RAINDROP SIZE DISTRIBUTION EXTRACTED FROM RAIN ATTENUATION DATA

HATEM ALMOKHTAR OMAR ABDULKABEER

Universiti Teknologi Malaysia

RAINDROP SIZE DISTRIBUTION EXTRACETD
FROM RAIN ATTENUATION DATA

HATEM ALMOKHTAR OMAR ABDULKABEER

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical - Electronics and Telecommunication)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

NOVEMBER 2008

To

My beloved parents and brother and sisters for their unwavering love, sacrifice and inspiration.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my utmost gratitude to my supervisor, Associate Professor Dr. Jafri bin Din for being a dedicated mentor as well as for his valuable and constructive suggestions that enabled this project to run smoothly.

Also, not forgetting my friends and classmates, I convey my full appreciation for their on-going support and contributions toward this project, whether directly or indirectly.

Last but not least, I am forever indebted to all my family members for their constant support throughout the entire duration of this project. Their words of encouragement never failed to keep me going even through the hardest of times and it is here that I express my sincerest gratitude to them.

ABSTRACT

Attenuation due to rain plays a significant role in the terrestrial and earth-space communication systems especially at frequencies above 10 GHz. Although models proposed by ITU-R for the prediction of rain attenuation give a good estimation about the signal attenuation caused by rain for temperate regions, recent studies shows that it underestimates the same tropical regions. Tropical regions are characterized by high intensity rainfall, enhanced frequency of rain occurrence and the increased presence of large raindrop when compared with temperate climates. This project will look into the prediction of raindrop size distribution by analyzed and convert the summarized collected data on rain attenuation. The summarized data are taken from point to point microwave link measurements at Skudai, Johor Bahru. The data needs to be taken into consideration on many aspects that will involve in wave propagation phenomena. An accurate estimation of the drop size distribution (DSD) is essential in the interval of rainfall parameters from microwave measurement and in the modeling of microwave propagation through rain. Information of raindrop size distribution (DSD) is important for prediction of the microwave signal attenuation due to rain. Drop size distribution is one of major parameters that effects on microwave signal degradation due to rain, detail information on (DSD) leads better accuracy on the attenuation prediction due to rain thus, (DSD) profile is extracted from locally collected rain attenuation data base at operating frequencies 26 and 38 GHz. The Singapore model of drop size distribution gives better prediction for rain specific attenuation due to the rain attenuation data was collected in Johor.

ABSTRAK

Kehilangan data yang dihantar menggunakan teknologi komunikasi wayarles akibat hujan mempunyai impak yang besar dalam system komunikasi yang menggunakan spektrum frekuensi di atas 10GHz. Walaupun ITU-R telah menyediakan cadangan model bagi menganggarkan kesan kehilangan akibat hujan bagi negara-negara yang mempunyai empat musim, namun model ini tidak sesuai untuk aplikasi negara-negara tropika. Negara di kawasan tropika mengalami kekerapan hujan yang lebih tinggi, hujan yang lebih lebat dan titisan air hujan yang lebih besar berbanding di negara-negara empat musim. Projek ini menyelidik anggaran distribusi saiz titian air hujan daripada data yang telah dikumpul dan dianalisis berkenaan kesan hujan pada kehilangan maklumat yang dihantar secara wayarles. Data-data telah diambil daripada satu laluan komunikasi gelombang mikro titik-ke-titik yang ukurannya dilakukan di Skudai, Johor Bahru. Maklumat-maklumat berkenaan fenomena pemancaran gelombang telah diambil kira dalam projek ini. Anggaran tepat berkenaan distribusi saiz titisan air hujan, atau DSD sangat penting dalam menyediakan satu model berkenaan karakteristik pemancaran gelombang dalam keadaan hujan. Oleh sebab DSD merupakan parameter yang mempengaruhi pemancaran gelombang mikro, justeru anggaran yang dibuat melalui pengukuran pengumpulan, dan penganalisaan data-data ini mampu membantu dalam membuat penggangaran tepat kesan kehilangan data akibat hujan. Profil DSD telah diambil dari satu sesi pengukuran yang dilakukan secara local pada frekuensi beroperasi 26 dan 38 GHz. Model DSD Singapura memberi anggaran kesan kehilangan data melalui komunikasi wayarles akibat hujan yang lebih baik.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	-	Attenuation
a, b	-	Regression coefficients
$A_{0.01}$	-	Attenuation at 0.01% of time
a_1	-	excess attenuation (dB) due to water vapor
a_2	-	excess attenuation (dB) due to mist and fog
a_3	-	excess attenuation (dB) due to oxygen
a_4	-	sum of absorption losses (dB) due to other gases
a_5	-	excess attenuation due to rainfall
A_m	-	Measured attenuation
A_p	-	Predicted attenuation
$Area_P$	-	Drop cross section area (m^2)
C_P	-	Number of drops in the *p*th size
dB	-	Decibel unite
d	-	Separation (km) between the two sites
D_P	-	Mid size of the *p*th channel (mm)
f	-	Frequency
GHz	-	Giga Hertz
k, α	-	Regression coefficients
km	-	Kilometer
L_{eff}	-	Effective Path length
L	-	path length
m	-	Meter
mm	-	Millimeter
$N(D)dD$	-	Number density of raindrops with equivalent diameter D in the interval dD

Nt	-	Total number of drops per cubic meter per millimeter
P	-	Probability
P (%)	-	Percentage in time of the year
$Q_t(D)$	-	Total extinction cross section
$R_{(p)}$	-	Rain rate at percentage in time of the year
$r(P)$	-	Horizontal reduction factor of percentage in time of the year
$r_{0.01}$	-	Horizontal reduction factor for 0.01% time of the year
$R_{0.01}$	-	Rain rate at 0.01% of time of the year
$V(D)$	-	The terminal velocity of drops in m/s
ΔD_p	-	Width of the *p*th channel (mm)
Δt	-	Sampling time (s).
θ	-	The path elevation angle
γ_R	-	Specific attenuation

LIST OF ABBREVIATIONS

AGCV	-	Automatic Gain Control Voltage
C	-	Centigrade
dB	-	Decibel
dBm	-	Decibel mili watt
DBSG5	-	ITU-R Study Group Three Data Bank
GHz	-	Giga Hertz
IEEE	-	Institute of Electrical and Electronic Engineering
ITU-R	-	International Telecommunication Union Radio-Broadcasting
mm/h	-	milimetre per hour
MMS	-	Malaysia Metrological Services
NASA	-	National American Space Agency
S	-	second
TRMM	-	Tropical Rainfall Measuring Mission
UTM	-	Universiti Teknologi Malaysia

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

The rapid development in communication systems has brought saturation to the most desirable frequency band (1 to 10GHz). This fact has led to the utilization of higher frequencies extending the radio frequency spectrum into the millimeter wavelength region. Rain is dominating source of attenuation at higher frequencies. Its intensity and distribution greatly effects transmission quality and limits system's availability. Rain effects on microwave systems are more critical in tropical and equatorial zones, where rain fall is higher than in temperate zones. In temperate regions the rain effects becomes significant above 10GHz, while in tropical climates in general and in equatorial climate particularly, since the rain drops are larger than in temperate climates. When designing microwave links operating above such frequencies, the major problem in link design is to determine the excess attenuation due to rainfall.

Malaysia has tropical climate and due to its maritime exposure it experiences heavy rainfall with mean annual ranging between 2400mm to 3200mm and about 150-200 rainy days per year [1]. It is subject to Northeast monsoon from October to

March and Southwest monsoon from April to September. Rain is classified into two categories; convective and stratiform or widespread. Convective rain is cellular in nature and covers a limited area. Small cells of heavy rainfall are often embedded in larger regions. Light and medium intensity rainfall on the other hand is usually widespread in character, is for a longer duration and covers a wider area. Malaysian climate is mostly subject to convective rains and heavy downpour rain is the most seriously damaging to radio transmission at higher frequencies.

In the design of radio communication system, one of the major concerns is to assess system unavailability also called outage time. Unavailability or outage time is the amount of time during which system's performance will be below some threshold value or that it will not be useable. For designing a reliable system, the amount of outage time has to be kept below some objective. In microwave systems, outages can occur either due to equipment failure or it can be propagation outage. In modern systems, the equipment outage time can be made negligibly small by using standby equipment and automatic protection switching systems. However, at high frequencies, attenuation by rain can cause an outage, which can be easily protected. Therefore the practical way of achieving a reliable radio system at those frequencies where there is substantial rain attenuation is to design the system in such a way that the expected amount of rain outage is below some objective [2]. For a reliable communication system, unavailability time during a year has to be kept at 0.01 percent [3]. This corresponds to availability time of 99.99 percent during a year.

Most of the studies on rain attenuation have been carried out in the temperate regions of the world. The rain characteristics in the tropics differ appreciably from those of the temperate regions in the empirical relationships obtained in the later may not be very suitable for system designing in the former [4]. There is generally a limited amount of data available on direct attenuation and rain rate measurements in tropical regions. Consequently, many of recommendations of the ITU-R are based on data mainly obtained from temperate regions of the world. The increasing use of high microwave frequencies for telecommunication and broadcasting services thus necessitate the need for rain attenuation studies in the tropics.

Research in radio wave propagation In Malaysia commenced in 1990s at University Sains Malaysia (USM), [1], [5] and at University Teknoliogi Malaysia (UTM),[[6], [7]]. One minute rain rate using rain gauges and drop size distribution using distrometer were measured and new values of regression of coefficients a,b were proposed by Din [6].

1.2 Problem Statement

The problem statement of this project is stated in the following points:

i- The incapability of the published prediction models to be sensitive of the available knowledge of rainfall on Malaysia climate.

ii- The lack of drop size distribution studies in Malaysia, especially for higher frequency band.

iii- There is no previous calculation for prediction of rain drop size distribution in Malaysia.

1.3 Objective

The objective of this project is to determine rainfall drop size distribution (DSD) extracted from the UTM rain attenuation data base measured at operating frequencies 26 GHz and 38 GHz.

1.4 Scope of Work

The primary objective of this thesis is to determine rainfall drop size distribution (DSD) extracted from the UTM rain attenuation data base measured at operating frequencies 26 and 38 GHz.

Practical approach is adopted to study the rain attenuation through direct measurement. The rain attenuation data were measured continuously from the available point-to-point terrestrial microwave link operating at 26 and 38GHz in UTM-Skudai. Two years rain attenuation data were collected. Tipping bucket type of rain gauge with 0.5mm sensitivity was used to collect the one-minute integration time of rain rate. In the analysis, the measured rain attenuation data was analyzed to evaluate the ITU-R and other prediction models.

Rain does not distribute uniformly along the terrestrial microwave link. The horizontal reduction factors are taking into account in order to calculate the total rain attenuation throughout the link. These reduction factors are accounted for in-homogeneity of rain rate horizontally. Consequently, the horizontal reduction factor would make the effective path length of the microwave link shorter than the actual path length. As a result, the information of one-minute integration time of rain rate, regression coefficient factors and reduction factors would provide adequate information for the researchers in order to predict the rain attenuation effect on the microwave links accurately.

1.5 Thesis Outline

This thesis organized into five chapters to completely cover the whole research activities. The following paragraphs describe each of the following chapters.

Chapter 2 provides brief summary of literature review on the rain attenuation and drop size distribution. It includes the study on specific attenuation and effective path length.

Chapter 3 gives an overview of the raindrop size distribution measurements.

Chapter 4 presents drop size distribution equations.

Chapter 5 and resents the results, analysis and discussion for the simulation program, the calculation of the attenuation and drop size distribution.

Chapter 6 Concludes the thesis. The conclusion is given based on the analysis of results from the previous chapter. Recommendations for future works are also presented.

REFERENCES

1. Yusof, M.A, "Studies on One-Minute Rainfall Rate Distributions Affecting The Communication Systems in Malaysia", M.Sc. Thesis, Universiti Sains Malaysia, Malaysia, 1991.

2. Osborne, T.L, "Application of Rain Attenuation Data to 11 Ghz Radio Path Engineering", The BELL system technical journal, Vol. 65, No 9, November 1977.

3. ITU-R Recommendations, "Propagation in Non-Ionized Media", Volume PN Series, 1994

.

4. Ajayi G., O, Feng, S., Radicella, S. M and Reddy, B. M. "Handbook on Radio Propagation Related to Satellite communications in Tropical and Sub-Tropical Countries", URSI Standing Committee on Development Countries, 1996.

5. Zainal, A. R., Glover, I. A., Watson, P. A. and S. Hassan, S. I, "Rain Rate and Drop Size Distribution Measurements in Malaysia", Proceedings of the 1993 International Geoscience and Remote Sensing Symposium, (IGRSS'93) – Japan, Vol. I, pp. 309 – 311, 1993.

6. Din, Jafri," Influence of Rainfall Drop Size Distribution on Attenuation at Microwave Frequencies in a Tropical Region", Ph.D. Thesis, Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), 1997.

7. Chebil J, "Rain Rate and Rain Attenuation Distribution for Microwave Propagation Study in Malaysia" IEEE Ph.D. Thesis, Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), 1997.

8. Ayoade, “Introduction to Climatology for the Tropics”, John Wiley and Sons Inc., 1983.

9. Malaysian Meteorological Service (1987). Annual report 1987.

10. Ooi Jin Bee and Chia Lin Sien, “The Climate of West Malaysia and Singapore”, Oxford University Press, Singapore, 1974.

11. Freeman, R.L. “Radio System Design for Telecommunications (1 – 100 GHz)”, 2nd edition, John Wiley & Sons Inc, 1997.

12. ITU-R Recommendations, “Radio meteorological Data”, CCIR XVIIth Plenary Assembly, Dusseldorf, 1990, pp. 34.

13. Oguchi, T. “Electromagnetic Wave Propagation and scattering in Rain and other Hydrometers”, Proceeding of IEEE, Vol. 71, No. 9, September 1983.

14. Pruppacher, H. R. and Beard, K. V., “A Wind Tunnel Investigation of the Internal Circulation and Shape of Water Drops Falling at Terminal Velocity in Air”, Quaterly J. R. Met. Soc., Vol.96, pp. 247-256, April 1970.

15. Nelson, A. R. and Gokhale N. R., ”Oscillation Frequencies of freely Suspended Water Drops”, J. Geophys. Res., Vol. 77, pp. 2724-2727, May 1972.

16. Ugai, S., Kato K., Nishijima, M., Kan, T and Tazaki, K., “Fine Structure of Rain Fall”, Ann. Telecommuni., Vol. 32, pp. 422-429, Nov. Dec 1977.

17. Olsen, R. L., Rogers and D. B. Hodge, “The aR^b Relation in the Calculation of Rain Attenuation”, IEEE Transactions on Antennas and Propagation, Ap-26, n.2 pp.547-566, 1978

18. Fedi, F., “Attenuation due to Rain on a terrestrial Path”, Alta Frequenza, 66, pp.167-184, 1979.

19. Maggiori, D., “Compute Transmission through Rain in the 1-400 GHz Frequency Range for Spherical and Elliptical Raindrops and any Polarization”, FUB Report, IC379, 1981.

20. Laws, J. O. and Parsons D. A., “The Relation of Raindrop to Intensity”, Transactions on American Geophysics Union, Vol. 24, pp. 452-460, 1943.

21. Gunn, R. and Kinzer, G. D., “The Terminal Velocities of Fall of Water Droplet in Stagnant Air”, Journal of Meteorology, 6 pp. 243-248, 1949.

22. Ray, P. S. (1972), “Broadband Complex Refractive Indices of Ice and Water”, Applied Optics, 11, n. 8 pp. 1836-1844, 1972.

23. Ajayi G. O. and Olsen, R. L., “Modeling of a Tropical Raindrop Size Distribution for Microwave and Millimeter Wave Applications”, Radio Science, Vol. 20, No. 2, pp.193-202, 1985.

24. Maciel, L. R. and M. S. Assis, “Tropical Rainfall Drop size Distribution”, International Journal of Satellite Communication Vol. 8, pp. 181-186 , 1990.

25. Z. Zhao (2003), “A prediction model of rain attenuation along Earth-Space path”, J. IEICE Japan. Vol. 83, Trans, Antenna propagation. pp. 7803-7831.

26. Joss, J. and I. Zawadzki, 1997, “Raindrop size distributions again?” 28th Conference on Radar Meteorology, AMS, 326-327.

27. Sheppard, B. E., 1990: The measurement of raindrop size distribution using a small Doppler radar. J. Atmos. Oceanic Technol., 7, 180-183.

28. Sheppard, B. E. and P. I. Joe, 1994: Comparison of raindrop size distribution measurements by a Joss-Waldvogel disdrometer, a PMS 2DG spectrometer, and a POSS Doppler radar. J. Atmos. Oceanic Technol., 11, 874-887.

29. M. A. Awang, J. Din, "Comparison of the Rain Drop Size Distribution Model in Tropical Region", Wireless Communication Center (WCC), Malaysia.

30. Leonardo R. Meciel and Mauro S. Assi, "Tropical Rainfall Drop Size Distribution", International Journal of Satellite Communications, Vol. 8, No.3, pp. 181-186, 1990.

31. ITU-R (1997), Rain Height module for prediction methods, in Propagation in Non- Ionized Media, Rec. P839-2.ppl, P.839-3, Geneva, Switzerland, 2001.

32. M. R. Islam & A. R. Tharek, "Propagation Study of Microwave Signals Based on Rain Attenuation Data at 26GHz and 38GHz Measured in Malaysia", Wireless Communication Research Lab, Faculty of Electrical Engineering, University of Technology Malaysia, IEEE 1999.

33. Ayman.A.A. Alwarfalli, "The Effect of Rain Rate Modeling for the Prediction of Satellite Propagation in Malaysia" M. Sc thesis, faculty of electrical engineering, University Technology Malaysia (UTM), 2005.