RAIN ATTENUATION PREDICTION BASED ON RAINDROP SIZE DISTRIBUTION MEASUREMENT IN MALAYSIA

MANHAL JAAFAR JABER ALHILALI

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Faculty of Engineering
Universiti Teknologi Malaysia

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To my beloved parents...

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ABSTRACT

Attenuation due to rain at frequencies above 10 GHz in temperate climates and above 7 GHz in tropical ones is a critical factor for both terrestrial and satellite link system designers. Knowledge of the rain drop size distribution (DSD) is essential for an accurate estimate of the attenuation experienced by electromagnetic waves traveling through the rain. Large uncertainties remain in the variability of DSDs and their dependence on rainfall types and climatological regimes. Such uncertainties are much more critical in the equatorial region, where there are only limited experimental results of DSD data. In this study, a two-year measurement of DSD, using a 2D video distrometer (2DVD) installed for the first time in UTM Johor Malaysia, has been used. The 2DVD is an advanced instrument that not only can measure large ranges of DSD but also can capture the raindrop shape, axial ratio, oscillation mode and drop fall velocity, so it can provide a higher accuracy of estimations than any other instrument. A millimeter wave (mmwave) link operating at 38 GHz and a meteorological station installed at the same location, as well as earlier DSD data from Kuala Lumpur, are used to validate the findings. Based on the statistical analysis of the measured data samples, DSD parameters are computed using T-Matrix calculations. Specific attenuation of mmwave signals is presented for vertical and horizontal polarisations. Satisfactory results are achieved in comparison with other prediction models. Further, the study separates stratiform and convective rain types using the characteristics of the main DSD parameters. Seasonal variations are studied to elucidate characteristics of DSD in the Asian monsoon region. It is found that DSDs are affected by diurnal convective cycles and seasonal variations in precipitation characteristics. The implications of the variations on specific attenuation are presented. The results of this study will be helpful for the proper design and allocation of the wireless communication system to achieve the expected quality of service (QoS) in Malaysia.

ABSTRAK

Pemerosotan isyarat oleh hujan pada frekuensi melebihi 10 GHz di iklim sederhana dan melebihi 7 GHz di tropika, merupakan faktor penting bagi pereka sistem pautan terestrial dan satelit. Pengetahuan tentang taburan saiz titik hujan (DSD) adalah penting untuk peramalan yang tepat bagi pemerosotan yang dialami oleh gelombang elektromagnetik yang merambat dalam hujan. Ketidaktentuan yang besar wujud pada DSD dan kebergantungannya terhadap jenis-jenis hujan dan rejim klimatologi. Ketidaktentuan ini menjadi lebih kritikal di kawasan khatulistiwa yang mempunyai pengukuran DSD yang terhad. Dalam kajian ini, pangukuran DSD selama dua tahun menggunakan 2D *video distrometer* (2DVD) yang dipasang untuk kali pertama di UTM Johor Malaysia telah digunakan. *Distrometer* ini adalah peralatan termaju yang mampu bukan sahaja untuk mengukur julat DSD yang besar tetapi juga dapat merekod bentuk hujan, nisbah paksi, mod ayunan dan halaju titik hujan, dengan ketepatan yang lebih tinggi. Stesen meteorologi dan pautan gelombang milimeter (*mmwave*) yang beroperasi pada 38 GHz dipasang di lokasi yang sama serta data DSD terdahulu dari Kuala Lumpur digunakan untuk mengesahkan kajian. Berdasarkan analisis statistik sampel data yang diukur, parameter DSD dikira menggunakan pengiraan T-Matrix. Pemerosotan spesifik pada isyarat *mmwave* dibentangkan pada polarisasi menegak dan mendatar. Hasil yang memuaskan diperolehi berbanding dengan model ramalan yang lain. Kajian ini juga memisahkan jenis hujan *stratiform* dan jenis olakan menggunakan ciri-ciri parameter DSD. Variasi musim dikaji untuk menjelaskan ciri-ciri DSD di rantau monsun Asia. Adalah didapati bahawa DSD dipengaruhi oleh kitaran olakan diurnal dan variasi bermusim dalam ciri hujan. Implikasi variasi mengenai pemerosotan tertentu dilaporkan. Hasil kajian ini akan membantu dalam reka bentuk sistem komunikasi wayarles yang tepat untuk mencapai kualiti perkhidmatan yang diharapkan (QoS) di Malaysia.

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LIST OF ABBREVIATIONS

2DVD	-	2D Video Distrometer
DSD	-	Drop size Distribution
EHF	-	Extremely High Frequency
FSA	-	Forward Scattering Amplitude
HF	-	High Frequency
IUT	-	Indoor User Terminal
LF	-	Low Frequency
MJO	-	Maddan - Julian Oscillation
NE	-	Northeast
OU	-	Outdoor Unit
PSU	-	Power Supply Unit
QPE	-	Quantitative Precipitation Measurements
QPF	-	Quantitative Precipitation Forecast
ITU	-	International Telecommunication Union
UTM	-	University Teknologi Malaysia
ITCZ	-	Inter Tropical Convergence Zone
SW	-	Southwest
preNE	-	Pre-Northeast
preSW	-	Pre-Southwest
PDF	-	Probability Density Function
M-P	-	Marshall-Palmer
MoM	-	Method of Moments
MLE	-	Max likelihood estimation
T-C	-	Two component rain attenuation model

CCDF	-	Complimentary Cumulative Distribution Function
XPD	-	Cross-Polar Discrimination
SG	-	Singapore
STD	-	Standard Deviation
Sk	-	Skewness

LIST OF SYMBOLS

γ	-	Specific attenuation
σ	-	Standard Deviation
λ	-	Wave Length
R	-	Rain Rate
P	-	Power
A_R	-	effective aperture
$N(D)$	-	Raindrop size Distribution Function
D_m	-	Mass Weighted Diameter
D_max	-	Maximum Drop Size
D_i	-	Drop size in bin i
D_0	-	Median Diameter
d_a	-	Size Interval
N_0	-	Maximum Raindrop size Distribution
μ	-	Mean Shape Parameter
Λ	-	Slope Parameter
N_t	-	total Concentration
N_w	-	Generalized Intercept Parameter
f_h	-	Horizontal Scattering Amplitude
f_v	-	Vertical Scattering Amplitude

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The significant developments in the radar, earth-space and terrestrial communications, resulted in the development of the wireless transmission media, evolving over low frequency (LF), high frequency (HF), extremely high frequency (EHF) radio, to microwave and millimetre wave transmission, to free space optics, each having its distinct properties, advantages and disadvantages (Proakis *et al.*, 1994; Tomasi, 1987). The availability of wider bandwidths for carrying wireless signals at the millimetre wave spectrum is of major interest for the industry. Such bandwidths are useful for many applications, such as improved anti-jam performance for secure communications, video distribution, high speed data transmission and smaller component sizes (Marcus and Pattan, 2005).

These advantages can however be offset very easily due to increased propagation problems as the frequency of operation increases. Several propagation mechanisms affect these systems performances and constitute a major concern to system planners and designers. These mechanisms include ice depolarization, gaseous attenuation, sky noise, cloud and fog attenuation, rain attenuation and amplitude scintillation. However, attenuation due to rain is the most severe (Crane, 1980; Strangeways, 2006), especially at frequencies above 10 GHz, and particularly in tropical and equatorial regions like Malaysia (Lam *et al.*, 2015). In fact, precipitation causes attenuation due to scattering and absorption of the electromagnetic energy and leads to significant performance degradation.

To understand how this attenuation is influenced by rain parameters, a detailed understanding of the inherent raindrop size distributions (DSD) and the corresponding scattering mechanisms at these operating frequencies is essential (Townsend *et al.*, 2009). DSD is a fundamental microphysical property of precipitation. Understanding the variability of DSD is important for improving quantitative precipitation estimation (QPE) and microphysics parameterization in numerical weather prediction models for accurate quantitative precipitation forecast (QPF) (Milbrandt and Yau, 2005; Raupach and Berne, 2015; Zhang *et al.*, 2006).

The differences in DSD characteristics have been studied around the world using surface disdrometer measurements and are known to vary both spatially and temporally across different precipitation types, atmospheric conditions, geographical locations or climatic regimes, and orography (Thurai *et al.*, 2007; Tokay and Short, 1996; Ulbrich, 1983; Zhang *et al.*, 2006). DSDs are also affected by diurnal convective cycles and seasonal variations in precipitation characteristics. The probable duration of rain, the time of day when it is likely to occur, and how frequently it happens are all important aspects to consider in the design of the wireless communication systems (Allnutt, 1989). It's also found that the climate in the tropics is primarily organized by the intertropical convergence zone and the MaddenJulian oscillation (MJO), and is deeply influenced by monsoons (Zhang *et al.*, 2006).

To that aim, numerous propagation measurement campaigns have been actively carried out to characterise behavior of DSD variation and the resulted rain attenuation experienced by wireless links. However, most of the studies have been concentrated in temperate regions (García-Rubia *et al.*, 2013; Matricciani and Pawlina, 2000; Van de Kamp, 2003) that exhibit different DSD characteristics compared with tropical and equatorial regions. Therefore, characteristics of rain attenuation in temperate regions does not represent the characteristics of tropical and equatorial regions (ITU-R Study Group 3, 2012). Although several propagation studies have been carried in the past few decades at several locations in heavy rain regions such as Brazil, India, Indonesia (Castanet, 2011; Das *et al.*, 2010; Marzuki *et al.*, 2010) and Singapore and even Malaysia (Kumar, 2010; Lam, 2012). However, the features of precipitation in such areas are often dominated by local climatic peculiarities; furthermore, drop size distribution measurement are usually expensive and time consuming and older disdrometer types underestimated the lower end of the distribution due its limitations (Thurai *et al.*, 2016). Additionally, identifying the dominant modes of tropical rain variability still need to be investigated, causing a major source of uncertainty in ground-based, ship-borne, and spaceborne radar rainfall estimation (Raupach and Berne, 2015).

Therefore, this study is carried to explore those crucial statistics in an equatorial site by exploiting the DSD measurements carried out at Universiti Teknologi Malaysia (UTM) in Johor Bahru, Malaysia. The work seeks to determine the regional raindrop size distribution as well as present the statistical variations, and investigate it's corresponding specific attenuation.

1.2 Problem Statement

As mentioned earlier, the differences in DSD characteristics play a major role in the design of wireless communications especially millimetre wave systems. Therefore, several problem statements to be addressed in this thesis work are summarized below:

The knowledge of DSD is essential to make an accurate estimation of the attenuation experienced by electromagnetic waves travelling through rain. Although there have been numerous studies to understand, parametrize and estimate DSD from various locations, however, large uncertainties remain in variability of DSD and their dependence on rainfall types and climatological regimes. (Thurai *et al.*, 2009). Such uncertainties are much more critical in equatorial region where there are only limited experimental results of DSD data. Therefore, it is worthwhile to further investigate and estimate the natural characteristics of DSD in Malaysia with respect to the experimental database available and several well-known DSD models from the established literature.

Besides the estimation of natural characteristics of DSD, attenuation of millimetre wave signal due to rain also can be estimated from the knowledge of rain rates as recommended by ITU-R Recommendation (ITU, 2005). Such estimation provides specific attenuation values directly from the rainfall intensity without the needs of measured DSD data. However, employment of ITU-R recommendation P.838-3 might marked some discrepancies with respect to the calculated values derived from the measured DSD collected from different climatic region (Thurai *et al.*, 2007). Hence, in order to estimate reliable specific attenuation values, it is therefore of key importance to carefully assess the relationship between specific attenuation and rainfall rate from this climatic region directly inferred from the measured DSD.

It is also crucial to investigates the influence of critical seasonal and diurnal variation of the in Malaysia localized climate. on the estimations of the attenuation to help provide better mitigation technique and provide high quality of service.

1.3 Research Objectives

Due to the technology development and the problems mentioned in the previous section, the main goal of this study is to provide valuable information for the millimeter wave propagation channel during rain in Equatorial regions, specifically Malaysia, other main objective are as listed below:

i To characterize the Raindrop Size Distribution (DSD), in Johor, Malaysia, and describe its seasonal variations and its dependency on precipitation types.

ii To analyze specific attenuation, and provide its relationship coefficients with rainfall rate based on the measured DSD.

iii To validate the performance of millimeter wave propagation, with respect to the characteristics of precipitation in Malaysia.

1.4 Scope of Work

The scope of this research consist of two parts, DSD investigation with detailed statistical analysis of it's variation providing all the detailed characteristics of rain physics, and measure the specific attenuation directly from the DSD measurment using advanced T-Matrix Technique, to achieve that the scope points are:

i Analyze and characterize raindrop size distribution from the two-year 2D video disdrometer measurement, collected at Johor, Malaysia.

ii Statistical analyses of raindrop size distribution parameters directly from the measured DSD database, and compare it to other equatorial locations.

iii Inferred the specific attenuation due to precipitation for the millimeter wave frequencies and derived the coefficient of specific attenuation power law model.

iv Analyze the local climatology characteristics (i.e. seasonal and diurnal variations) in equatorial Malaysia based on the one-minute rainfall rate data-set recorded for 2 years.

1.5 Research Contributions

The need for higher band width has urged the use of frequencies above 10 GHz which is in tropical and equatorial regions frequently suffer from severe propagation impairments mainly due to rain. In order to over come these issues, accurate propagation channel models based on accurate estimations are required. To this aim this work mainly focused on characterizing and providing all possible information on the DSD inferred directly form 2DVD data and their variations with detailed classifications and modeling. The following are the points identified to be the main contribution for the requirement of propagation channel modeling:

i The first contribution concerned the statistical properties of raindrop size distribution parameters identified through the local measured raindrop size distribution in equatorial Malaysia. Such parameters are particular importance for the calculation of specific rain attenuation through raindrop size distributions models for the prediction of rain attenuation.

ii The second contribution is the determination of new power-law relationship coefficients between specific attenuation and rainfall rate, which are directly derived from the local disdrometer measurement in the heavy rain region. These new coefficients allowed inferring the values of specific rain attenuation in-both vertical and horizontal polarization.

iii Third Contribution is to provide detailed data on the seasonal and diurnal variations of DSD parameters which can help not only propagation studies, but can be used for meteorological analysis to help better understand the climate in Equatorial regions.

1.6 Thesis Organization

This thesis is presented in five chapters. This chapter presents a brief research background of the investigated topic, identifying the motivations which have led to this research. The scientific objectives and the key contribution in this work are outlined and highlighted with a clear identification of the novel content in the research. The remaining chapters of the thesis are organized as follows.

Chapter 2 begins by discussing the electromagnetic propagation and the atmospheric effect. Detailed physical and microp-physical properties of rain drops are described, followed by a review of raindrop size distribution (DSD) together with its models and the characteristics of specific attenuation and the models used in it's prediction. Main features of climatology characteristic in tropical and equatorial regions, concentrating, in particular on equatorial Malaysia also discussed.

Chapter 3 investigates rain attenuation in an equatorial site by exploiting two years of rain Drop Size Distribution (DSD) measurements collected by a disdrometer in Johor, Malaysia. The methodology of the work is presented in this chapter, the instruments used and the detail maintenance and calibration process. The chapter further introduce data processing steps, the calculation of the main parameters, and database validation.

Chapter 4 focuses on the main characteristic of rain and its microphysical properties in tropical and equatorial regions, concentrating in particular on Johor, Malaysia. Details on the classification of rain types and seasonal variations are given.

Chapter 5 provides an analytical approach to raindrop size distribution and its effect on specific rain attenuation. Similarly, the influence of the disdrometers on specific rain attenuation over millimeter links in Malaysia is also analyzed. On the basis of the different rainfall regimes.

Chapter 6 presents the conclusion and future works. The major works in this thesis are concluded and summarized, followed by some constructive recommendations on the further work given.

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