RAIN PROFILE CHARACTERIZATION AND RAIN EFFECT ANALYSIS OF LAND MOBILE SATELLITE BASED ON MEASUREMENT IN MALAYSIA

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ABSTRACT

Precipitation affects modern satellite communication operating above 10 GHz frequencies causing deep signal fades, particularly in equatorial regions. Many studies had considered the Fixed Satellite Services (FSS), however recent studies show that the same conditions in FSS cannot be applied for Land Mobile Satellite (LMS) systems, as the LMS has completely different characteristics. The receiver of LMS is moving in complex environments where optimal propagation conditions are rarely fulfilled. Past studies on the LMS channel at Ku band and above considered exclusively the attenuation coming from the multi-path effect along the route. Nevertheless, limited attention has been considered to model tropospheric effects on the LMS. Thus, the present study aims to explore the LMS propagation channel operating at Ku and Ka bands, by addressing the problem of rain attenuation for mobile receivers in equatorial Malaysia. Investigated utilizing two years of meteorological radar observation in Kluang, Johor to obtain the rain rate time series for the area. Then the attenuation time series at Ku and Ka band frequencies are calculated. The attenuation results are then verified with link operating at Ku band at 12 GHz of a beacon experimental data to the satellite MEASAT-1, and a Ka band link data operating at 20 GHz, to the satellite Syracuse 3A. A statistical approach has been chosen and a modelling approach has been presented and detailed. The proposed approach builds upon well-established research on rain attenuation time series. Fixed and mobile cases are then simulated to assess the model effectiveness in estimating strong signal fades in equatorial regions. Additionally, we have reported a method to scale the cumulative distribution function, for a given attenuation exceeded in fixed terminals, to that for a given attenuation exceeded in mobile terminals, using simulated city patterns and simulated freeways. the scaling factor for different speeds and probability of directions was presented, ranging between 0.36-0.8 and is 20 percent higher in comparison with temperate regions. The speed of the mobile receiver was modelled as a lognormal random variable. In all cases, the results can be considered frequency-independent. We found that in inner-city roads results depending on movement speed modelling and starting conditions. While in freeways attenuation can change significantly in different straight lines and opposite directions. The movement of rain cells was also considered and a simulation over the radar coverage area was carried with multiple mobile terminals within it. More than three hundred thousand different rain intensity values are generated during the simulation. It was observed that the terminals' disconnection ratio increases with rain intensity almost monotonically. However, for high rain intensities (above 50 mm/h) the exceedance probability is low (around 10^{-4}). Nonetheless, 10 percent of the terminals become disconnected even at relatively low rain intensities (around 20 mm/h). It is shown that this propagation study may provide significant aid, in LMS system simulations and the design and optimization of fade mitigation techniques (FMTs). This work also shows that the LMS system requires unique treatment when designing such systems, taking into account that the channel modelling should study the mobility and the rainfall effects concurrently.

ABSTRAK

Presipitasi mempengaruhi komunikasi satelit moden yang beroperasi pada frekuensi tinggi menyebabkan isyarat mengalami pemudaran yang tinggi, terutama di kawasan khatulistiwa. Banyak kajian tertumpu kepada sistem Fixed Satellite Services (FSS), namun kajian terbaru menunjukkan bahawa kajian ke atas FSS tidak dapat diaplikasikan pada sistem Land Mobile Satellite (LMS), kerana LMS mempunyai ciri yang sama sekali berbeza. Penerima LMS juga bergerak di persekitaran yang kompleks di mana keadaan perambatan optimum jarang dipenuhi. Kajian lepas pada sistem LMS jalur-Ku dan ke atas, mengambil kira secara eksklusif pelemahan dari kesan multi-path di sepanjang laluan. Namun, kajian tidak tertumpu kepada permodelan kesan troposfera pada LMS. Oleh itu, kajian ini bertujuan untuk meneroka saluran penyebaran LMS, dengan menangani pelemahan oleh hujan yang di alami oleh penerima mudah alih di khatulistiwa Malaysia. Kajian melibatkan penggunaan data radar meteorologi selama dua tahun di Kluang, Johor bagi memperolehi taburan kadar hujan siri masa. Seterusnya, pelemahan siri masa bagi jalur frekuensi Ku dan Ka di hitung. Nilai pelemahan isyarat in seterusnya di sahkan dengan pengukuran penerimaan isyarat jalur Ku pada 12 GHz dari satelit MEASAT-1 dan pengukuran isyarat beacon jalur Ka pada 20GHz dari satelit Syracuse 3A. Pendekatan statistik telah di ambil dan pendekatan pemodelan telah dikemukakan dan diperincikan. Pendekatan yang dicadangkan adalah berdasarkan kajian yang mendalam mengenai pelemahan hujan siri-masa. Pendekatan yang di ambil melibatkan penggunaan kajian pelemahan hujan siri-masa yang terkemuka. Simulasi keadaan statik dan bergerak dilakukan untuk menguji keberkesanan model terutamanya bagi keadaan pelemahan hujan yang tinggi di kawasan khatulistiwa. Juga, kaedah penskalaan masa kumulatif pelemahan tertentu bagi terminal statik pada sesuatu masa, kepada nilai pelemahan tertentu bagi terminal bergerak menggunakan corak simulasi bandar dan simulasi lebuh raya telah dilaporkan. Faktor penskalaan bagi kadar kelajuan yang pelbagai dan kebarangkalian pelbagai arah yang diperolehi adalah dalam julat 0.36 hingga 0.8 dengan nilai 20 peratus lebih tinggi berbanding kawasan beriklim sederhana. Kelajuan penerima bergerak telah dimodelkan menggunakan pemboleh ubah rawak lognormal. Keputusan bagi semua keadaan menunjukkan ianya tidak dipengaruhi oleh frekuensi. Didapati bahawa keputusan bagi jalan raya pusat bandar bergantung kepada permodelan kelajuan pergerakan dan keadaan permulaan. Manakala pelemahan di lebuhraya pula menunjukkan perubahan yang sangat signifikan bagi perbezaan pergerakan garis lurus dan arah bertentangan. Simulasi dilakukan dengan melibatkan pergerakan sel, dengan beberapa terminal bergerak dalam kawasan liputan radar yang di kaji. Simulasi melibatkan penjanaan lebih dari tiga ratus ribu kadar hujan yang berbeza. Didapati bahawa nisbah pemutusan terminal meningkat secara monotonus dengan peningkatan kadar hujan. Namun, bagi kadar hujan yng tinggi (melebihi 50 mm/j), kebarangkalian terlampau adalah rendah (sekitar 10-4). Walau bagaimana pun, 10 peratus terminal akan terputus walau pun pada kadar hujan yang rendah (sekitar 20 mm/j). Kajian ini berjaya menekankan kepentingan melibatkan kajian perambatan dalam simulasi LMS dan reka bentuk serta pengoptimum teknik mitigasi pemudaran (FMT). Kajian ini juga mendapati bahawa sistem LMS memerlukan pendekatan tersendiri dalam mereka bentuk permodelan saluran dengan mengambil kira kedua-dua faktor mobiliti dan kesan hujan secara serentak.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

QoS	-	Quality of Service
PIMTs	-	Propagation Impairment Mitigation Techniques
RRM	-	Radio Resource Management
FMT	-	Fade Mitigating Technique
LMS	-	Land Mobile Satellite
UTM	-	Universiti Teknologi Malaysia
ITU	-	International Telecommunication Union
HAPs	-	High Altitude Platform Stations
mmWave	-	Millimetre Wave
1G	-	First Generation Cellular Communication System
2G	-	Second Generation Cellular Communication System
3G	-	Third Generation Cellular Communication System
4G	-	Fourth Generation Cellular Communication System
5G	-	Fifth Generation Cellular Communication System
ECMWF	-	European Centre for Medium-Range Weather Forecasts
ITU-R	-	International Telecommunication Union - Radiocommunication Sector
CCDF	-	Complementary Cumulative Distribution Function
DSD	-	Drop Size Distribution
SST	-	Synthetic Storm Technique
SC	-	Stratiform-Convective
E.M.B	-	Enhanced Maseng-Bakken model
EU	-	European Union
ESA	-	European Space Agency
CAPPI	-	Constant Altitude Plane Position Indicator
NASA	-	National Aeronautics and Space Administration
GPS	-	Global Positioning System
GEO	-	Geostationary Earth Orbit
MEO	-	Medium Earth Orbit
LEO	-	Low Earth Orbit

HEO	-	Highly Elliptical Orbit
EM	-	Electromagnetic
VHF	-	Very High Frequency
UHF	-	Ultra-High Frequency
SHF	-	Super High Frequency
EHF	-	Extremely High Frequency
IEEE	-	Institute of Electrical and Electronic Engineers
WARC	-	World Administrative Radio Conference
FSSs	-	Fixed Satellite Systems
LOS	-	Line of Sight
NLOS	-	Non-Line of Sight
ICD	-	Intercellular Distance
NNICD	-	Nearest Neighbor Intercellular Distance
FSL	-	Free Space Loss
AWGN	-	Additive White Gaussian Noise
RRM	-	Radio Resource Management
MMD	-	Malaysia Meteorological Department
ASCII	-	American Standard Code for Information Interchange
M-P	-	Marshall-Palmer
Z-R	-	Reflectivity – Rain Rate
NE	-	North-East
SW	-	South-West
RG0	-	Rain Gauge 0
RG1	-	Rain Gauge 1
PreNE	-	Pre-Northeast
PreSW	-	Pre-Southwest
USRP	-	Universal Software Radio Peripheral
FFT	-	Fast Fourier Transform
RBW	-	Resolution Bandwidth
C/N0	-	Carrier-to-Noise-Density Ratio
2DVD	-	2D-Video-Distrometer
OPEX	-	OLYMPUS Propagation Experiment

LIST OF SYMBOLS

$A_{0.01}$	-	Attenuation Exceeding 0.01% of the Year
γ	-	Specific Attenuation
L_E	-	Effective Length
R	-	Rain Rate
$R(\mathrm{P})$	-	Rain Rate Profile
$R_{\max}$	-	Peak Rain Rate
k	-	Shape Factor
x_0	-	Location of Ground Station
Δx	-	Shift that Account the Path from x_0
H	-	Rain Height
m	-	Mean
σ	-	Standard Deviation
Z	-	Reflectivity
R_i	-	Effective Radius of Cell *i*
x_i, y_i	-	Position of the Barycenter *i*
d_A	-	Actual Distance
k , α	-	Power Law Coefficients
$p_{straight}$	-	Probability of straight line
$p_{left,right}$	-	Probability of changing direction
$P_F(A)$	-	Cumulative probability that the same value of attenuation *A* is exceeded in the fixed system
$P_M(A)$	-	Cumulative probability that the same value of attenuation *A* is exceeded in the Mobile system
ξ	-	Scaling Factor
$A(\theta_0)$	-	Attenuation Value at specific angle θ
$\bar{R}$	-	Mean Rain Rate
R_{rms}	-	Root mean square rain rate
R_{th}	-	Rain Rate Threshold

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Our generation has witnessed a revolution in wireless communication systems. A long time has already passed since the first mobile services were introduced to the public in the 1980's and the 1990's, and nowadays cell phones and wireless networks can be found everywhere. People expect to have a mobile connection and fast internet access wherever they go. For this reason, current and future telecommunication markets are pushing towards wide bandwidth with high-speed data rates due to the increasing demand from the end user and the congestion of the lower frequency bands. Thus, telecommunication service providers are required to offer the systems that operate at high frequencies, typically in the Ka band (20 GHz) and above Q/V bands (40/50 GHz) [1].

With rapidly growing telecommunication technologies, a mobile receiver with high data throughput becomes more and more important. Terrestrial mobile communications infrastructure has made deep inroads around the world. Even rural areas are obtaining good coverage in many countries. However, there are still geographically remote and isolated areas without good coverage, and some countries do not yet have coverage in towns and cities. On the other hand, satellite mobile communications offers the benefits of true global coverage, reaching into remote areas as well as populated areas. This has made them popular for niche markets like news reporting, marine, military and disaster relief services. However, until now there has been no wide-range adoption of mobile satellite communications to the mass market.

Current terrestrial mobile communication systems are inefficient in the delivery of multicast and broadcast traffic, due to network resource duplication (i.e. multiple base stations transmitting the same traffic). Satellite based mobile communications offers great advantages in delivering multicast and broadcast traffic because of their intrinsic broadcast nature. The utilization of satellites to complement terrestrial mobile communications for bringing this type of traffic to the mass market is gaining increasing support in the standards groups, as it may well be the cheapest and most efficient method.

Current mobile satellite communication systems however often suffer from poorer Quality of Service (QoS) due to high path loss, shadowing, blockage, tropospheric effects, limited satellite power and high link delay. Unfortunately, even with state of the art high power satellites with narrow spot beams or multiple satellite constellations, link availability is not always possible when the signal is blocked by buildings, and indoor coverage is often poor. With future satellites providing substantially more radiated power and possibly using diversity techniques, users may someday perceive the same QoS from a satellite or terrestrial communication system. However there is a long way to go before this is achieved. Satellite communication system operators are always trying to achieve adequate QoS with the minimum fade margin (and therefore cost). A figure of 16.5 dB was used in the Iridium constellation system [2]. However, signal blockage can easily be 30 dB or more, and the link would be dropped. Even with multiple satellites offering satellite diversity, signal availability is not guaranteed.

The future mobile satellite systems will provide some major changes to the current systems. It will be designed to deliver higher capacity with the use of higher frequency band [3,4], such frequencies will suffer from the strong attenuation phenomena due to atmospheric effects. Among these, rain is the certainly dominant impairment that limits the reliability and high availability of the system. In fact, this phenomenon is particularly significant in the extremely heavy rain region (i.e. equatorial regions) [5]. In this situation, signal fades due to the rain can no longer be overcome by static power margins, instead application of advanced Propagation Impairment Mitigation Techniques (PIMTs) are necessary [6].

The implementation of such smart strategies as well as the design of modern telecommunication system requires the detail’s knowledge of precipitation characteristics. Temporal dynamics of the propagation channel is highly dependent on the dynamics of rain events. On the other hand, the knowledge of spatial rain structures over specific range of distance can serve as a crucial input for the mobile satellite channel model when optimizing the Radio Resource Management (RRM) to obtain high traffic throughput with a given limited resources. In fact, such information shows it might vary from location to location, specifically in tropical/equatorial region with high intensity rain localized in a small area.

To this end, various research projects aimed at tackling these issues being actively carried out. Unfortunately, most of the studies are concentrated in temperate regions which exhibit much lower rainfall intensity with respect to the tropical/equatorial regions. In fact, the findings or model proposed for the temperate region might not reflect the dynamics and actual rainfall structure in equatorial and tropical areas. Although several propagation studies have been carried in the past few decades at several locations lying in heavy rain regions such as Brazil, India, Indonesia and Singapore [7]–[9], however, most of the studies focused mainly on fixed services rather than mobile terminals.

As a consequence, spatial and temporal properties of precipitation in these heavy rain regions remain as interesting topics to be explored by the propagation communities. This work will discuss the rain attenuation effects, as the rain will remain the biggest challenge, especially in tropical regions such as Malaysia [10], [11].

1.2 Problem Statement

Variations in the atmospheric condition have a major effect on earth-sky channel performance, particularly at frequencies above 10 GHz [10], [11]. Rain attenuation at Ku-band has a dominant impact on signal attenuation in space, followed by cloud attenuation [12]. Consequently, such channel impairments increase the need for developing channel models to predict the atmospheric fade level and for proposing a proper Fade Mitigating Technique (FMT). Raindrops and cloud content of liquid water absorb and scatter signal energy, resulting in degradation of performance level of instantaneous energy to certain values, depending on the instantaneous weather parameters.

Channel modelling for Land Mobile Satellite (LMS) systems that incorporates weather dynamics effect has recently gained interest for frequencies above 10 GHz [8]. Atmospheric variations are higher in tropical regions than in temperate areas because of their different weather parameters [10], [14]. Consequently, recent advances in satellite communication technologies in the tropical regions have led to significant increase in the demand for services and applications that require high channel quality for mobile satellite terminals [13]. Several rain attenuation prediction models [14]–[17] have been developed and have gained worldwide acceptance. These models were developed through many years of monitoring and observations and were proposed for application to temperate and tropical regions. However, some studies [5], [18]–[20] proved that these models have a significant inaccuracy level when applied to tropical regions on the basis of their specific atmospheric parameters. Moreover, the signal propagated in the satellite communication link is affected by cloud impairments. Cloud effect should be considered in the design of LMS channel models for frequencies above 10 GHz; otherwise, serious problems may be encountered because of the inaccuracy of the model, particularly during cloudy weather [18]. Clouds in tropical regions are more dense and cause more attenuation than those in temperate regions [15].

Channel dynamics, along with the lack of an accurate and reliable channel model for satellite networks in tropical regions, increase the need to develop a channel model for these regions to replace the existing channel models that were previously developed in temperate regions. Thus, the effective atmospheric impairments in the tropical regions, namely, rain, cloud, and tropospheric scintillation, on the channel performance and quality should be considered to index the atmospheric fade level and to select a suitable FMTs.

Subsequently, more accurate weather impairments modelling for mobile terminal in tropical regions becomes a necessity and a challenge because the model should approach the realistic measured channel impairments under different weather conditions. In addition, channel impairment measurement campaigns have not been conducted yet for mobile terminal scenario at Ku-band; therefore, measurements of LMS channel performance under a rainy environment are highly needed and can be added to the global database. Such measurement campaign can be used to recognize the accuracy of the proposed channel models. Moreover, rain-induced attenuation calculated in these measurements can be easily scaled to investigate the channel condition using different frequencies and movement speeds as well should be considered in the design of the impairments produced in LMS systems.

1.3 Research Objective

In regards to recent technological advances and problems mentioned above, the main goal of this study is to provide critical information for the propagation channel model in space and time for land mobile satellite (LMS) services in equatorial areas, particularly in Malaysia. More specifically, the main research objectives are listed below:

1. To analyse the rainfall statistics and rain cell characteristics based on measured weather radar data in Malaysia.
2. To investigate the rain effects on Land Mobile Satellite Links links and develop scaling model to predict the induced attenuation from measurements of fixed satellite terminals.
3. To evaluate the performance of Land mobile satellite links in different scenarios in tropical climate and provide a criterion for the improvement in site diversity technique.

1.4 Research Scope

This study focusses on the rain attenuation effects on LMS communication systems in a tropical region, namely Malaysia, based on two years data (2007-2008) obtained by the metrological radar station in Kluang, Malaysia, and verified by several tipping bucket rain gauges located in Universiti Teknologi Malaysia (UTM) Skudai. Additionally, The results are verified with link operating at Ku band at 12 GHz of a beacon experimental data collected at Kuala Lumpur to the satellite MEASAT-1 in the year August 1996 to July 1999, and a Ka band link data operating at 20 GHz collected in Johor, to the satellite Syracuse 3A, in the period 2015-2016. The datasets used in this study are described in Table 1.1.

Table 1.1 Datasets used in the study.

Dataset	Description	Time period of dataset	Reason of dataset use
Metrological Radar images	S-band weather radar managed by Malaysia Meteorological Department located at Kluang, Johor (latitude 2.02° N, longitude 103.3° E), Malaysia. The database consists of 69,351 rainfall maps.	2 years dataset 2007 -2008	First it was used for the analysis and modelling of horizontal structure of rain cells. Then the horizontal structure was extended to 3D area to simulate the coverage of LMS System
Satellite Link 1	link operating at Ku band at 12 GHz of a beacon experimental data collected at Kuala Lumpur to the satellite MEASAT-1	August 1996 to July 1999	To evaluate the statistics of rain attenuation on 12 GHz links in tropical regions. Then to be used for the simulation of LMS links scenarios and compare and verify the results
Satellite Link 2	Ka band link data operating at 20 GHz collected in Johor, to the satellite Syracuse 3A.	2 Years 2015-2016.	To evaluate the statistics of rain attenuation on 20 GHz links in tropical regions. Then to be used for the simulation of LMS links scenarios and compare and verify the results

Tipping bucket rain gauges	3 rain gauges that are installed on the same roof as the satellite link 2. With different time periods	RG0 3Years 1998-2000 RG1 3Years 2015-2018.	To generate the time series of rain rate and compare it with the time series of rain attenuation to verify the records of the link. Further, it was used to compare point rain rate statistics to radar coverage rain rate statistics

The research scopes are:

1. Analyse the local climatology characteristics (i.e. seasonal and diurnal variations) in equatorial Malaysia based on the one-minute rainfall rate dataset recorded for 3 years.

2. Further improve currently available rain attenuation models for the LMS communication application which reproduces the physical mechanism underlying the precipitation-attenuation phenomena as much as possible in this heavy rain region.

3. Validate the performance of the proposed model with respect to the beacon measurement results from the MEASAT satellite and Syracuse 3A.

4. Exploit the new proposed model to demonstrate the performance of LMS system in the heavy rain region.

5. Asses the performances of LMS systems in equatorial Malaysia through the all-weather radar images.

6. The analyses in this thesis work focus on several frequencies in Ku, Ka and Q/V band, such as, 12 GHz (MEASAT satellite) , 18.9 GHz (WINDS satellite), 20 GHz and 30 GHz (common operating frequency in Ka band) , 28 GHz (downlink frequency allocated by ITU to High Altitude Platform Stations (HAPs) in

Malaysia), 48 GHz (Q/V band frequency that is planned to be used in the next future for satellite services).

7. The locations of the analyses in this work are restricted only to the locations in Peninsula Malaysia covered with Kluang meteorological radar station and southern peninsula Malaysia (Johor) for rain gauge verification and satellite links.

Ultimately, the work done here is intended to provide the necessary procedure to follow when designing higher-frequency LMS communication links in tropical regions. The data collected and the result presented will be highly beneficial to the design and execution of LMS links.

1.5 Research Contributions

The Mobile satellite communications will play a significant role in the 5th generation mobile services. The use of high-frequency bands will be the enabler of this advancement. However, at high frequencies, excess rain attenuation causes severe signal losses and presents a major threat for the system availability, especially in the tropical region. To that end, this study presents the rain attenuation impact on mobile satellite communications estimated using long-term radar measurements in Malaysia, by exploiting the horizontal structure of rain from the radar database and simulating inner-city and highway mobile terminals scenarios. The following are the points identified to be the main contributions:

1. The first contribution concerned the characterization of rain intensity distribution and temporal and spatial characteristics of rain cells from the weather radar measurement at equatorial Malaysia. Such parameters are particular importance for the calculation of rain induced attenuation for the design of rain attenuation models. These parameters are presented for the first time in the content of LMS link scenarios on maps created based on radar database in Malaysia.

2. The second contribution is to develop an appropriate rain attenuation model for land mobile satellite communication application in equatorial Malaysia. The main

advantage of this model lies in its adaptability to the local precipitation physical mechanisms which can be extended to any other equatorial site. A scaling factor is presented for the first time in equatorial region, with details on the use of it with different LMS scenarios. The factor can be used to calculate the expected rain attenuation on LMS link by scaling the available fixed link data.

3. The third contribution investigating the availability of the LMS system during different rain scenarios, which can serve in selecting a mitigation technique to maximize data throughput for future systems, based on the defined model. Several scenarios were simulated and the availability of an entire LMS system was presented.

4. The Fourth contribution to this work is the demonstration of the performance effectiveness in LMS system operating in the equatorial region assessed by means of weather radar images. In addition, such radar resources have proven to provide useful and reliable indications of the large-scale spatial distribution features of local precipitation for the simulation of advanced PIMTs techniques.

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 discussed the main features of climatology characteristic in tropical and equatorial regions, concentrating, in particular on equatorial Malaysia. A review of the LMS systems together with its models and the characteristics of specific attenuation with respect to radio wave propagation are given next followed by the main slant path attenuation prediction models that has been developed and proposed in the literature so far. Spatial characteristics and its well-known model currently available are also presented in terms of spatial distribution. Finally, some brief introductions of propagation impairment techniques currently used by the advanced satellite communication system are reviewed.

Chapter 3 presents the methodology followed in this work as well as an investigation on the statistical properties of the rain. To this aim, radar derived rainfall database from meteorological Malaysia located at Kluang, Johor are employed, from which the characteristics of actual rain cells are extracted and investigated. This analysis also permits the determination of the most suitable synthetic rain cell analytical profile that preserved the actual spatial characteristics of the rain cells. Finally, large numbers of the weather radar images are employed for the investigation of satellite systems performances operating in the equatorial region.

Chapter 4 investigates the relation between LMS and tropical rainfall effects and develop a rain attenuation model for LMS communication application in equatorial Malaysia, the model is then tested in multiple scenarios and the properties of rain attenuation in equatorial Malaysia is exploited. Then, the evaluation of the impact and performances of the system with respect to the temporal dynamic and spatial characteristics of precipitation in equatorial regions model is done. Further the availability of LMS system is investigated, to maximize the availability of the LMS system in general.

Chapter 5 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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APPENDIX A

LIST OF PUBLICATIONS

A.1 Journals

Abo-Zeed M, Din J, Shayea I, Ergen M. Survey on land mobile satellite system: Challenges and future research trends. IEEE Access. 2019 Sep 17;7:137291-304.

Abozeed MI, Alhilali M, Yin LH, Din J. Rain attenuation statistics for mobile satellite communications estimated from radar measurements in Malaysia. Telkomnika. 2019 Jun 1;17(3):1110-7.

Shayea, I, Nissirat, LA, Abozeed, MI, et al. Rain attenuation and worst month statistics verification and modeling for 5G radio link system at 26 GHz in Malaysia. Trans Emerging Tel Tech. 2019; 30:e3697.