a receiver system for satellite telecommunication in Surabaya, can be performed by studying those statistical distributions.

Each type of the satellite telecommunication services has a restriction on the availability of the system. For instance, the system availability of television broadcasting, must fulfil 99% of the time. It means that the rain attenuation exceeding 1% of the time must be included in designing the link budget of a receiver system for that service.

From Figure 5.15, the rain attenuation exceeding 1% of the time is about 1 dB. A 1 dB reduction on the satellite signals must be considered by increasing the effective isotropically radiated power (EIRP). The cost must be paid for this receiver system is still reasonable. Therefore it is feasible to offer satellite television broadcasting in the

K_u-band for Surabaya and in general for Indonesia.

For telephony and data communication services via satellites, a higher system availability of 99.99% must be guaranteed. It means that the rain attenuation exceeding 0.01% must be included in the link budget calculation of the receiver system. Figure 5.15 shows that it is about 13 dB from the first year measurement and it is about 15 dB from the second and the third measurements. It is difficult to design a receiver system which can remedy these impairments.

To overcome these high rain attenuations, a site diversity reception may be considered. In site diversity operation, two or more earth stations spaced a few kilometers apart are available to communicate with the same transponder. Since heavy rain occurs in geographically small cells, there is a probability that equally heavy rain will not effect those stations at the same time. Thus those earth stations will probably not experience the same rain attenuation at the same time.

The improvement of the system performance is called diversity gain. The more earth stations are operated in a site diversity operation, the larger improvement can be given [62]. However, the increase of diversity gain reduces as the amount of the stations increases. The price of diversity depends on the amount of the earth stations. For economical reason, a site diversity using two ground stations is chosen.

Pratt and Bostian [47] include an expression to estimate the diversity gain G_D for two sites,

$$G_D(p) = a'(1 - e^{-b'd}) \qquad \text{in dB} \qquad (6.1)$$

where $a' = A(p) - 3.6[1 - e^{-0.24\,A(p)}]$

$b' = 0.46[1 - e^{-0.26\,A(p)}]$

For every p percentage of the time, the diversity gain G_D must be calculated according the attenuation A at p percentage of the time. The parameter d is the site separation distance in kilometers.

The 'dis_91' from Figure 5.15 is given again in Figure 6.1. Using this result the site diversity technique is applied with d equal to 1 km, 5 km and 10 km, respectively. The diversity gain increases as the separation distance d increases.

If the separation distance d is equal to 10 km, the rain attenuation exceeding 0.01% of the time will be about 3.5 dB. The rain attenuation is strongly reduced, it becomes possible to offer the telephony and data communication services.

This distance of 10 km can easily be connected with two optical fiber cables since the optical fiber technology has been developed. Comparing with another technique which uses the coaxial cables to connect that two stations, the cost of a site diversity using the optical fiber is lower. The signals can be transmitted in a high frequency mode. A down-conversion to an intermediate frequency is not necessary. This technique only needs the use of an amplifier. During a transmission the signals are attenuated, therefore an amplifier must be submitted. The suggestion of using two optical fiber cables is to provide the site diversity signals on both sides.

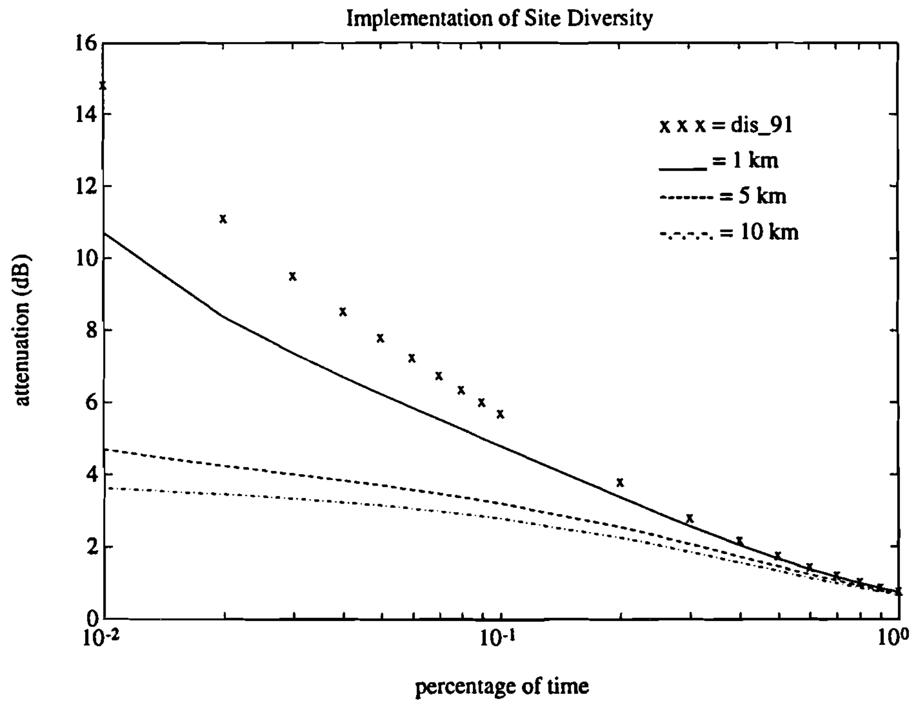


Fig.6.1. The decrease of rain attenuation by using a site diversity technique

6.3. The diurnal characteristics of the rain attenuation and the rain intensity

A number of services, for example telephony, facsimile, data communication, videoconference and television broadcasting, have a fluctuating demand during the day. Therefore it is important for the system designers to know the diurnal characteristics of the rain attenuation along the desired path.

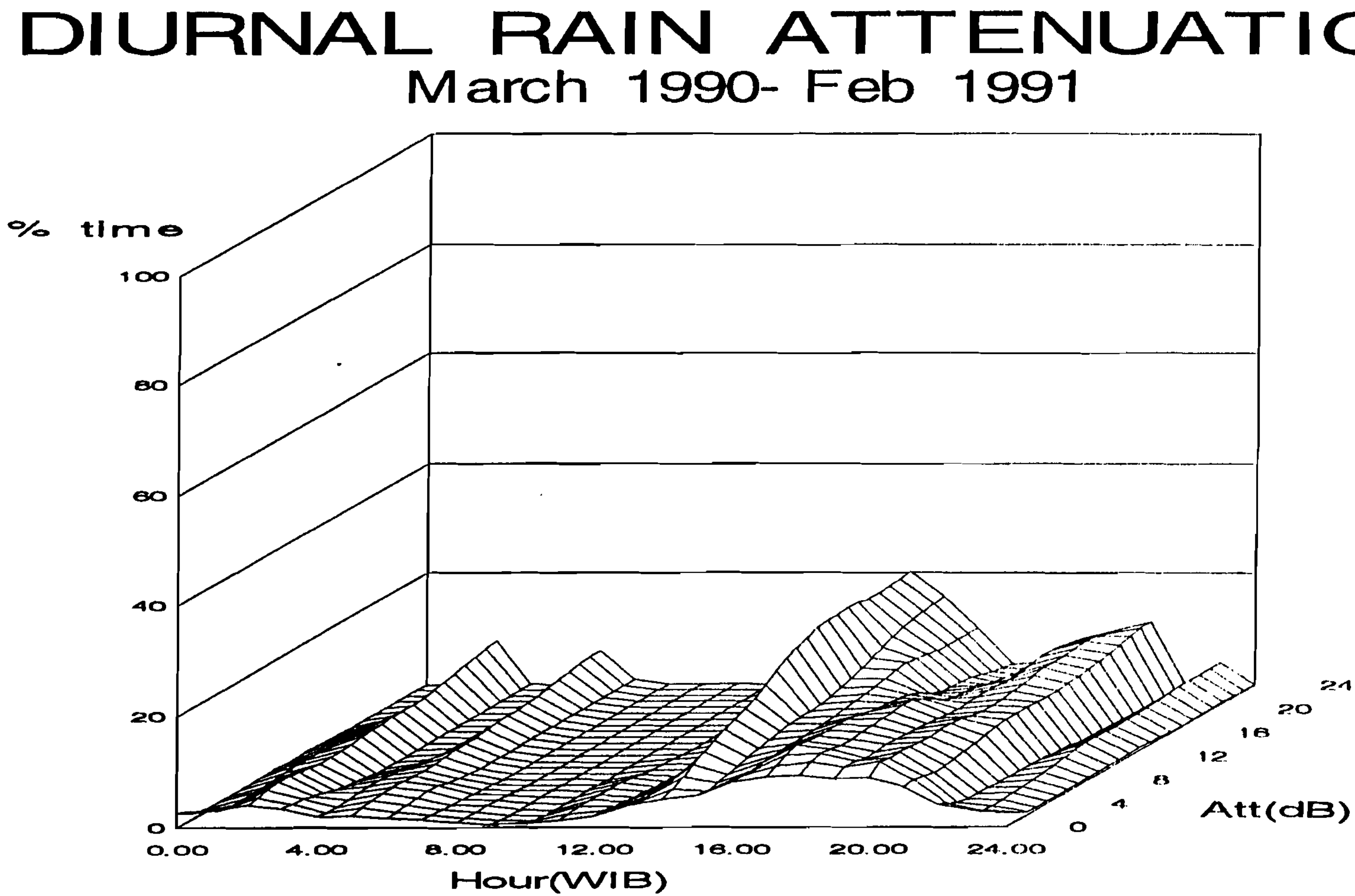
6.3.1. The diurnal characteristics of the rain attenuation

The first year and the second year data of the INTELSAT telecommunication research project in Surabaya have been processed to reveal the diurnal characterictics of the rain attenuation. For this data processing, a computer programming technique has been involved. Many programs have been developed by using Pascal.

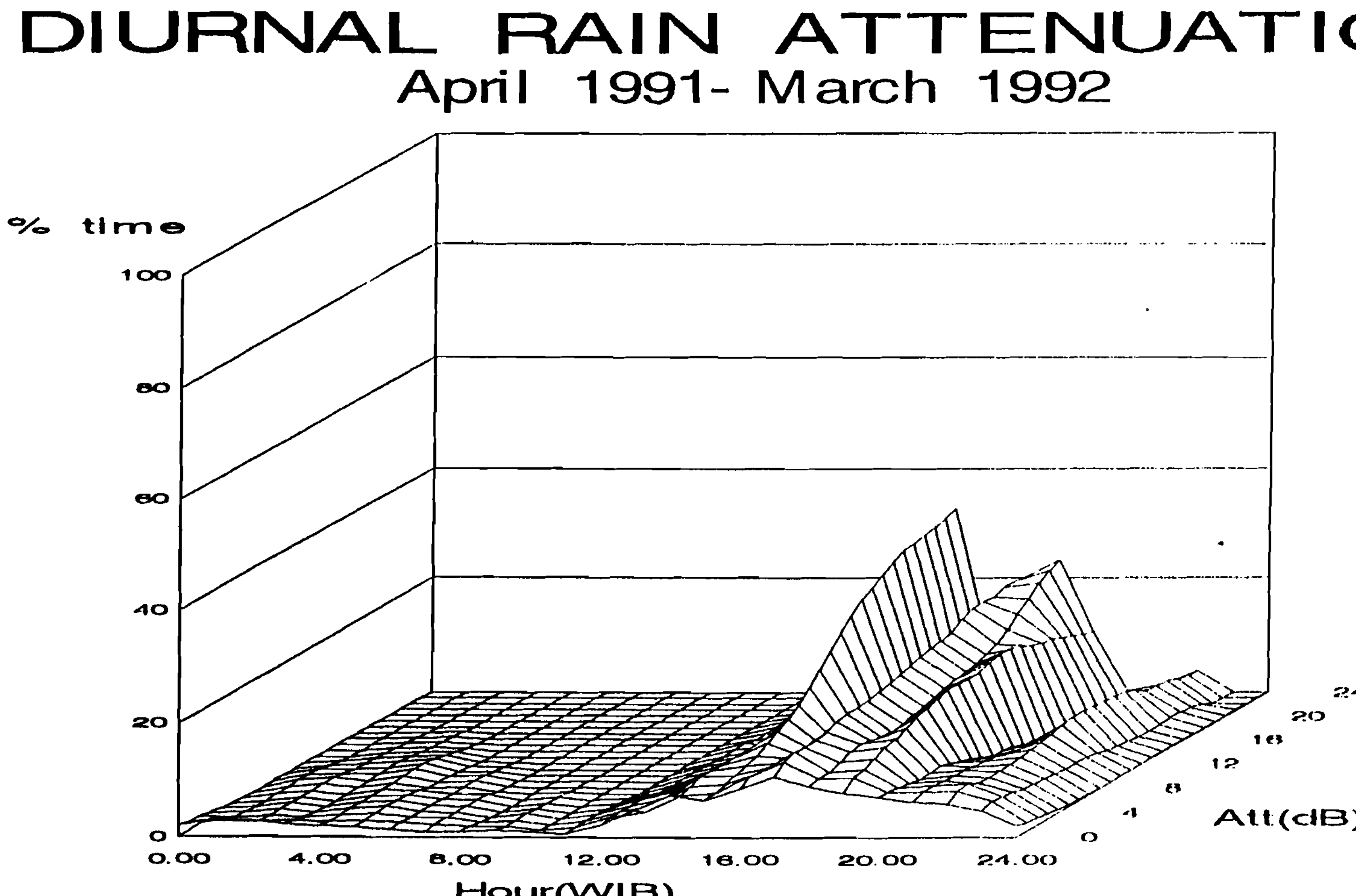
In Figure 6.2 the diurnal charateristics of the rain attenuation is presented in a three dimensional picture. The x-axis refers to the hour, from 0:00 until 24:00. WIB is an abbreviation of Waktu Indonesia Barat (West Indonesian Time), that is the local time of Surabaya. The y-axis refers to the attenuation in dB and the z-axis refers to the time percentage of the total day. A point (14:00, 24, 20) means, that at 14:00 the chance that attenuation of 24 dB will be reached is 20% of the total day.

Figure 6.2 illustrates that the diurnal characteristics of the rain attenuation in the first year and the second year show the same characteristic. The rain attenuation accumulates in the evening hours. The satellite signals are hardly attenuated during the morning.

It provides an information to the system designers that telephony and other services with high system availability are possible to be offered from 0:00 until 12:00. The working hours in Indonesia is started around 8:00 and is ended around 17:00. Offering any kind of satellite telecommunication services between 12:00-24:00 in the K_u-band must consider the high impairments of the satellite signals under rainy conditions.


DIURNAL RAIN ATTENUATION
March 1990- Feb 1991
% time
100
80
60
40
20
0
0.00
4.00
8.00
12.00
16.00
20.00
24.00
Hour(WIB)
0
4
8
12
16
20
24
Att(dB)

(a) first year



(b) second year

Fig.6.2. The diurnal characteristics of the rain attenuation

6.3.2. The diurnal characteristics of the rain intensity

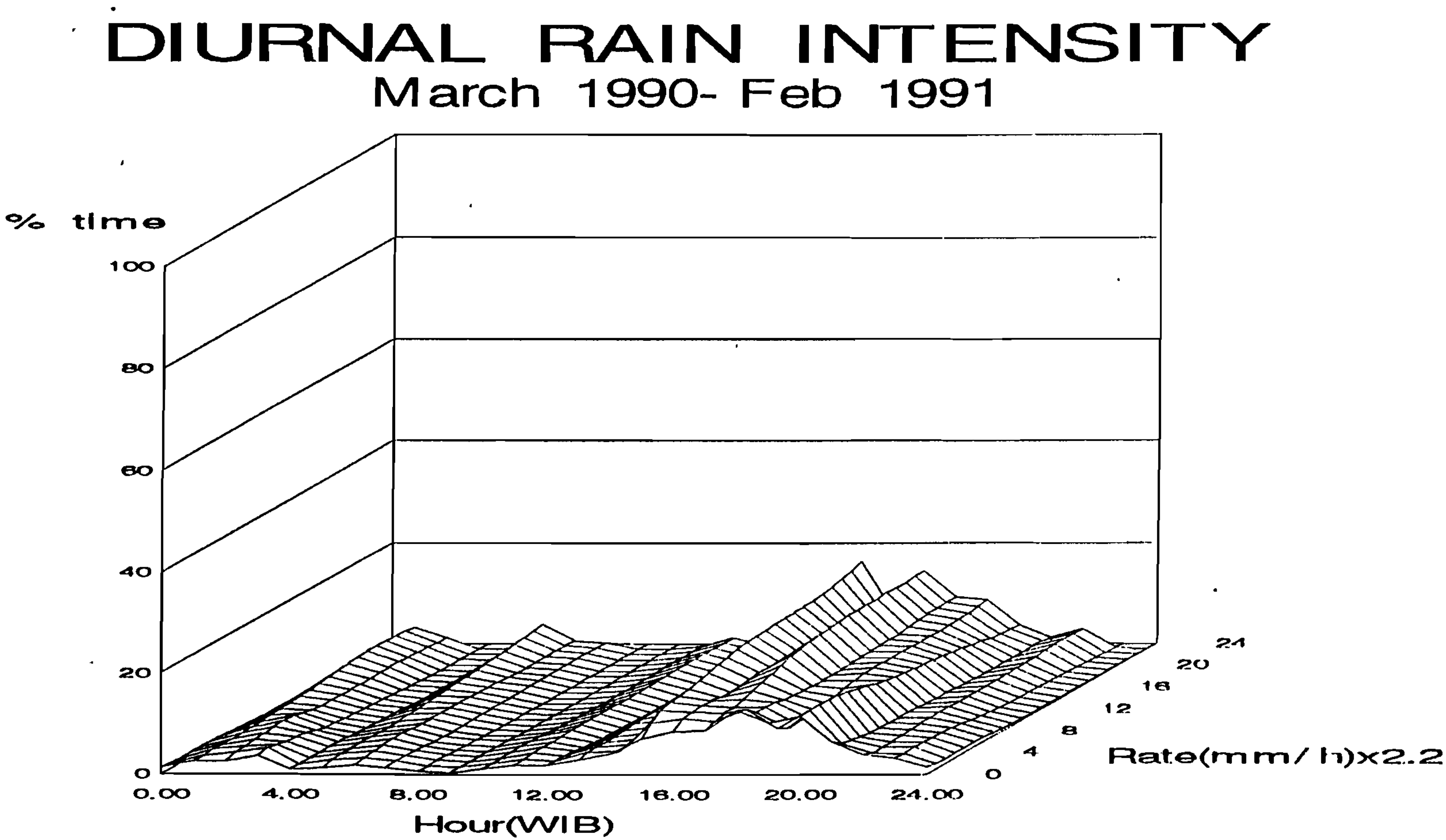
For economical reason and simplicity, the measurements of rain intensity are more often conducted than the measurements of rain attenuation. The INTELSAT research project in Surabaya has provided both of them, it becomes possible to investigate the relation of the diurnal charateristics of the rain attenuation and the rain intensity.

The first year and the second year data of the rain intensity have been processed. Figure 6.3 gives the diurnal characteristics of the rain intensity in the first year and the second year. The results from both years show the same characteristic. The rain events with high rain intensity are accumulated in the evening hours. From 0:00 until 12:00 there is hardly event with high rain intensity.

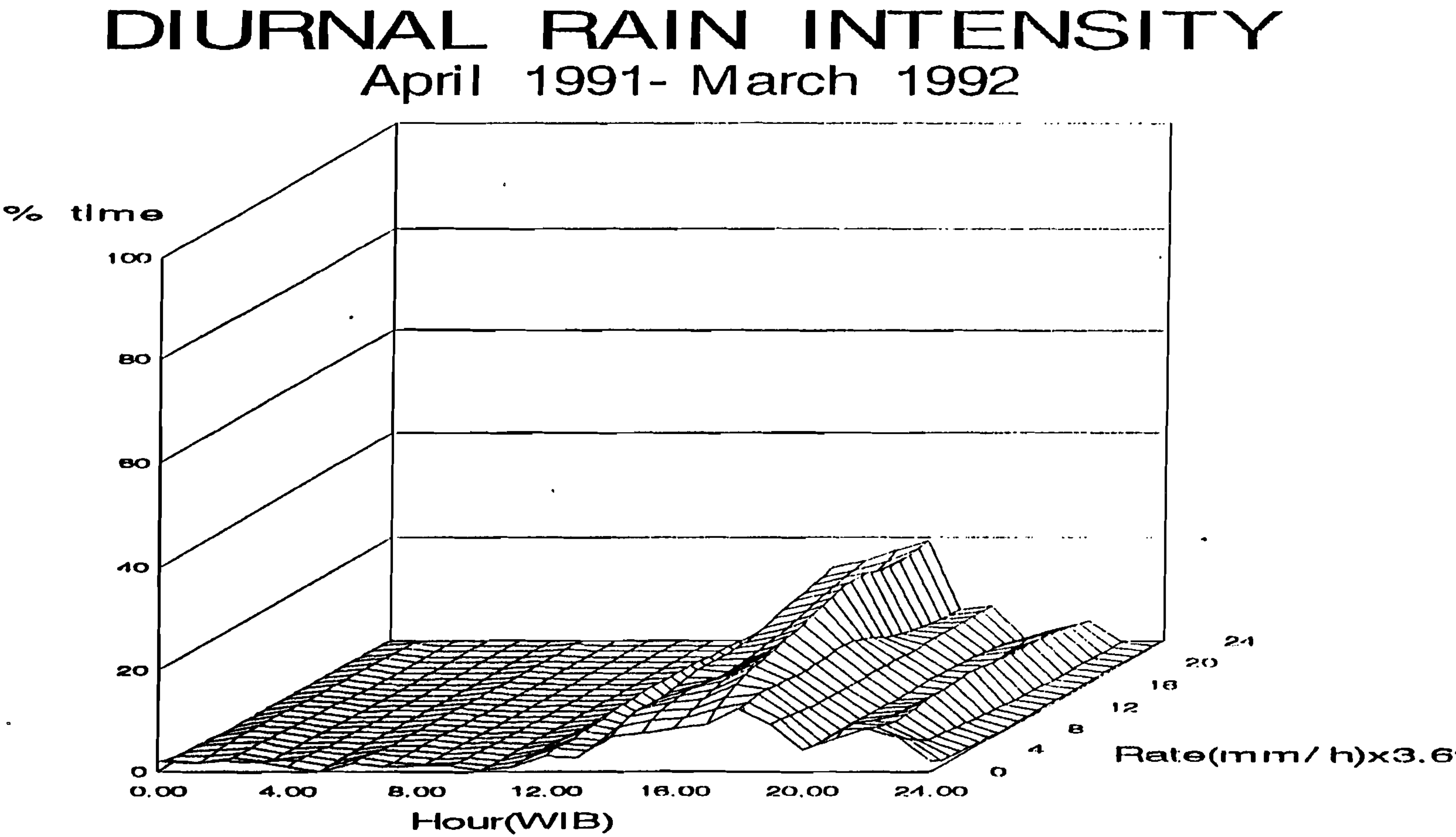
For comparison with Figure 6.2, the maximum rain intensities are 53 mm/h and 86 mm/h for the first year and the second year respectively. Those values are chosen regarding to the smallest percentages of the time being reached on the rain attenuation cumulative distributions of the first year and the second year. As an example, the smallest percentage of the time being reached on the rain attenuation cumulative distribution of the first year is 0.078%, the rain intensity at the same percentage of the time is about 53 mm/h. See again Figure 2.3 and Figure 2.6.

Comparing Figure 6.3 with Figure 6.2, their contours are almost similar especially during the morning hours. Considering the long path from Surabaya to the INTELSAT satellite, the satellite signals may encounter more than one rain cell along the path. It was recognised from the severe impairments of the signals which were detected ate the earth station while the registered rain intensity remained low. Therefore the rain attenuation and the rain intensity may not be related in the event analysis. However in the long term, the investigation on Figure 6.2 and Figure 6.3 shows that they may be related.

The diurnal characteristics of the rain attenuation of a particular path may then be obtained from the diurnal characteristics of the point rainfall rate. For other locations in the tropical region, the same investigation is strongly recommended.


DIURNAL RAIN INTENSITY
March 1990- Feb 1991
% time
100
80
60
40
20
0
0.00
4.00
8.00
12.00
16.00
20.00
24.00
Hour(WIB)
24
20
16
12
8
4
0
Rate(mm/h)x2.2

(a) first year



(b) second year

Fig.6.3. The diurnal characteristics of the rain intensisty

6.4. A more accurate analysis in the feasibility study

Based on the analysis in the previous sections, the cumulative distributions of the rain attenuation and the rain intensity are given in Figure 6.4 and Figure 6.5. A day is divided into four groups of 6-hours. The statistical distributions are presented according those groups.

Figure 6.4 gives the statistical distributions of the rain attenuation which are clasified in those groups. The group of 6:00-12:00 gives the lowest attenuation, while the group of 12:00-18:00 gives the highest attenuation at high percentages of the time. These conditions can be expected considering the analysis in the previous sections.

Comparing Figure 6.4 with Figure 2.3 and noticing the measurements results of the first year and the second year. From those figures, the spreading of the yearly statistic distributions to the yearly statistic distributions on a 6-hourly basis can be noticed. As an example, the group of 18:00-24:00 of the first year gives 25 dB for the rain attenuation exceeding 0.1% of the time. The yearly statistic distribution of the first year in Figure 2.3 shows that the rain attenuation at the same percentage of the time is about 20 dB. The ratio of 25/20 is 1.25. Offering satellite television broadcasting via the INTELSAT satellite with an outage time of 1% in this prime hours must consider that ratio.

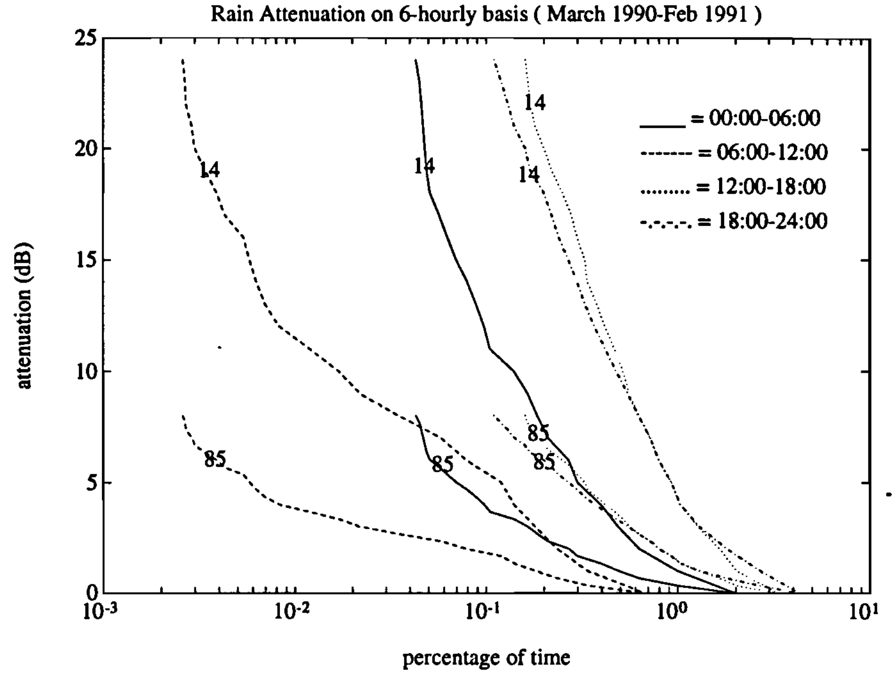
Those yearly cumulative distributions on a 6-hourly basis are also scaled using Equation (5.9) with an elevation angle of 84°44'. The elevation scaling technique has been applied as in Chapter 5 to study the impairments of satellite signals from the Palapa B4. Comparing these distributions with Figure 5.15 or Figure 6.1. It can be noticed that the rain attenuation exceeding 1% of the time of about 2 dB, instead of 1 dB, must be considered for offering television broadcasting from 12:00-24:00. Offering this service in the morning hours (0:00-12:00) will give a good quality of television broadcasting because the rain attenuation is 0 dB.

Other services with higher system availability, for instance telephony, are possible to be offered without using a site diversity technique during 6:00-12:00. The rain attenuation exceeding 0.01% of the time for that duration is about 4.5 dB. Taking this amount as the margin of the signal impairments in calculating the link budget of the satellite receiver system is reasonable.

However, offering telephony and data communication between 12:00-18:00, which shows the highest rain attenuationm, can be done by implementing a site diversity technique. Extrapolating the statistic distribution of this group from the first year of measurements gives about 24 dB for the rain attenuation exceeding 0.01% of the time. Applying Equation (6.1) will give a rain attenuation of about 4 dB if the site separation distance d is 10 km.

Figure 6.5 shows the statistical distributions of the rain intensity which are also classified in those four groups of 6-hours. The group of 6:00-12:00 gives the lowest rain intensity, while the group of 12:00-18:00 gives the highest rain intensity.

Noticing Figure 6.4 and Figure 6.5, the rain intensity and the rain attenuation may be related. The group of 6:00-12:00 from both years gives the lowest rain intensity which also gives the lowest rain attenuation.



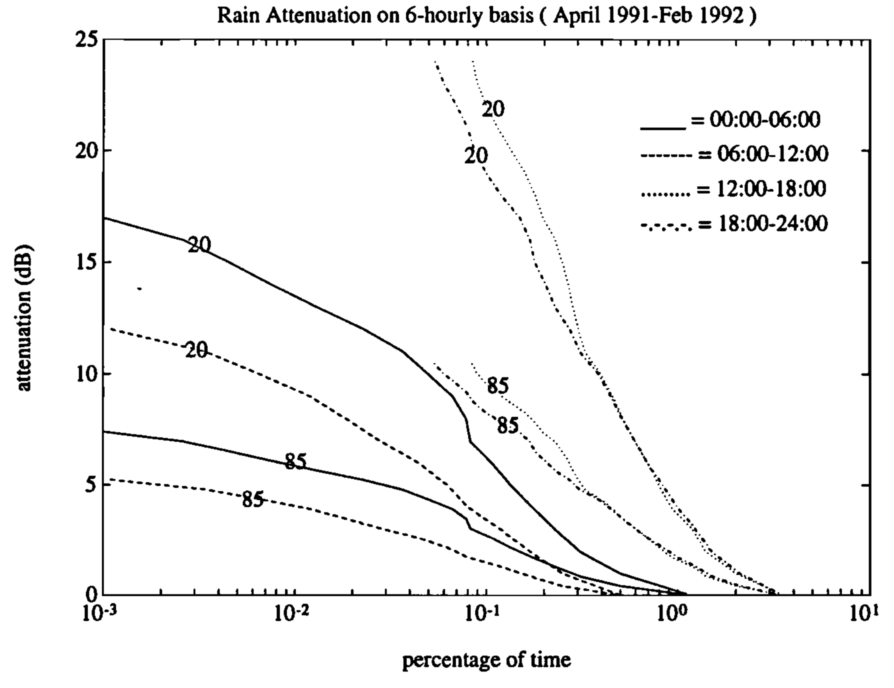
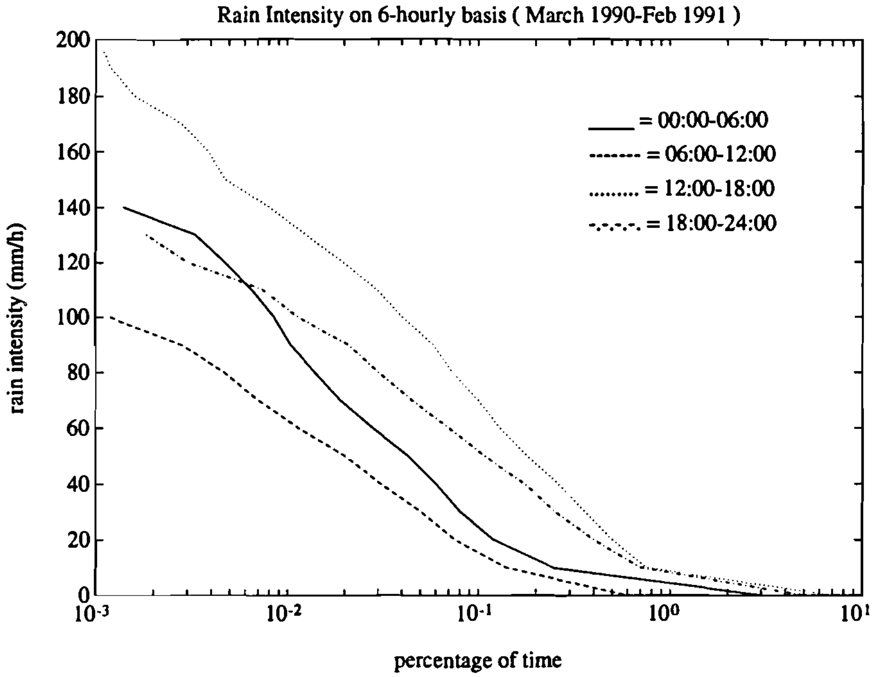


Fig.6.4. The cumulative distributions of the rain attenuation which are clasified into four groups of 6-hours



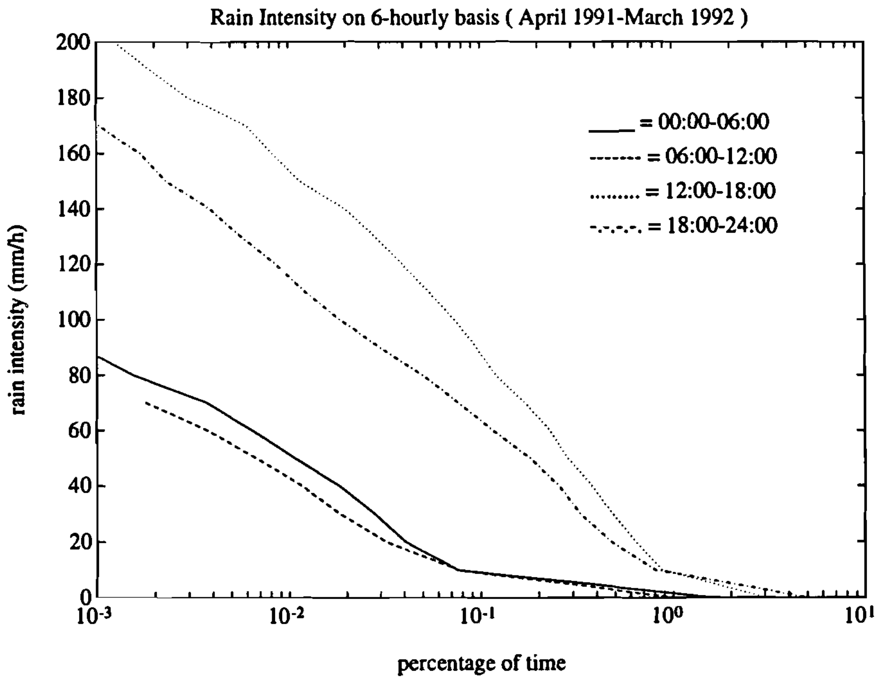


Fig.6.5. The cumulative distributions of the rain attenuation which are clasified into four groups of 6-hours

7. Conclusions and Recommendations

7.1. Conclusions

- The rain attenuation prediction methods according ITU-R, Ajayi, Dissanayake-Allnutt and Pontes-Silva-Souza underestimate the rain attenuation at small percentages of the time compared to the measured rain attenuation in Surabaya.
- The results of the implementation of a curve fitting method and the saturation phenomenon arouse doubtfulness in using the Pontes et.al method to predict the rain attenuation along a satellite path from Surabaya to the Palapa B4.
- Using the modified Dissanayake-Allnutt method, the rain attenuation along a satellite path from Surabaya to the Palapa B4 is obtained.
- The implementation of an elevation scaling technique by using the scaling ratio derived from the Dissanayake-Allnutt method produces a result which confirms the calculation of the predicted rain attenuation above.
- The rain attenuation exceeding 1% of the time is 1 dB which means the television broadcasting in the K_u-band can be offered to the customers in Surabaya, and likely also at all of places in Indonesia.
- A site diversity system using two ground stations with a separation distance of 10 km, may be applied to reduce the rain attenuation exceeding 0.01% of the time for offering the telephony and data communication services.
- The diurnal characteristics of the rain attenuation along a satellite path from Surabaya to the INTELSAT satellites show that the rain attenuation accumulates in the evening hours.
- A more accurate analysis in the feasibility of K_u-band telecommunication services can be obtained by presenting the cumulative distribution on a 6-hourly basis.

7.2. Recommendations

- To process the measured data which were collected at ITS to obtain more information, for instance the medium temperature as a function of time, the medium temperature as a function of the sky temperature, etc.
- To conduct a measurement using the radiometer which has been installed already at ITS. Point this radiometer to the direction where the Palapa B4 is located. The results can be compared later with the results of this analysis.
- To conduct more rain intensity measurements in the tropical regions to obtain an accurate rainfall rate mapping. Notice the suitable integration time for tropical regions, since the one-minute integration time may not be acceptable.
- To conduct more rain attenuation measurements in the tropical regions to collect data for the analysis of the satellite impairments in the K_u-band. The results can be used to develop a more accurate method to predict the rain attenuation in the tropical regions.
- To conduct a measurement to reveal the rain height for Surabaya and in general for Indonesia.
- To apply the same procedure as described in Chapter 5 for the implementation of a curve fitting method to the Dissanayake-Allnutt method for other measured data in tropical regions to find the common constants for **b** and **t**.
- To notice the rain attenuation cumulative distribution on a 6-hourly basis and not only the yearly statistics of the rain attenuation, before designing a system receiver to offer the satellite telecommunication services in the K_u-band in Indonesia.
- To produce the rain attenuation cumulative distribution on a 6-hourly basis and to present the diurnal charateristics of the rain attenuation in a three dimensional picture.
- To produce the rain intensity cumulative distribution on a 6-hourly basis and to present the diurnal charateristics of the rain intensity in a three dimensional picture.
- To offer satellite telecommunication services in the K_u-band in Indonesia.

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Appendix A :

Calculating rain rate from the drop size distribution

Equation (3.4) gives the relation between the rain rate R and the drop size distribution N(D) as follow,

$$R=6\pi.10^{-4}\int_0^\infty D^3 N(D)V(D)dD \qquad (3.4)$$

V(D) will be assumed as a constant multiplied by a diameter D referring to the Atlas et.al. expression and Foote and DuToit expression [56]. Thus,

$$V(D) = aD \qquad \text{where a is a constant} \qquad (A.1)$$

B.1. Choosing the M-P drop size distribution as the N(D)

By implementing the M-P drop size distribution, the rain rate R will be derived. As written in (3.2), the drop size distribution according Marshall and Palmer is

$$N(D) = N_0 e^{-\Lambda D} \qquad (3.2)$$

The rain rate R can be written as

$$R=6\pi.10^{-4}\int_0^{D^*} D^3 N_0 e^{-\Lambda D} aDdD \qquad (A.2)$$

$$R=6\pi.10^{-4} aN_0\int_0^{D^*} D^4 e^{-\Lambda D} dD$$

$$R=6\pi.10^{-4}aN_0[D^4\frac{e^{-\Lambda D}}{-\Lambda}+\frac{1}{\Lambda}\int_0^{D^*}e^{-\Lambda D}4D^3dD]$$

$$R=6\pi.10^{-4}a\frac{N_0}{\Lambda}[-D^4e^{-\Lambda D}+4(D^3\frac{e^{-\Lambda D}}{-\Lambda}+\frac{1}{\Lambda}\int_0^{D^*}e^{-\Lambda D}3D^2dD)]$$

$$R=6\pi.10^{-4}a\frac{N_0}{\Lambda}[-D^4e^{-\Lambda D}+\frac{4}{\Lambda}(-D^3e^{-\Lambda D}+3[D^2\frac{e^{-\Lambda D}}{-\Lambda}+\frac{1}{\Lambda}\int_0^{D^*}e^{-\Lambda D}2DdD])]$$

$$R=6\pi.10^{-4}a\frac{N_0}{\Lambda}[-D^4e^{-\Lambda D}+\frac{4}{\Lambda}(-D^3e^{-\Lambda D}+\frac{3}{\Lambda}[-D^2e^{-\Lambda D}+2(D\frac{e^{-\Lambda D}}{-\Lambda}+\frac{1}{\Lambda}\int_0^{D^*}e^{-\Lambda D}dD)])]$$

$$R=6\pi.10^{-4}a\frac{N_0}{\Lambda}[-D^4e^{-\Lambda D}+\frac{4}{\Lambda}(-D^3e^{-\Lambda D}+\frac{3}{\Lambda}[-D^2e^{-\Lambda D}+\frac{2}{\Lambda}(-De^{-\Lambda D}-\frac{e^{-\Lambda D}}{\Lambda})])]$$

$$R=-6\pi.10^{-4}a\frac{N_0}{\Lambda}e^{-\Lambda D}[D^4+\frac{4}{\Lambda}D^3+\frac{12}{\Lambda^2}D^2+\frac{24}{\Lambda^3}D+\frac{24}{\Lambda^4}]$$

$$R=-6\pi.10^{-4}a\frac{N_0}{\Lambda}e^{-\Lambda D^*}[D^{*4}+\frac{4}{\Lambda}D^{*3}+\frac{12}{\Lambda^2}D^{*2}+\frac{24}{\Lambda^3}D^*+\frac{24}{\Lambda^4}]+6\pi.10^{-4}a\frac{N_0}{\Lambda}e^0\frac{24}{\Lambda^4}$$

Finally,

$$R=6\pi.10^{-4}a\frac{N_0}{\Lambda}(\frac{24}{\Lambda^4}-e^{-\Lambda D^*}[D^{*4}+\frac{4}{\Lambda}D^{*3}+\frac{12}{\Lambda^2}D^{*2}+\frac{24}{\Lambda^3}D^*+\frac{24}{\Lambda^4}])$$

B.1. Choosing the lognormal drop size distribution as the N(D)

The rain rate R will also be derived by using the lognormal drop size distribution. Equation (3.3) gives the expression for the lognormal drop size distribution N(D),

$$N(D)=\frac{N_T}{\sigma D\sqrt{2\pi}}\exp[-½(\frac{lnD-\mu}{\sigma})^2] \qquad (3.3)$$

where $N_T = 108\ R'^{0.363}$

$\mu = -0.195 + 0.199 \ln R'$

$\sigma^2 = 0.137 - 0.013 \ln R'$

Equation (3.3) is inserted into equation (3.4) and equation (A.1) is used to estimate V(D), the rain rate R can be further written as

$$R=6\pi.10^{-4}\int_0^{D^*} D^3\frac{N_T}{\sigma D\sqrt{2\pi}}\exp[-½(\frac{lnD-\mu}{\sigma})^2]aDdD$$

$$R=6\pi.10^{-4}\frac{aN_T}{\sigma\sqrt{2\pi}}\int_0^{D^*} D^3\exp[-½(\frac{lnD-\mu}{\sigma})^2]dD$$

The polynomial series of e^x is

$$e^x=1+x+\frac{x^2}{2!}+... \qquad \text{for } x<\infty$$

With

$$x=-½(\frac{lnD-\mu}{\sigma})^2$$

the rain rate R can be further derived

$$R=6\pi.10^{-4}\frac{aN_T}{\sigma\sqrt{2\pi}}\int_0^{D^*} D^3[1-½(\frac{lnD-\mu}{\sigma})^2+..]dD$$

$$R=6\pi.10^{-4}\frac{aN_T}{\sigma\sqrt{2\pi}}[\int_0^{D^*} D^3dD-½\int_0^{D^*} D^3(\frac{lnD-\mu}{\sigma})^2dD]$$

The first term in the bracket is called integral I and the second term is called integral II. Integral I can be simply solved,

Int. I :

$$\int_0^{D^*} D^3dD=\frac{1}{4}D^4$$

$$=\frac{1}{4}D^{*4}$$

Int. II :

$$½\int_0^{D^*} D^3(\frac{lnD-\mu}{\sigma})^2dD=½[D^3X-\int_0^{D^*} X3D^2dD]$$

with

$$X=\int_0^{D^*}(\frac{lnD-\mu}{\sigma})^2dD$$

assume

$$y = \frac{lnD - \mu}{\sigma} \qquad y\sigma = \ln D - \mu$$

$$\frac{dy}{dD} = \frac{1}{\sigma D} \qquad D = e^{y\sigma + \mu}$$

then,

$$X = \int y^2 \sigma e^{y\sigma + \mu} dy = \sigma e^{\mu} \int y^2 e^{y\sigma} dy$$

$$X = \sigma e^{\mu}[y^2 \frac{e^{y\sigma}}{\sigma} - \int \frac{e^{y\sigma}}{\sigma} 2y dy]$$

$$X = e^{\mu}[y^2 e^{y\sigma} - 2(y\frac{e^{y\sigma}}{\sigma} - \int \frac{e^{y\sigma}}{\sigma} dy)]$$

$$X = e^{\mu}[y^2 e^{y\sigma} - \frac{2}{\sigma}(ye^{y\sigma} - \frac{e^{y\sigma}}{\sigma})] = e^{\mu + y\sigma}[y^2 - \frac{2}{\sigma}(y - \frac{1}{\sigma})]$$

$$X = D[(\frac{lnD - \mu}{\sigma})^2 - \frac{2}{\sigma}(\frac{lnD - \mu}{\sigma} - \frac{1}{\sigma})]$$

$$X = \frac{D}{\sigma^2}[(lnD - \mu)^2 - 2(lnD - \mu) + 2]$$

Inserting X in Integral II,

Int. II :

$$\tfrac{1}{2}\left(D^3\frac{D}{\sigma^2}[(lnD-\mu)^2-2(lnD-\mu)+2]-3\int_0^{D^*}D^2\frac{D}{\sigma^2}[(lnD-\mu)^2-2(lnD-\mu)+2]dD\right)$$

$$=\tfrac{1}{2}\left(\frac{D^4}{\sigma^2}[(lnD-\mu)^2-2(lnD-\mu)+2]-\frac{3}{\sigma^2}\int_0^{D^*}D^3[(lnD-\mu)^2-2(lnD-\mu)+2]dD\right)$$

The second term must be solved. It consists of three integrals,

Int. A :

$$\frac{3}{\sigma^2}\int_0^{D^*}D^3 2dD=\frac{6}{\sigma^2}\frac{1}{4}D^4$$

$$=\frac{3}{2}\frac{D^{*4}}{\sigma^2}$$

Int. B :

$$\frac{3}{\sigma^2}\int_0^{D^*}D^3 2(lnD-\mu)dD=\frac{6}{\sigma^2}\int_0^{D^*}(D^3lnD-D^3\mu)dD$$

$$=\frac{6}{\sigma^2}\left[\frac{D^4}{16}(4lnD-1)-\mu\frac{1}{4}D^4\right]$$

$$=\frac{3}{2}\frac{D^4}{\sigma^2}\left[lnD-\frac{1}{4}-\mu\right]$$

Int. C :

$$\frac{3}{\sigma^2}\int_0^{D^*} D^3(lnD-\mu)^2 dD$$

assume y = ln D - μ D = $e^{y+\mu}$

$$\frac{dy}{dD}=\frac{1}{D}$$

therefore Integral C can be written as follow

$$\frac{3}{\sigma^2}\int e^{4(y+\mu)}y^2dy=\frac{3}{\sigma^2}e^{4\mu}\int y^2e^{4y}dy$$

$$=\frac{3}{\sigma^2}e^{4\mu}[y^2\frac{e^{4y}}{4}-\int\frac{e^{4y}}{4}2ydy]$$

$$=\frac{3}{\sigma^2}e^{4\mu}[y^2\frac{e^{4y}}{4}-\frac{2}{4}(y\frac{e^{4y}}{4}-\int\frac{e^{4y}}{4}dy]$$

$$=\frac{3}{\sigma^2}\frac{e^{4\mu}}{4}[y^2e^{4y}-2(y\frac{e^{4y}}{4}-\frac{e^{4y}}{16})]=\frac{3}{\sigma^2}\frac{e^{4(\mu+y)}}{4}[y^2-\frac{1}{2}y+\frac{1}{8}]$$

$$=\frac{3}{4}\frac{D^4}{\sigma^2}[(lnD-\mu)^2-\frac{1}{2}(lnD-\mu)+\frac{1}{8}]$$

Now, Integral II can be written as

$$½(\frac{D^4}{\sigma^2}[(lnD-\mu)^2-2(lnD-\mu)+2]-\frac{3}{4}\frac{D^4}{\sigma^2}[(lnD-\mu)^2-\frac{1}{2}(lnD-\mu)+\frac{1}{8}]$$

$$+\frac{3}{2}\frac{D^4}{\sigma^2}[(lnD-\mu)-\frac{1}{4}]-\frac{D^4}{2\sigma^2})$$

$$=½\frac{D^4}{\sigma^2}[\frac{1}{4}(lnD-\mu)^2-\frac{1}{8}(lnD-\mu)+\frac{1}{32}]$$

$$=\frac{1}{8}\frac{D^{*4}}{\sigma^2}[(lnD^*-\mu)^2-\frac{1}{2}(lnD^*-\mu)+\frac{1}{8}]-0$$

Finally, the rain rate R is

$$R=6\pi.10^{-4}\frac{aN_T}{\sigma\sqrt{2\pi}}(\frac{1}{4}D^{*4}-\frac{1}{8}\frac{D^{*4}}{\sigma^2}[(lnD^*-\mu)^2-\frac{1}{2}(lnD^*-\mu)+\frac{1}{8}])$$

$$R=6\pi.10^{-4}\frac{aN_T}{\sigma\sqrt{2\pi}}\frac{1}{4}D^{*4}(1-\frac{1}{2\sigma^2}[(lnD^*-\mu)^2-\frac{1}{2}(lnD^*-\mu)+\frac{1}{8}])$$

Appendix B :

Calculation of coefficients k and α for specific attenuation

For a given data of :

- frequency, f in GHz
- polarization tilt angle relative to the horizontal, τ in degree, namely :
  - * 45° for circular polarization
  - * 0° for horizontal polarization
  - * 90° for vertical polarization
- elevation angle, θ in degree;

the values k and α can be calculated as follows

$$k = \frac{k_H + k_V + (k_H - k_V)\cos^2\theta\cos 2\tau}{2}$$

$$\alpha = \frac{k_H\alpha_H + k_V\alpha_V + (k_H\alpha_H - k_V\alpha_V)\cos^2\theta\, cos 2\tau}{2k}$$

To find k_H, k_V, α_H and α_V use table I which is adopted from the ITUR Report 721-3.

Table I

f (GHz)	k_H	k_V	α_H	α_V
10	0.0101	0.00877	1.276	1.264
12	0.0188	0.0168	1.217	1.200
15	0.0367	0.0335	1.154	1.128
20	0.0751	0.0691	1.099	1.065

If the frequency f is intermediate between f_1 and f_2 ($f_2 > f_1$) in table I, k_H and k_V can be obtained by interpolation using a logarithmic scale, while α_H and α_V can be calculated by using a linear scale; as follows

$$\log k(f) = (\log k_2 - \log k_1)\frac{\log f - \log f_1}{\log f_2 - \log f_1} + \log k_1$$

$$\alpha(f) = (\alpha_2 - \alpha_1)\frac{\log f - \log f_1}{\log f_2 - \log f_1} + \alpha_1$$

Appendix C :

Derivation of the rain height according Pontes et.al.

The expression for rain height is derived from equation (4.31) :

$$L_s(R_p) = \frac{h_R(R_p) - h_s}{\sin\theta} \qquad (4.31)$$

$$h_R(R_p) = L_s(R_p) \sin\theta + h_s$$

$$h_R(R_p) = \frac{L_e(R_p)}{r(R_p)} \sin\theta + h_s$$

$$h_R(R_p) = \frac{A_p}{\gamma(R_p)} \left(1 + \frac{L_s(R_p)\cos\theta}{L_0(R_p)}\right)\sin\theta + h_s$$

$$h_R(R_p) = \frac{A_p}{\gamma(R_p)} \left[\sin\theta + \frac{\frac{h_R(R_p) - h_s}{\sin\theta}\cos\theta\sin\theta}{L_0(R_p)}\right] + h_s$$

$$h_R(R_p) - \frac{A_p}{\gamma(R_p)} \left(\frac{h_R(R_p) - h_s}{L_0(R_p)}\cos\theta\right) = \frac{A_p}{\gamma(R_p)}\sin\theta + h_s$$

$$h_R(R_p) - \frac{A_p}{\gamma(R_p)} h_R(R_p) \frac{\cos\theta}{L_0(R_p)} + \frac{A_p}{\gamma(R_p)} h_s \frac{\cos\theta}{L_0(R_p)} = \frac{A_p}{\gamma(R_p)}\sin\theta + h_s$$

$$h_R(R_p)[1-\frac{A_p}{\gamma(R_p)}\frac{\cos\theta}{L_0(R_p)}]=\frac{A_p}{\gamma(R_p)}\sin\theta+h_s[1-\frac{A_p}{\gamma(R_p)}\frac{\cos\theta}{L_0(R_p)}]$$

$$h_R(R_p)=\frac{A_p\sin\theta}{\gamma(R_p)[1-\frac{A_p}{\gamma(R_p)}\frac{\cos\theta}{L_0(R_p)}]}+h_s$$

Finally (5.1) is obtained, that is

$$h_R(R_p)=\frac{L_0(R_p)\sin\theta}{\frac{\gamma(R_p)}{A_p}L_0(R_p)-\cos\theta}+h_s \qquad (5.1)$$

Appendix D :

Collection of Letters to/from the companies/instutions

(pages D-1 to D-17)

Ir. C.M. Sriwedari Adji
Faculty of Electrical Engineering
Telecommunications Division (EH-11.02)
Eindhoven University of Technology (EUT)
P.O. Box 513
5600 MB Eindhoven
The Netherlands
Telephone -31 40 474007
Telefax -31 40 455197

Eindhoven, 10 Oktober 1994

Kepada Yth.
Ir. Budi Prasetyo
GM Perencanaan, Penelitian dan Pengembangan
PT. Indosat
Jl. Medan Merdeka
Jakarta Pusat

Dengan hormat,

Proyek eksperimen gelombang mikro pada frekuensi K_u-band di Surabaya dari INTELSAT, Washington DC., telah usai pada bulan April 1993. Berdasarkan data pengukuran yang kami dapat, kemungkinan penerapan frekuensi K_u-band di Indonesia sedang kami analisa dengan titik berat dari sisi akibat redaman curah hujan terhadap sinyal satelit. Dalam rangka ini kami membutuhkan informasi lebih lanjut mengenai :

- kebenaran dan kejelasan dari informasi bahwa anda sedang menganalisa masa depan jasa telekomunikasi di Indonesia dengan menggunakan frekuensi K_u-band,
- sekiranya hal di atas benar, kami ingin mengetahui lebih lanjut prospek penggunaan frekuensi ini menurut anda, harapan-harapan anda dari penggunaan K_u-band untuk jasa telekomunikasi di Indonesia dan kapan jasa telekomunikasi dengan frekuensi ini akan diterapkan,
- informasi lebih mendalam mengenai satelit Palapa B4 (yang sedang dioperasikan sekarang) dan kemungkinan penerapan transponder K_u-band pada satelite Palapa mendatang,
- nomor telepon dan nomor facsimile dari instansi anda.

Kami mengharapkan tanggapan anda atas surat ini. Sekiranya anda bahkan menambahi dengan memberi keterangan lebih lanjut diluar permohonan yang kami sebutkan di atas, hal tersebut akan sangat kami hargai. Sebelumnya tidak lupa kami ucapkan terimakasih banyak atas perhatian dan kerjasama anda. Tentunya jika anda berminat, hasil akhir dari analisa kami akan kami kirimkan nanti.

Hormat kami,

Ir. C.M. Sriwedari Adji

Ir. C.M. Sriwedari Adji
Faculty of Electrical Engineering
Telecommunications Division (EH-11.02)
Eindhoven University of Technology (EUT)
P.O. Box 513
5600 MB Eindhoven
The Netherlands
Telephone -31 40 474007
Telefax -31 40 455197

Eindhoven, 10 Oktober 1994

Kepada Yth.
Ibu Ir. Woerfiendanti
P.T. SATELINDO
Jl. Rasuna Said No. 8, Kav - 6
Jakarta Selatan

Dengan hormat,

Proyek eksperimen gelombang mikro pada frekuensi K_u-band di Surabaya dari INTELSAT, Washington DC., telah usai pada bulan April 1993. Berdasarkan data pengukuran yang kami dapat, kemungkinan penerapan frekuensi K_u-band di Indonesia sedang kami analisa dengan titik berat dari sisi akibat redaman curah hujan terhadap sinyal satelit. Dalam rangka ini kami membutuhkan informasi lebih lanjut mengenai :

- kebenaran dan kejelasan dari informasi bahwa anda sedang menganalisa masa depan jasa telekomunikasi di Indonesia dengan menggunakan frekuensi K_u-band,
- sekiranya hal di atas benar, kami ingin mengetahui lebih lanjut prospek penggunaan frekuensi ini menurut anda, harapan-harapan anda dari penggunaan K_u-band untuk jasa telekomunikasi di Indonesia dan kapan jasa telekomunikasi dengan frekuensi ini akan diterapkan,
- informasi lebih mendalam mengenai satelit Palapa B4 (yang sedang dioperasikan sekarang) dan kemungkinan penerapan K_u-band transponder pada satelite Palapa mendatang,
- nomor telepon dan nomor facsimile dari instansi anda.

Kami mengharapkan tanggapan anda atas surat ini. Sekiranya anda bahkan menambahi dengan memberi keterangan lebih lanjut diluar permohonan yang kami sebutkan di atas, hal tersebut akan sangat kami hargai. Sebelumnya tidak lupa kami ucapkan terimakasih banyak atas perhatian dan kerjasama anda. Tentunya jika anda berminat, hasil akhir dari analisa kami akan kami kirimkan nanti.

Hormat kami,

Ir. C.M. Sriwedari Adji

Translation of the letter from PT. INDOSAT

Number : 301/GRL/HM.030/94
Supplement : 1
Subject : measurements project in the K_u-Band

Jakarta, 25 October 1994

Ir. C.M. Sriwedari Adji
Faculty of Electrical Engineering
Telecommunication Div. (EH-11.02)
Eindhoven University of Tech.
PO Box 513
5600 MB Eindhoven
The Netherlands

1. The conducted propagation measurements at the K_u-Band in Indonesia by PT. Indosat was a realization of the cooperation programme among Indonesian government (Directorate General Post and Telecommuncations) and Canadian government (Communication Research Centre), and other two ASEAN countries, namely Singapore and Thailand.

2. Indonesian government assigned PT. Telkom and PT. Indosat to conduct propagation measurements started from February 1992 until February 1994 by using the equipments which were financed by the Canadian government.

3. The measurements equipements at PT. Indosat did not function so well that the measurements result for Indonesia could only be collected from the one installed at PT. Telkom in Bandung.

4. Until now PT. Indosat as an Intelsat signatory only controls and operates the Intelsat system as a satellite transmission instrument, while the operation of the Palapa satellite is conducted by PT. Telkom and PT. Satelindo.

5. For further information about this measurements project, you may contact the included addresses. We are thanking you for your attention.

General Manager
Planning, Research and Development
signed by Mr. Budi Prasetyo

INDOSAT

Jl. Medan Merdeka Barat 21
P.O. Box 2905
Jakarta 10110
Indonesia

Telephone .
National : 021-3810727, 3810777, 3802614
Tel : + 62 21 3810777, 3810727, 3802614
Fax : + 62 21 3809833, 370484
Telex : 44383, 46134, (INDSAT IA)

Nomor : 301/GRL/HM.030/94
Lampiran : 1 berkas
Perihal : Proyek Pengukuran Ku-Band

Jakarta, 25 Oktober 1994

Kepada

Yth. Ir. C.M. Sriwedari Adji
Faculty of Electrical Engineering
Telecommunication Div.(EH-11.02)
Eindhoven University of Tech.
PO Box 513
5600 MB Eindhoven
The Netherland

1. Pengukuran propagasi Ku-Band di Indonesia yang dilakukan oleh PT Indosat merupakan hasil kerjasama pemerintah Indonesia (Direktorat Jenderal Pos dan Telekomunikasi) dan pemerintah Canada (Communication Research Center), dan dua negara ASEAN lainnya, yaitu Singapura dan Thailand.

2. Pemerintah Indonesia menugaskan masing-masing: PT Telkom dan PT Indosat untuk melakukan pengukuran propagasi, dimulai pada bulan Februari 1992 sampai dengan bulan Februari 1994, dengan menggunakan peralatan bantuan Canada.

3. Perangkat terpasang di Indosat tidak bekerja dengan baik sehingga hasil pengukuran untuk Indonesia hanya didapat dari perangkat yang dipasang di PT Telkom Bandung.

4. PT Indosat sebagai signatory Intelsat sampai saat ini hanya mempergunakan dan mengoperasikan sistem Intelsat sebagai sarana transmisi satelit sedangkan pengoperasian sistem Palapa dilakukan oleh PT Telkom dan PT Satelindo.

5. Untuk informasi lebih lanjut mengenai proyek pengukuran ini, dapat ditanyakan pada alamat terlampir. Atas perhatian ~~Bapak~~ Ibu kami ucapkan terima kasih.

GENERAL MANAGER
PERENCANAAN, PENELITIAN,
DAN PENGEMBANGAN

INDOSAT PERSERO

BUDI PRASETYO

NIK: 58820888

1. Mr. K. S. McCormick
   Executive Vice President

   Communication Research Center
   3701 Carling Avenue
   PO Box 11490, Station H
   Ottawa, Ontario K2H 8S2
   Tel : +1 613 998 2770
   Fax: +1 613 998 7987

2. Bapak Suwito Tjokro, MSIE
   Kasubditbintektel

   Departemen Pariwisata, Pos dan Telekomunikasi
   Direktorat Jenderal Pos dan Telekomunikasi
   Jl. Tomang Raya 14
   Jakarta 11430
   Tel: +62 21 566 8145
   Fax: +62 21 566 9317

3. Bapak Jaja Wachja
   Manager Uji Kaji

   Pusrenbangti PT Telkom
   Jl. Gegerkalong Hilir 47
   Bandung 40153
   Tel: +62 22 212 512
   Fax: +62 22 214 669

D-

Ibu Ir. C.M. Sriwedari Adji
Faculty of Electrical Engineering, Telecommunications Division (EH-11.02)
Eindhoven University of Technology (EUT)
P.O. Box 513, 5600 MB Eindhoven, The Netherlands
Telephone -31 40 474007
Telefax -31 40 455197

Eindhoven, 27 Oktober 1994

Kepada Yth.
Bpk. Jaja Wachja
Manager Uji Kaji Pusrenbangti PT. Telkom
Jl. Gegerkalong Hilir 47, Bandung 40153, Indonesia

Dengan hormat,

Proyek eksperimen gelombang mikro pada frekuensi K_u-band di Surabaya dari INTELSAT, Washington DC., telah usai pada bulan April 1993. Berdasarkan data pengukuran yang kami dapat, kemungkinan penerapan frekuensi K_u-band di Indonesia sedang kami analisa dengan titik berat dari sisi akibat redaman curah hujan terhadap sinyal satelit.

Kami mendapatkan informasi dari Bpk. Ir. Budi Prasetyo -GM Perencanaan, Penelitian dan Pengembangan PT. Indosat- bahwa dalam rangka kerjasama antara Indonesia, Canada, Singapura dan Thailand, PT Telkom ditugaskan untuk melakukan pengukuran propagasi mulai dari Februari 1992 sampai dengan Februari 1994 di Bandung. Untuk informasi lebih lanjut mengenai proyek tersebut, beliau memberikan alamat anda.

Kami membutuhkan informasi lebih lanjut mengenai :

- data dari stasiun bumi dan sistim perangkat pengukuran di Bandung,
- jika ada, hasil pengukuran seperti :
  - > kumulatif distribusi dari intensitas curah hujan
  - > kumulatif distribusi dari redaman curah hujan
  - > karakteristik diurnal dari redaman curah hujan

  cat: tolong sertakan pula "rain intensity integration time" yang anda pilih,
- jika dapat, informasi yang sama untuk pengukuran propagasi di Singapura dan Thailand,
- kebenaran dan kejelasan dari informasi bahwa anda sedang menganalisa masa depan jasa telekomunikasi di Indonesia dengan menggunakan frekuensi K_u-band. Sekiranya benar, kapan jasa telekomunikasi dengan frekuensi ini akan diterapkan,
- informasi lebih mendalam mengenai satelit Palapa B4 (yang sedang dioperasikan sekarang) dan kemungkinan penerapan K_u-band transponder pada satelite Palapa mendatang.

Kami mengharapkan tanggapan anda atas surat ini. Sekiranya anda bahkan menambahi dengan memberi keterangan lebih lanjut diluar permohonan yang kami sebutkan di atas, hal tersebut akan sangat kami hargai. Sebelumnya tidak lupa kami ucapkan terimakasih banyak atas perhatian dan kerjasama anda. Tentunya jika anda berminat, salinan dari laporan akhir dari proyek INTELSAT di Surabaya akan kami kirimkan.

Hormat kami,

Ir. C.M. Sriwedari Adji

D-7

Ms. Ir. C.M. Sriwedari Adji
Faculty of Electrical Engineering
Telecommunications Division (EH-11.02)
Eindhoven University of Technology (EUT)
P.O. Box 513
5600 MB Eindhoven, The Netherlands
Telephone -31 40 474007 / Telefax -31 40 455197

Eindhoven, 27 October 1994

Mr. K.S. McCormick
Executive Vice President
Communication Research Centre
3701 Carling Avenue
P.O. Box 11490, Station H
Ottawa, Ontario K2H 8S2, Canada

The three-years radiowave propagation measurements at the K_u-band in Surabaya, Indonesia, was completed in April 1993. This research project was conducted by the Institute Technology of Surabaya (ITS) and the Eindhoven University of Technology (EUT), and financed by the INTELSAT, Washington DC., and the NUFFIC, the Netherlands. Based on the collected data measurements, the feasibility of K_u-band telecommunications services in Indonesia is being analized.

Ir. Budi Prasetyo - the GM of Planning, Research and Development of PT. Indosat, Indonesia - has informed me that another radiowave propagation measurements in Indonesia was conducted from February 1992 until February 1994, on the frame of the cooperation research programme among Indonesia, Singapore, Thailand and Canada. For further information, he recommends to contact you.

I need a detail information about the propagation measurements in Bandung conducted by the PT Telkom, Indonesia, and the Communication Research Centre, Canada. Would you please inform me about :
- the measurements set-up and the data of the earth station
- if available, the measurements results, especially :
  > the rain intensity cumulative distribution
  > the rain attenuation cumulative distribution
  > diurnal rain attenuation characteristic

  note : would you please mention the chosen integration time of the rain intensity
- the same information for other measurements in Singapore and Thailand

You might have an idea already about the feasibility of using K_u-band in Indonesia and/or tropical regions, an extra information and commentary will be greatly appreciated. I am thanking very much for your attention and your cooperation. For your interest, today I also mail a copy of the final report of the INTELSAT propagation research project executed in Surabaya. I am looking forward for your answer.

Sincerely yours,

Ms. Ir. C.M. Sriwedari Adji

D-

Industry Canada Industrie Canada
Communications Centre de recherches
Research Centre sur les communications

TO:
Ms. Ir. C.M. Sriwedari Adji

Eindhoven University of Technology

DATE:
27 October 1994

Fax. No.: 31 40 455197
Tel. No.: 31 40 474007

FROM:

K.S. McCormick

Fax. No.: 613 998 9875
Tel. No.: 613 998 2768

Number of pages: 1 + 4

I am sending to you a copy of a paper that was presented at the Climpara '94 meeting in Moscow last June. I think that most of your questions will be answered by this paper.

If you need more detailed information, such as the actual numbers used in the preparation of the graphs or larger scale versions of the graphs, please let me know. The only real constraint that I have is that I need the agreement of all countries to release data to third parties. We will also be preparing joint submissions to the ITU-R.

The experiments are still operating, but will terminate at the end of February 1995.

I assume that you are an associate of Professor Brussaard. Please give him my best regards.

Stu McCormick

P.O. Box 11490, Station H
3701 Carling Ave.
Ottawa, Ontario, Canada K2H 8S2
Fax: 613 998 9875

C.P. 11490, Succursale H
3701, avenue Carling
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RAIN ATTENUATION MEASUREMENTS IN SOUTH-EAST ASIA

R. Lekkla[1], S.L. Lim[2], J. Wachja[3], K.S. McCormick[4]

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[4] - Communications Research Centre, 3701 Carling Ave, Ottawa K2H 8S2, Canada
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ABSTRACT

In South-East Asia, with its severe rain climates, significant attenuation will occur on earth-satellite paths in the 14/11 GHz bands. In August of 1993, at ISRP'93, the results from the first year of radiometric measurements of rain attenuation were presented for four locations in Thailand, Singapore and Indonesia. This paper describes the results from the second year of measurements, and compares them with the results obtained in the first year.

Keywords: Rain, Attenuation, Satellite.

1. INTRODUCTION

In 1989, an agreement was signed between the Association of South-East Asian Nations (ASEAN) and Canada to carry out a cooperative measurement program in the measurement of rain attenuation statistics on earth space paths. Of particular interest was the feasibility of using the Ku band frequencies of the INTELSAT Pacific Ocean Region (POR) satellites. The heavy rainfall conditions, combined with the relatively low elevation angles to the POR satellites, may make it impractical to use the higher frequency bands for certain satellite communications applications in the region.

Three countries are participating in the experiment: Thailand, Singapore and Indonesia, covering a wide geographical area. Part of Thailand lies in ITU-R rain climate zone N (tropical moderate) and part in rain climate zone P (tropical wet), while the other countries are entirely within rain climate zone P.

2. EXPERIMENTAL ARRANGEMENTS

In February 1992, measurement equipment was installed at Bangkok and Si Racha, Thailand, at Bukit Timah, Singapore, and at Bandung, Indonesia, as shown in Table 1. Another set of equipment was installed at Jakarta, but equipment problems at that site have not been resolved, and no data are available from Jakarta.

In Table 1, "Long." and "Lat." refer to the longitude and latitude of the measurement location, "Alt." is the altitude of the radiometer antenna above sea level, "Elev." and "Az." give the pointing angle to a satellite, "Rain" is the average annual rainfall amount, and "Rain Zone" is the ITU-R rain climate. The satellite position chosen was 174°E longitude except for Singapore, where an experiment was already in progress using an INTELSAT beacon from an Indian Ocean satellite, and the radiometer antenna was pointed in the direction of a satellite at 60°E.

The experimental equipment consists of radiometers operating at a frequency of 12.0 GHz. These are of the dual-slope type, using an antenna of 1.2m diameter. Measurements of sky noise temperature are made every two seconds, and stored in the radiometer memory. A tipping-bucket raingauge is mounted near each radiometer, and the time of each tip is also stored. Periodically, communications are established between the radiometer and a (remote) personal computer, and the radiometer memory is examined. If significant temperature fluctuations are found within a given hour, all the sky-noise measurements for that hour are transferred to the computer and recorded to disk. For quiescent

Table 1. *Characteristics of the experimental locations*

Location	Long.	Lat.	Alt. (m)	Elev. (deg)	Az. (deg)	Rain (mm)	Rain Zone
Bangkok	100.5°E	13.7°N	54	7.4	94.0	1460	N
Si Racha	100.8°E	13.1°N	30	7.9	93.9	1350	N
Bukit Timah	103.9°E	1.3°N	20	39.4	268.3	2285	P
Bandung	107.6°E	6.9°S	870	15.0	87.0	2164	P

periods, only the average noise temperature and its variance are retained for each hour. The times of all rain gauge tips are always saved. Since detailed recordings of sky noise temperature are retained only when there is significant activity, this recording procedure has proven quite efficient, in that only about five megabytes of data will be recorded for each site during a twelve-month period.

3. DATA ANALYSIS

This paper presents data for the two year period March 1992 to February 1993, and March 1993 to February 1994. At each experimental site, there were occasional equipment failures caused by lightning strikes, computer, and other equipment failures. Figure 1 shows the percentage of time that valid data were obtained for each of the sites. Severe equipment problems at Si Racha caused a complete loss of data for the months April through July 1993. Unfortunately, the data for Bandung for the period December 1993 to February 1994 were not received in time to be analyzed for this paper. For the two year period, the data availabilities from the experiments are 77%, 87%, 94%, and 78% for Bandung, Bangkok, Singapore and Si Racha, respectively. (When the data for Bandung are included, the figure will rise from 77% to 88%).

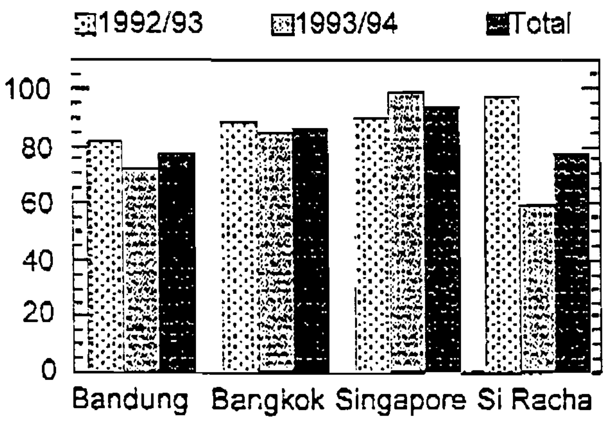

Figure 1. *Percentage of time that valid data were obtained for each of the experimental sites.*

The radiometric measurements of sky noise temperature were converted to path attenuations using the relation $A = 10\log(T_m - T_{cs})/(T_m - T_a)$, where A is the attenuation in dB, T_{cs} is the sky noise temperature in the absence of precipitation, T_a is the measured noise temperature, and T_m is the 'effective' temperature of the absorbing medium. In this analysis, T_{cs} was assumed to be 30°K. Selecting a value for T_m is difficult since it varies from one rainstorm to another, and even within a single storm. Various authors have used different techniques to determine this quantity. In this analysis it was decided to examine all the attenuation events and to select those for which the radiometer appeared to reach saturation (i.e. the measured sky noise temperature approached the effective medium temperature). These saturation temperatures were then plotted against the date on which they occurred, and a value of T_m was selected through examination of the values on the plot. This semi-quantitative approach yielded values of T_m equal to 280°K for Bangkok, Si Racha and Bandung, and 290°K for Singapore. From these values, time series of radiometrically-inferred attenuations were calculated from all the measured noise temperatures, and these data were then used to calculate monthly distributions of attenuation for each location.

The rain gauge data presented in this paper have not been integrated over one-minute periods. The times of each tip were simply used to calculate a time series of "instantaneous" rainfall rates, which were further processed to form cumulative distributions for each month.

4. RESULTS

The results of the data analysis for each location are given in Figures 2 and 3. Figure 2 shows distributions of rain rate, and Figure 3, distributions of attenuation.

In each of the plots of Figure 2, the label (a) refers to a pair of curves representing the distributions of measured rainfall rate for each of the one-year periods. In the first plot, for Bandung, the 1993/94 data are represented by the lower curve. In each of the other cases, the 1993/94 data are given by the upper curve of the pairs, indicating that 1993/94 tended to have more rain than the previous year. The curves associated with the label (b) are intended to represent "worst month" conditions. They were constructed from monthly distributions of rainfall rate by considering 1 mm/hr intervals, and selecting the largest of the monthly percentages for each interval. Curves N and P represent the distributions of rainfall rate given in ITU-R Recommendation 837 for rain climatic zones N and P.

The measured data for Bandung, Bangkok and Si Racha tend to lie closer to rain climate N than to climate P, while the data for Singapore lie between N and P. In all four cases, rain climate P seems to be a fairly good descriptor of the "worst month" data.

In each plot of Figure 3, the label (a) is associated with a pair of curves showing the 12 GHz attenuation inferred from the radiometer measurements. As in Figure 2, the lower curve of the pair represents the 1993/94 data for Bandung, while for the other three cases the lower curves show the 1992/93 values. Label (b) is again associated with "worst month" values, where in this case they were derived by considering 0.1 dB intervals of attenuation, and choosing the greatest monthly percentage of time for each 0.1 dB interval. In each case, label (c) denotes the annual attenuation distribution predicted using the procedure in ITU-R Recommendation 618-2, for a frequency of 12.0 GHz, and the location data given in Table 1. In the calculation, the rain intensity for 0.01 percent of the year was taken to be 86 and 91 mm/hr for Bangkok and Si Racha, respectively, which are average values over the two years. For Bandung and Singapore, the measured 0.01% values were in excess of 100 mm/hr, so that 100 mm/hr was used as prescribed in the Recommendation.

In all cases, the measured attenuation distributions for the two years are reasonably close, and for Singapore they are indistinguishable. At the lower elevation angles, Bandung, Bangkok and Si Racha, the measured distributions agree fairly well with the prediction, but with the prediction tending to underestimate the measured values. For Singapore, where the elevation angle of the measurement is much larger, the agreement is poor with a severe underprediction of the measured values.

5. CONCLUSION

This paper presents results from an extensive experiment designed to obtain rain attenuation information relevant to the design of satellite communications systems, in the 14/11 GHz bands, in South-East Asia. Indications from each of two years of measurements are that the ITU-R attenuation prediction technique gives reasonable agreement with measurements at relatively small elevation angles, but that the method seriously underpredicts the attenuation at relatively large angles for small percentages of time.

6. ACKNOWLEDGMENT

This work was supported by the Canadian International Development Agency, under project number 149-12982.

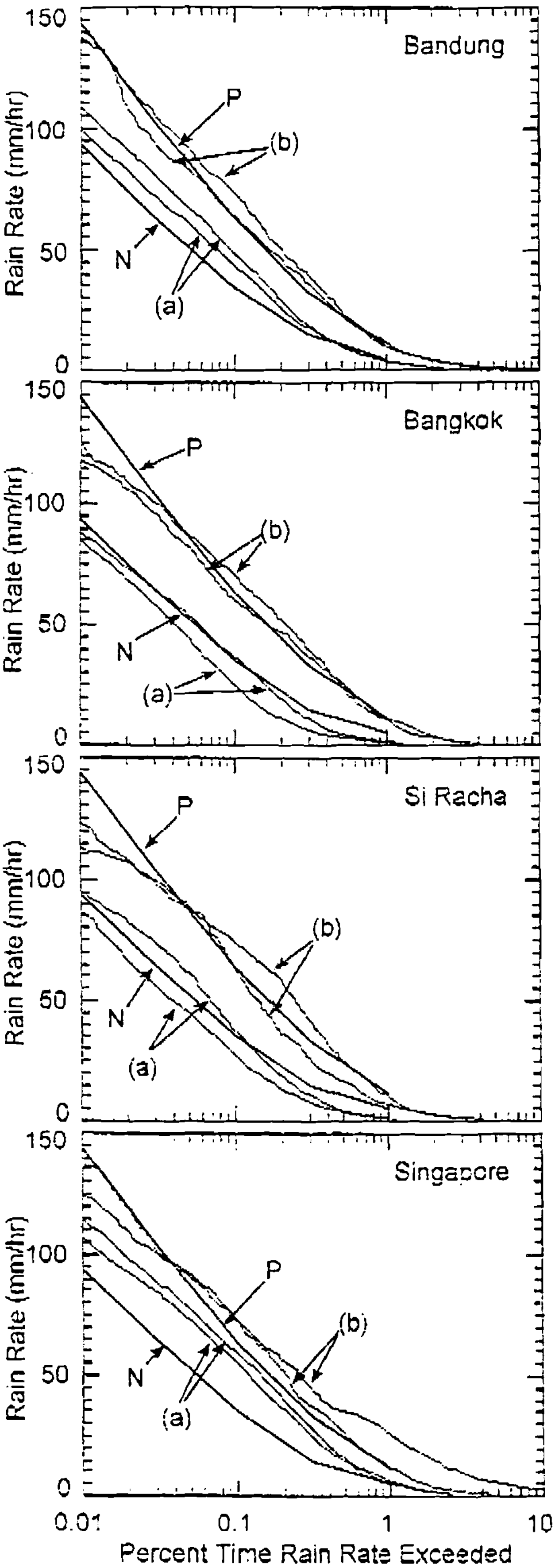

Figure 2. *Measured rainfall rate distributions for each of the four experimental locations.*

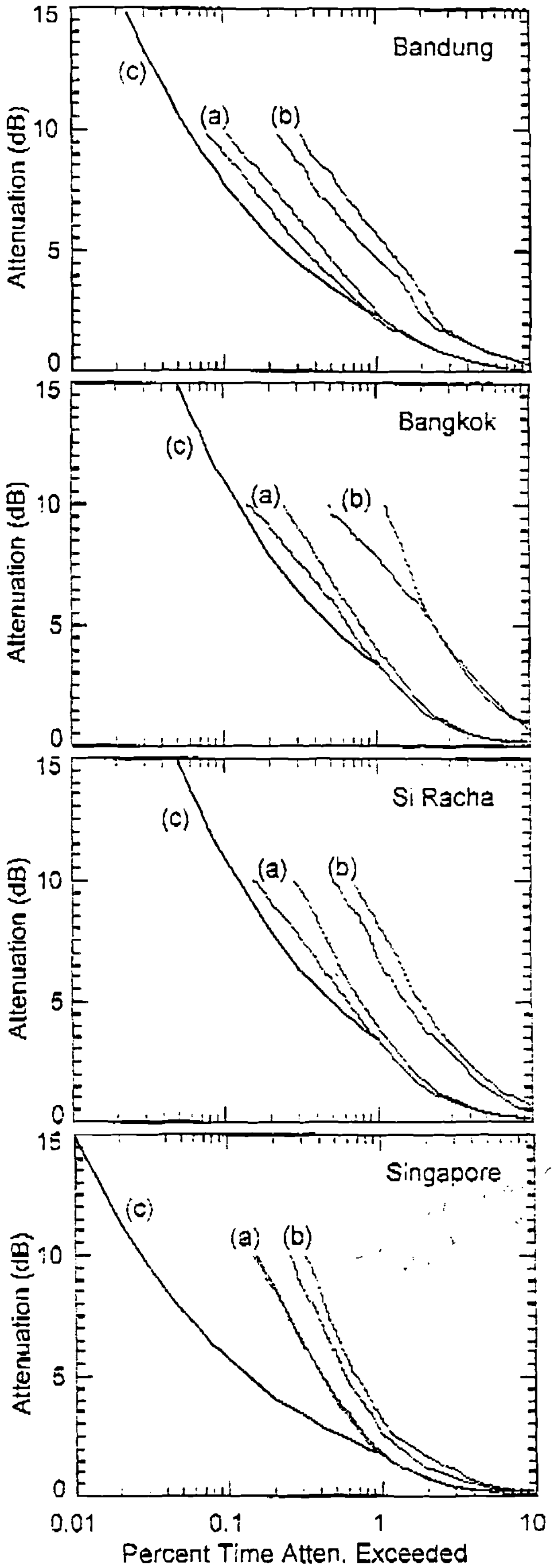

Figure 3. *Distributions of attenuation at 12 GHz inferred from radiometer measurements at each of the four experimental locations.*

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Eindhoven, 28 October 1994

Mr. K.S. McCormick
Executive Vice President
Communication Research Centre
3701 Carling Avenue
P.O. Box 11490, Station H
Ottawa, Ontario K2H 8S2
Canada

Number of pages : 1

Referring to your fax of 27.10.1994, I am thanking you for sending me a copy of your presented paper at the Climpara '94 meeting. I am glad that most of my questions are answered very clearly with the included extra information.

I need a more detailed information, that is the lists of the actual numbers of the measurements results which were used in the presentation of the figure 2 and the figure 3 in your paper. Would you send them to me.

I understand about the constraint of releasing data to the third parties. However if the diurnal rain attenuation characteristic graphs from the measurements are available, would you please let me know.

Professor Brussaard will be at the EUT again next week and I will give him your best regards. I hope the operation of your measurements will be terminated succesfully. Once again, thank you very much for your response.

Sincerely yours,

Caecilia M. Sriwedari Adji

c.c. : - Prof. dr. ir. G. Brussaard
- Ir. J. Dijk

D - :

Industry Canada Communications Research Centre
Industrie Canada Centre de recherches sur les communications

TO:
Ir. Caecelia M. Sriwedari Adji

DATE:
30 October 1994

Eindhoven University of Technology

Fax. No.: 31 40 455197
Tel. No.: 31 40 474007

FROM:

K.S. McCormick

Fax. No.: 613 998 9875
Tel. No.: 613 998 2768

Number of pages: 1

Please send your email address to me at

stu.mccomrick@crc.doc.ca

so that I can send you some numbers.

Stu McCormick

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Eindhoven, 2 November 1994

Kepada Yth.
Ibu Ir. Woerfiendanti
P.T. SATELINDO
Jl. Rasuna Said No. 8, Kav - 6
Jakarta Selatan

lampiran : 1

Dengan hormat,

Sehubungan dengan aktivitas kami dalam menganalisa kemungkinan penerapan Ku-band di Indonesia, kami mengirim surat tertanggal 10 Oktober 1994 untuk mendapatkan kejelasan dan informasi dari anda.

Kami mengetahui nomor fax anda dari surat tanggapan anda terhadap kolega kami. Kami menyimpulkan mungkin anda tidak menerima surat kami di atas, maka dari itu kami lampirkan kembali surat tersebut dalam fax ini.

Kami menunggu tanggapan anda dan kami ucapkan terimakasih atas perhatian anda.

Hormat kami,

Ir. C.M. Sriwedari Adji

Mengetahui : - Prof. dr. ir. G. Brussaard
- Ir. J. Dijk

Translation of the letter from PT. PASIFIK SATELIT NUSANTARA

Number L-325/PSN-XI/94

Jakarta, 3 November 1994

Ir. C.M. Sriwedari Adji
Faculty of Electrical Engineering
Telecommunication Div. (EH-11.02)
Eindhoven University of Tech.
PO Box 513
5600 MB Eindhoven
The Netherlands
Tel. 31-40-474007
Fax. 31-40-455197

We have received your letter of 10.10.1994. However, we would like to inform you that the name of our company is not PT Satelindo, but it is PT. Pasifik Satelit Nusantara (PSN).

The Palapa B4 satellite is not operated in the frequency Ku-band. The Palapa C1 and C2 which will be launched in November 1995, will bring the Ku-band transponders. PT. Satelindo owns those transponders, while PT. PSN owns the extended C-band transponder in those satellites. Therefore, for further information you can contact PT. Satelindo :

PT. Satelindo
Attn. Mr. Sahala Silalahi
Mulia Center 12 floor #1201
Jl. H.R. Rasuna Said Kav. X6 No. 8
Jakarta 12940 (Indonesia)
Tel. 62-21-5229322, Fax. 62-21-5229320

PT. PSN has been analysing the feasibility of using the Ku-band for the mobile satellite feeder link regarding that the frequency C-band is already crowded.

I am thanking very much for your attention.

signed by
director of PT. Pasifik Satelit Nusantara
Ir. L. Woerfiendanti S.

D - 17

PT. PASIFIK SATELIT NUSANTARA

No. L-325/PSN-XI/94

Jakarta, 3 November 1994

Kepada Yang Terhormat :
Ir. C.M. Sriwedari Adji
Faculty of Electrical Engineering
Telecommunications Division (EH-11.02)
Eindhoven University of Technology (EUT)
PO Box 513
5600 MG Eindhoven, The Netherlands
Tel. 31-40-474007
Fax. 31-40-455197

Dengan hormat,

Surat anda tertanggal 10 Oktober 1994 telah kami terima dengan baik, dan sebagai informasi, dengan ini diberitahukan bahwa perusahaan kami bukan PT. Satelindo melainkan PT. **Pasifik Satelit Nusantara (PSN)**.

Satelit Palapa B4 tidak menggunakan frekuensi Ku-band. Satelit yang menggunakan Ku-band adalah Palapa C1 dan C2 yang akan diluncurkan bulan November 1995, di mana transponder Ku-band tersebut dimiliki oleh PT. Satelindo sedangkan PSN memiliki extended C-band pada satelit tersebut. Oleh karena itu, untuk informasi selengkapnya anda dapat menghubungi PT. Satelindo di :

PT. SATELINDO
Attn. Bp. Sahala Silalahi
Mulia Center Lt. 12 #1201
Jl. H.R. Rasuna Said Kav. X6 No. 8
Jakarta 12940 - (Indonesia)
Tel. 62-21-5229322, Fax. 62-21-5229320

Untuk PSN sendiri saat ini sedang menjajagi kemungkinan penggunaan Ku-band bagi feeder link Mobile Satellite mengingat penggunaan C-band sudah sangat padat.

Demikianlah disampaikan dan atas perhatiannya, kami ucapkan terima kasih.

Hormat kami,
PT. PASIFIK SATELIT NUSANTARA

PT PASIFIK SATELIT NUSANTARA

Ir. J. Woerfiendarti S.
Direktur

/er

Appendix E :

Bibliotheekpracticum

(pages E-1 to E-17)

E - 1

Eindhoven University of Technology
Electrical Engineering Faculty
Telecommunications Division

Report of Bibliotheekpracticum

The Dependence of Rain Attenuation on Antenna Elevation Angle with Satellite Communication Link in Indonesia

by Caecilia M.S. Adji
No. 376391

Supervisor : Prof. G. Brussaard
Co-supervisor : Ir. J. Dijk

Proposal of graduation project

" The dependence of rain attenuation on antenna elevation angle with satellite communication links in Indonesia "

The demand of telecommunication services is increasing very rapidly. To fulfil this demand the service must be done in the higher and higher frequency. However this method can not be easily applied because the influence of rain in the troposphere is getting severe. The effects are also more pronounced in the tropical climate comparing to the one in the temperate climate.

To know how the rain effects the telecommunication system performance, many research projects have been executed at several places in the world. One of them was conducted in Indonesia which lies on the equator. It was a cooperation research project financed by INTELSAT, Eindhoven University of Technology (EUT) from the Netherlands and Institute Technology of Sepuluh November Surabaya (ITS) from Indonesia.

It observed the effect of rain attenuation in the frequency 11/14 GHz (Ku-band). The receiving antenna was installed on the top of building of the Electrical Engineering Department at ITS in Surabaya. The research was operated successfully for three years. In the first year the antenna received the co-polar signal from the INTELSAT - 508 at 180°E, thus the antenna elevation was 14°07'15". While in the other two years it received the signal from the INTELSAT - 510 at 174°E and in that case its antenna elevation was 20°20'34".

Nowadays the PALAPA satellite, a domestic satellite owned by the Indonesian Telecommunication Services, works in the frequency 4/6 GHz (C-band). Using commercially the higher frequency, for example Ku-band, is not perceptive because of the unknown characteristic of radiowave propagation in this frequency in Indonesia. However the above experiment in Surabaya may give information to the possibility of using this frequency.

In this final project the dependence of rain attenuation on antenna elevation angle will be analyzed based on the measurement result in Surabaya. From this analysis the expected rain attenuation on the signal from the Palapa satellite in the Ku-band will be derived by calculating the rain attenuation cumulative distribution for a higher elevation angle. The Palapa B2P satellite is located at 113°E, thus its elevation angle from Surabaya is about 90°. The characteristic of rain in the troposphere vertically and horizontally must be taken into account. After analyzing that result the future of telecommunication services in the Ku-band in Indonesia may be predicted.

Literature research assignment

A literature research must be performed in completing a graduation project. It is impossible to complete a graduation project without conducting a literature research. Performing a literature research is the first step.

The purpose of performing a literature research for this graduation project is collecting an information which relates to the subject of the graduation project. The right information must be collected first before entering the next step in completing the graduation project.

Refering to the assignment of the graduation project which has been illustrated in the previous page, the information about the radiowave propagation in the Ku-band in the tropical regions must be found. Some aspects of this subject which must be collected are the attenuation of the satellite signals induced by rain and its dependence on the antenna elevation angle.

According to the author's supervisor, the searching must be applied to the literature collection from about 1978 until the recent situation. The information can be retrieved from the symposium publications, the technical magazines and books.

This literature research can be performed at the Library of the Eindhoven University of Technology. Some tools have been provided, for instance VUBIS and INSPEC.

E-4

Concept of Contents, graduation report

List of Key-words, Searching Methods

First the searching was conducted by using VUBIS. Some search title words were used, that is :

- attenuation
- rain
- elevation
- tropical

Unfortunately, the results was not satisfying. The desired information could not be collected.

Searching of literature in INSPEC could not be provided only by using INSPEC on disc. Searching by using INSPEC on CD ROM could only cover the publications issued from 1989 until April 1994, while the searching also had to be conducted to retrace the publications that issued before 1989. For that case the searching was carried out by looking at the printed version of INSPEC. It was chosen that this searching covered the publications issued from 1976 up to 1988, because the ones published before 1976 were not related very well any more.

Therefore there were two types of lists of search words, one list for INSPEC on disc and another list for the printed version.

The list of search words for INSPEC on disc included :

- attenuation
- elevation
- tropic(s)
- tropical
- radiowave
- slant
- Dissanayake, A.W.
- Juy, M.
- Yokogawa

The last three words are the names of author. As an addition, ' 10 to 12 Ghz " was included from the frequency's Numerical Indexing.

The list of controlled key-words (thesaurus terms) for the printed version consisted of :

- attenuation measurement
- rain
- radiowave propagation

While using INSPEC on disc, in its index, the numbers of publications that included the above search words. For example, looking at the amount of hits on 'attenuation', it was 390. Combining the key-word ' attenuation ' with ' 10 to 12 GHz ' reduced the previous amount.

The titles and abstracts of those publications could be retrieved. After reading them, it could be determined whether they were the desired publications.

However, using the printed version of INSPEC was tiresome. This method had to be conducted very carefully and very patiently. Every time an interesting title was found, the related abstract had to be searched in a special volume containing the abstracts of publications.

Using the Science Citation Index on CD ROM was another way to find the related publications to this final project.

E

The information from the Science Citation Index on CD ROM could cover the publications from 1990 until April 1994.

An autonomous searching on author, that is Yokogawa, was performed using the Science Citation Index on CD ROM. Yokogawa was known that he wrote some publications in Japan. His publications in English version would like to be retrieved. The citation was implemented in the year 1990 - April 1994. Unfortunately the citation result was zero.

An citation analysis was also performed by using the Science Citation Index on CD ROM. The publication number 10 from the list of literature was citated. The author's supervisor found that the citation of that publication would be very interesting. The citation was implemented in the year 1991 until April 1994. The result was also zero.

Most of the publications were obtained from the EUT (Electrical Engineering) Library. However some of them were obtained from author's supervisor and co-supervisor, especially the ones from the latest symposium and two of them were obtained via Electrical Engineering Library from other library by interlending (IBL).

List of Sources

Source	Number of references found after 1st selection
VUBIS	0
INSPEC on disc (1989 - April 1994)	45
INSPEC printed (1976 - 1988)	60
Science Citation Index on disc (1990 - April 1994)	0
CCIR	Vol. V
Author's supervisors	4

Selection Criteria

The searching is strictly limited by the using language. Only the publications which were written in English would be chosen.

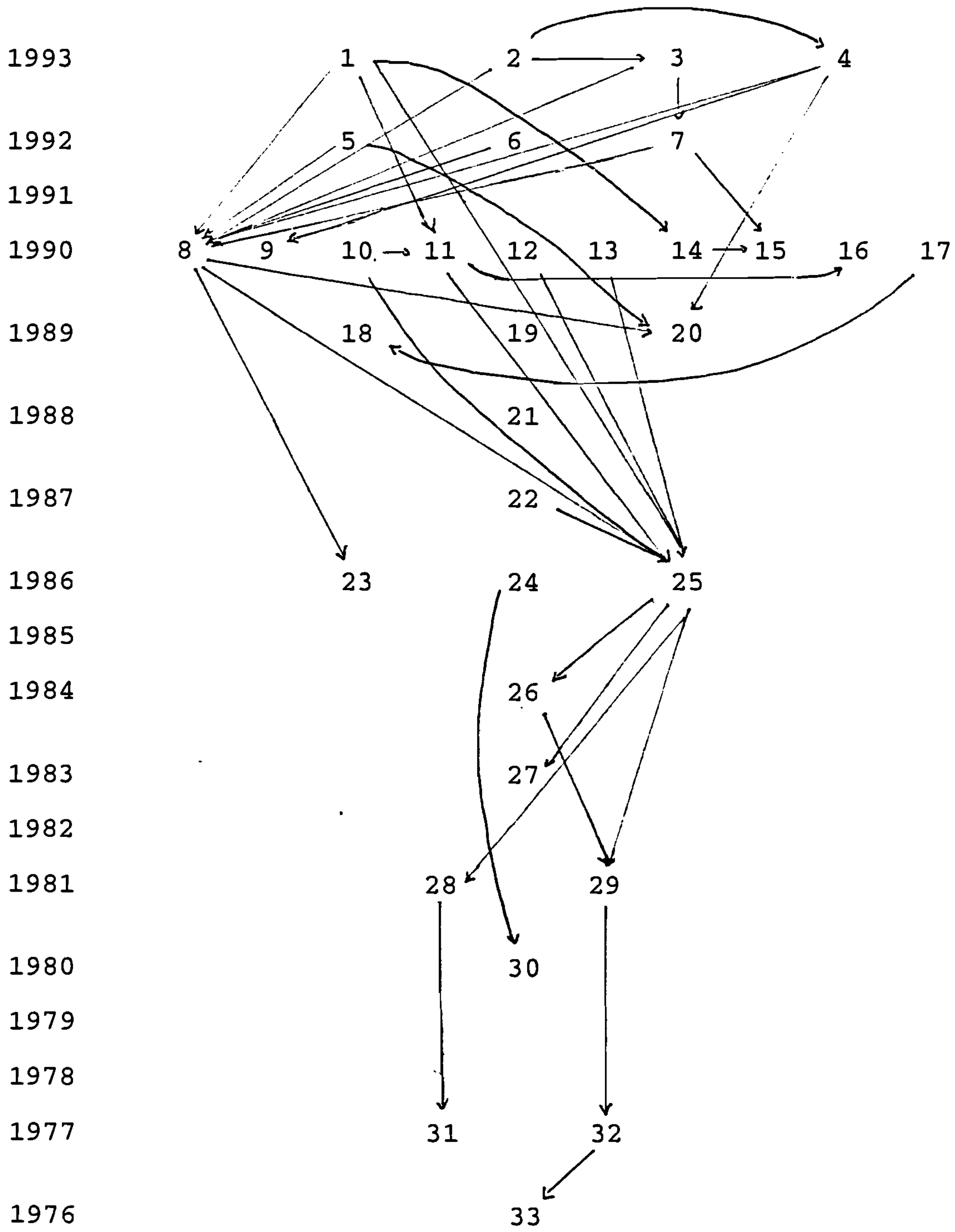
Searching the publications by using INSPEC on disc and INSPEC printed version was limited by the title. However, if the title was doubtful the searching was continued to abstract.

If the titel mentioned about 'rain attenuation'. the paper will be investigated further by reading the abstract. If the abstract contains a subject about elevation scaling technique or rain attenuation prediction method, then thepaper will be chosen.

Another criteria was the maximum delivery time. In this literature research the interlanding was used. Unfortunately, some publications were arrived late.

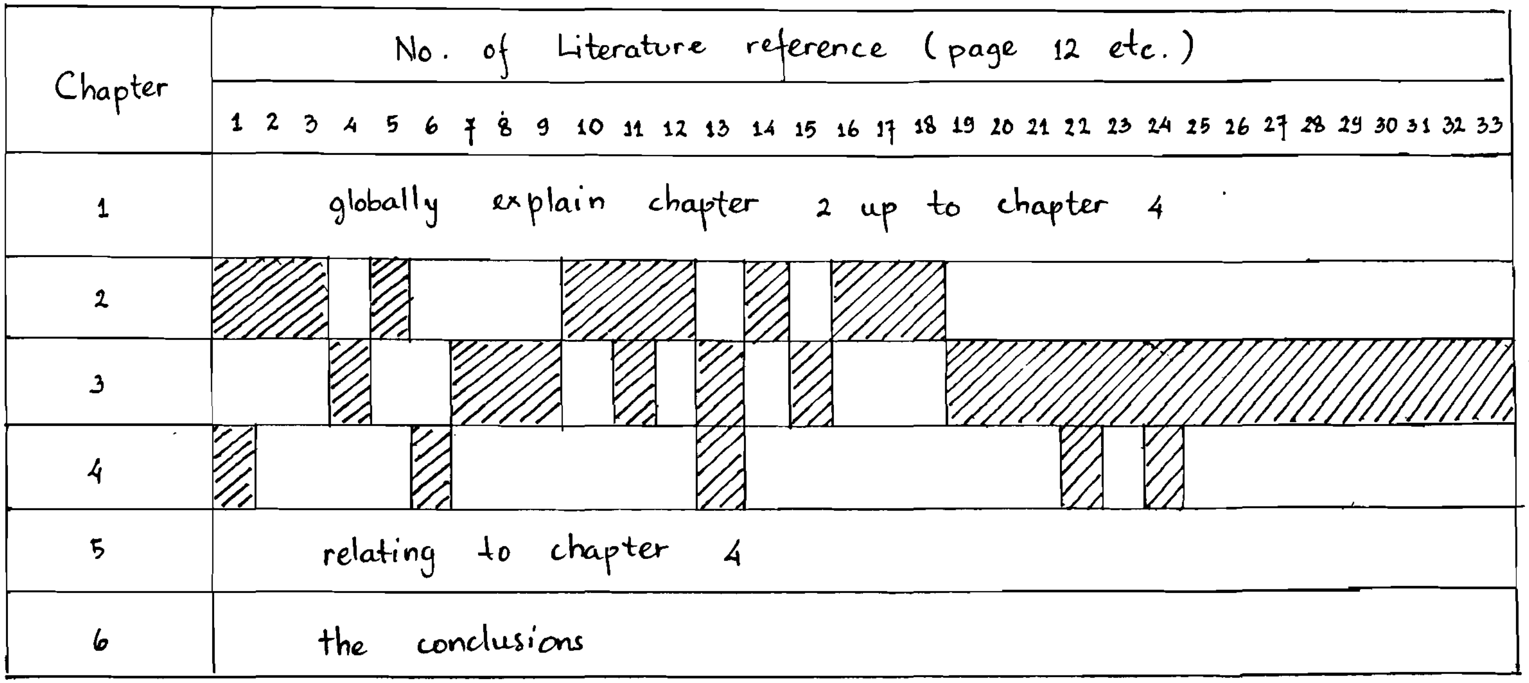
Snowball Method

In this literature observation, the snowball method is chosen. Here is its sketch :



The inputs in the snowball method are number 1, 2 and 3. Number 1 includes the results of the measurements which were conducted in Surabaya. Thus, it is the first input. Number 2 is a very good article which explains the present situation of the radiowave propagation for tropical regions. Number 3 introduces the results of the radiometric measurements in tropical Africa which can be use as comparison with the results of the measurements in Surabaya.

The Matrix Relation



Conclusions

By completing this 'Bibliotheekpracticum' the related publications to this final project could be collected.

Using VUBIS was not satisfying. It did not give any satisfying information relating to the graduation project assignment.

Using INSPEC on disc was very efficient and very convenient. It was possible to review the publications that issued from 1989 up to April 1994 very fast, comparing with the other method when the printed version was used. Using the last method was so tiresome and inconvenient. It would have been nice if INSPEC on disc could be used also to review the publications that were issued from 1976.

Another way was using the Science Citation Index. The autonomous searching on "Yokogawa" was unsuccessful. The citation analysis on Number 10 gave no result.

Based on the collected publications, the assignment of the graduation project is possible to be analysis. The theoritical background can be studied from the collected publications. Afterwards the solution in solving the problem can be found out.

The author's supervisors found that the publications which were written by M. Juy, were interesting. I myself found that Number 5 and Number 22 were very interesting. Number 1 is the kind of handbook for this graduation project assignment. Certainly, Number 8, that is the CCIR Vol. V, can not be neglected.

For this literature research, the author got support from the supervisors. Please notice the inputs of the snowball method were obtained from them. Number 5, 6, 10, 11, 16, 20 and 22 are very useful.

In general it certainly can be concluded that this 'practicum' is a good tool to collect publications that are needed in building and completing the final project.

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