SCINTILLATION MODELLING FROM SATELLITE TO EARTH LINK AT KU BAND

BY

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ABSTRACT

Fast evolution in new satellite services, for instance VSAT for internet access, LAN interconnection, multimedia applications has triggered an increasing demand of bandwidth usage for satellite communications. But, these systems are susceptible to propagation effects that become gradually significant as the frequency increases. The propagation measurements at frequencies above 10 GHz have been carried out widely in the temperate climatic region where most of the advanced and established countries are situated. This is different in the tropical countries where the data coverage for these countries are insufficient, even though they have much more complex and unpredictable climatic behavior compared to the temperate region.Scintillation is the rapid signal fluctuations of amplitude and phase of a radio wave which is significant in tropical climate. This thesis presents the data analysis of the tropospheric scintillation for satellite to earth link at Ku-band. 12 months (January 2011 till December 2011) data were collected and analyzed to evaluate the effect of tropospheric scintillation. The measured scintillation statistics were subsequently compared against six scintillation prediction models which include Karasawa, ITU-R, OTUNG, Van de Kamp, Ortgies-T and Ortgies-N. The findings show that the Ortgies-N has the lowest RMS error for the scintillation fades, with 34.3% whereas Van de Kamp has the lowest RMS error for the scintillation enhancements with 39.2%. The statistics were then further analyzed to inspect seasonal, worst-month, diurnal and rain induced scintillations. The scintillation studies are essential especially when predicting link quality for particular types of services. For instance, to fully evaluate the influence of scintillations on certain types of digital services, it is required to identify not only the total fade time but also the distribution of the durations of the individual fades. By using the measured scintillation data, a modification of the Karasawa model for scintillation fades and scintillation enhancements is proposed based on data measured in Malaysia.

ملخص البحث

التطور السريع في مجال الخدمات الفضائيه الجديده، على سبيل المثال VSAT لتشغيل الانترنت وشبكة الربط المحليه و تطبيقات الوسائط المتعدده ادى الى زيادة الاحتياج لاستخدام النطاق الترددي للاتصالات الفضائيه. ولكن، هذه الأنظمة تنتشر وتزداد اهميتها تدريجيا كلما ازداد التردد. وقد اجريت قياسات الانتشارعلى تردد فوق 10 غيغاهيرتز بشكل واسعفي المنطقة المعتدلة المناخ حيث تقع معظم الدول المتقدمة والحديثه. وهذا يختلف عنه في الدول الاستوائيه حيث تغطية البيانات لهذه الدول ليست كافيه على الرغم من ان لديها مناخ معقدا لا يمكن التنبؤ به مقارنة مع المنطقه المعتدله. الوميض هو الاشاره السريعه لتقلبات سعة ومرحله التموجات الكهرومغناطيسيه ذات الاهميه في المناخ الاستوائي. هذه الدراسه تقدم تحليل بيانات الوميض التروبوسفيري للاقمار الصناعيه لربط الارض بالنطاق Ku. في هذه الدراسه، البيانات جمعت و حللت في زمن مدته 12 شهرا (يناير 2011 - ديسيمبر 2011) لتقييم تأثير الوميض التروبوسفيري. فيما بعد تمت مقارنة احصائيات الوميض بسته نماذج تنبؤيه بالوميض والتي تشمل Karasawa، الاتحاد الدولي للاتصالات-R (ITU-R)، OTUNG، فان دي كامب، Ortgies –T و Ortgies –N. النتائج تدل على ان Ortgies-N لديها ادنى خطأ (34.3%) RMS لتلاشئ الوميض بينما فان دي كامب لديها ادنى خطأ (39.2%) RMS لتعزيز الوميض. ومن ثم، تم القيام بتحليل اضافي لتفقد الوميض الناتج عن اسباب موسميه، اسؤ شهر، النهار والمطر. فمثلا، عند تقييم تأثير الوميض على انواع معينه من الخدمات الرقميه تقييما كاملا فان ذلك لايتطلب تحديد الوقت الاجمالي للوميض فقط ولكن ايضا توزيع مدة الومضه الواحده المفرده. بأستخدام بيانات الوميض المقاسه تم اقتراح اجراء تعديلات على نموذج تلاشؤ وتعزيز الوميض بناءا على المعلومات المقاسه بماليزيا.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science Communications Engineering.

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Nadirah Binti Abdul Rahim

Signature………………………...……   Date……………………………..

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Signature	Date

I dedicate this research work to my beloved parents, Abdul Rahim and Sithi Khadheejah, siblings,Nazimah, Afifah, lecturers and friends. Thank you for your love, perseverance, advices and supports. Special dedication to my beloved niece, Aleesya who has been my constant inspiration and motivation whom has never failed to lift up my spirits. When the going gets tough, she is the reason I get tough to get going. May this research work benefits all of us. InsyaALLAH.

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LIST OF SYMBOLS

p	Atmospheric Pressure in Millibars (mb)
e	Water Vapor Pressure in Millibars (mb)
T	Temperature in degree K
X	Log Amplitude in dB
σ_X^2	Scintillation Variance
A	Signal Amplitude
$\langle A \rangle$	Mean Signal Amplitude
ΔA	Zero-Mean Fluctuating Signal Component
σ_{pre}	Predicted Signal Standard Deviation or “Scintillation Intensity”
f	Frequency in GHz
ε	Apparent Elevation Angle
$\mathrm{G}(D_c)$	Antenna Averaging
D_c	Effective Antenna Diameter
D	Geometrical Antenna Diameter
η	Antenna Aperture Efficiency
N_{wet}	Relative Humidity in Percentage due to Water Vapor in the Atmosphere
h	Height of the Turbulence
R_e	Effective Earth Radius
$n(p\,-)$	Time Percentage Factor of Scintillation Fades
$n(p\,+)$	Time Percentage Factor of Scintillation Enhancements
$X(p\,-)$	Scintillation Fades
$X(p\,+)$	Scintillation Enhancements
e_s	Saturated Water Vapor Pressure
L	Effective Path Length
D_{eff}	Antenna Diameter
$g(x)$	Antenna Averaging Factor
$a(p)$	Time Percentage Factor of Scintillation Fades
$A_s\,(p)$	Scintillation Fade Depth
X_{-a}	Scintillation Fadesof Annual
X_{+a}	Scintillation Enhancements of Annual
X_{-w}	Scintillation Fadesof Worst Month
X_{+w}	Scintillation Enhancements of Worst Month
W_{hc}	Average Water Content of Heavy Clouds $[kg/m^2]$
Q	Long-Term Average Parameter
$a_1(p)$	Time Percentage Factor
$a_2(p)$	Time Percentage Factor
$E_p(p)$	Scintillation Enhancements
$a_p(p)$	Scintillation Fades
x	Constant
$\sigma_{measured}$	Measured Scintillation Intensity

LIST OF ABBREVIATIONS

RMS	Root Mean Square
CD	Cumulative Distribution
CDF	Cumulative Distribution Function
dB	Decibels
GHz	GigaHertz

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

The use of satellites for communication purposes has increased conspicuously in order to fulfill the growing demand for the long distance communication (Timothy Pratt, 2003). The importance of satellite communication is that it is essentially used for the commercial purposes such as the voice services, the data transfer services, and etc. It is used for accessing the corporate resources, sending emails and browse internet. It can also be used to communicate through a very high quality voice compression without considering location across the globe (Timothy Pratt, 2003).

When one wants to communicate or to access to information regardless of the location of the information, wireless communication then comes in handy (Maral *et al.*, 2010). Nowadays, the utilization of higher band such as Ku-band (12/14 GHz) is in high demand since the lower frequencies are congested (M.Akhondi *et al.*, 2005). In Ku-band, the performance of the satellite systems basically depends on the propagation characteristics of the transmission medium that is the troposphere layer. Some of the significant tropospheric propagation effects are attenuation due to rain, depolarization, gas absorption and scintillation due to atmospheric turbulence (M.Akhondi, *et al.*, 2005). Though rain has the main impact on communication systems, scintillation now becomes significant for low-margin systems at high frequencies and low elevation angles (M.Akhondi, et al., 2005).

There are many phenomena that lead to loss of signal transmission through the earth's atmosphere. One of them is scintillation.

Scintillation is resulted from scattering atmospheric refractive index discontinuities. Thus, resulting in random fades and enhancements of the received signals amplitude about a mean level. It is one of the main sources of degradation that poses risk especially to low margin satellite communications systems operating at frequencies above 10 GHz (Mandeep et al., 2007b; Otung, 1996a). All contributions which lead to signal fluctuations by other propagation factors must be excluded before using the measured raw propagation data for scintillation studies (Otung, 1996b).

There are two types of scintillations. There are ionospheric scintillation and tropospheric scintillation. Ionospheric scintillation occurs when the irregular fluctuations or scintillation of amplitude, phase and angle of arrival are observed on radio waves propagating through the ionosphere (Crane, 1977). The ionosphere is assumed to cause little or no scintillation at frequencies above 10 GHz. Studies to determine the distribution of scintillation amplitude has been carried by many researchers.

At Ku-band, K-band and Ka-band frequencies, scintillation of satellite-to-ground propagation is due mainly to the troposphere, which lies within 10 kilometers above the earth's surface (Otung *et al.*, 1998). Tropospheric scintillation occurs because of dynamic small-scale variations in the index of refraction of the propagation medium along the propagation path. The main cause of scintillation, especially large scintillation magnitudes, is the moisture content and the turbulent mixing of the moisture content in the atmosphere; hence, relative humidity is the major parameter for many of the models. Rain, clouds, wind, multipathing, and even the size of the antenna and wavelength affect scintillation characteristics (Otung, et al., 1998). Scintillation is modeled as originating from a relatively moist and turbulent layer called the planetary boundary layer (Otung, et al., 1998).

The planetary boundary layer, otherwise called the turbulent layer, is tens to hundreds of meters thick and has an altitude between 0.5 to 5 kilometers (Otung, et al., 1998). Scintillation happens continuously, regardless of whether the sky is clear or rainy. However, in rainy conditions, signal-level fluctuations due to scintillation will accompany signal-level attenuation caused by the rain. Therefore, special attention should be given when analyzing scintillation data during rainfall (Moulsley *et al.*, 1982). This research will be focusing on the tropospheric scintillation. The aim of this research is to compare and develop tropospheric scintillation models that can fit with Malaysia’s tropical climate. The findings will be beneficial to the designers and engineers who are planning to build satellite with similar positioning and environmental conditions

1.2 PROBLEM STATEMENTS AND ITS SIGNIFICANCE

There are several scintillation models developed by the researchers in the past. However most of them were not developed for tropical countries. Most of these scintillation models were tailored for countries with four-season-climate. These models were based on data collection from countries like Japan, Germany, Finland, United Kingdom, US and etc. These models may not be applicable for tropical countries like Malaysia, Indonesia, Thailand, Singapore and etc. This is because these countries have different patterns of climate compared to the countries with four seasons. The tropical countries have mainly uniform temperature, high humidity and copious rainfall. So far, there have been very limited researches carried out on scintillation in tropical countries. Recent measurement carried out in Malaysia did not fit with any existing scintillation models (J. S. Mandeep, 2011; Mandeep *et al.*, 2007a; Mandeep, *et al.*, 2007b; Mandeep *et al.*, 2008; J.S. Mandeep *et al.*, 2011; Jit Singh

Mandeep, 2011; Jit Singh Mandeep, Anthony Cheng Chen Yee, *et al.*, 2011; Jit Singh Mandeep & RM Zali, 2011). Hence, scintillation models need to be further investigated based on scintillation data measured in tropical country. Scintillation data from tropical climatic countries are very limited especially at high elevation angle. Therefore, it is an urgent need to develop suitable scintillation prediction model based on data measured in tropical country. The reason being is that the scintillation fades can disrupt the operation of low-margin communications systems (Mandeep, 2009). Moreover, signal distortion and intermodulation noise could occur when sufficiently large scintillation enhancements drove the satellite transponder into its non-linear region of operation hence causing link failures (A.Ghorbani *et al.*, 2003).

1.3 RESEARCH OBJECTIVES

The **main objectives** of the research are:

1. To analyze the tropospheric scintillation data at Ku-band satellite to earth link from MEASAT 3 Downlink at high elevation angle
2. To enumerate the seasonal, monthly and diurnal variations and rain effects of the tropospheric scintillation
3. To analyze the scintillation fades and scintillation enhancements and compare against six available scintillation predictions models
4. To develop suitable scintillation fades and scintillation enhancements models at Ku-band based on the tropical characteristics and high elevation angle using measured scintillation data

1.4 RESEARCH METHODOLOGY

The research methodology’s flow chart is shown in Figure 1.1. Before performing any data processing, literature reviews on the definition of the tropospheric scintillations and the existing scintillation models were carried out. Next, the measured scintillation data (January 2011 till December 2011) were analyzed in this research. The main tool used for this research was MATLAB. The scintillation data were filtered and analyzed. The graphs were plotted using the same tool. The scintillation data were collected at International Islamic University Malaysia, at Block E2, Level 4, Satellite Lab, Kulliyyah of Engineering (3° 15’ N/ 101° 43’ E). The experimental setup diagram is shown in Figure 3.1. The measured scintillation data were compared against six scintillation prediction models. From the analysis, new scintillation models were developed using the measured scintillation data

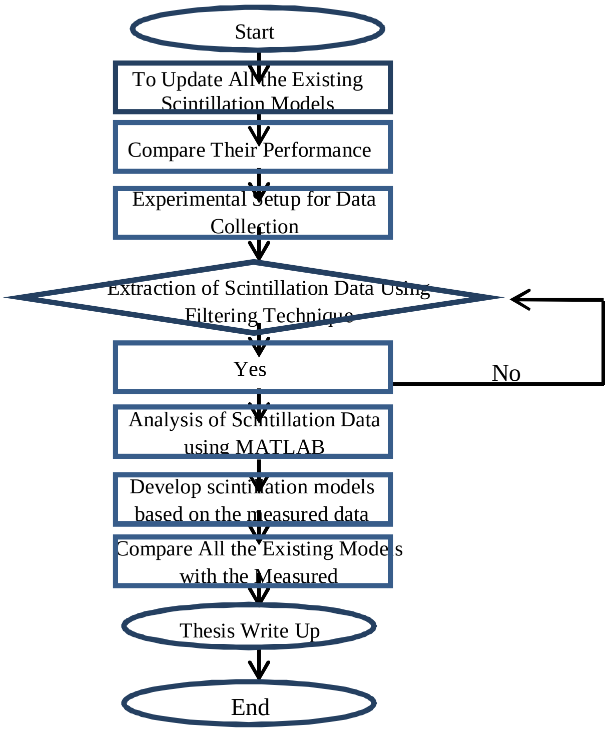

Figure 1.1 Research Methodology Flowchart

1.5 RESEARCH SCOPE

This research was focused on scintillation data that were experienced by MEASAT 3 Downlink at Ku-band. Besides that, this research focused on the statistical analyses of the measured scintillation fades, scintillation enhancements and scintillation intensity. The research also included analysis of the seasonal variations, worst-month, diurnal variations and rain induced scintillations. Moreover, the cumulative distribution functions of scintillation fades and enhancements were computed. These were compared with available scintillation prediction models. Furthermore, the percentage fractional error and RMS error were calculated for both scintillation fades and enhancements of the particular models to the measured scintillation data in the attempt to identify the better models. Lastly, modified new models for both scintillation fades and enhancements were developed.

1.6 THESIS ORGANIZATION

This dissertation is divided into six chapters. Chapter one discusses on the introduction of scintillation. Furthermore, it entails on the problem statements and its significance, research objectives, research methodology and research scope. Chapter two explains on the radio wave propagation mechanisms, the theoretical study and background of scintillation around the world. Chapter three elaborates on the research methodology and how the research was carried out in details. Chapter four explains about the results and analysis. It also discusses on the statistical analyses of both scintillation fades, scintillation enhancements and scintillation intensity which includes seasonal variations, worst month variations, diurnal variations and rain induced scintillations. Moreover, this chapter also compares the six models comprising Karasawa (Karasawa, Yamada, *et al.*, 1988) , ITU-R (P.618-10 2009), Otung (Otung, 1996b), Van de Kamp (Van de Kamp *et al.*, 1999), Ortgies (Ortgies, 1993) against the measured scintillation data. Chapter five describes about the percentage fractional error and RMS error of each prediction model and comparison made against the measured scintillation data. It also explains on the new modified scintillation fades and scintillation enhancements developed using the Karasawa model. Furthermore, the validation test was conducted on the new modified scintillation fades and scintillation enhancements models using the other measured scintillation data. Finally, this thesis ends with chapter six where it provides conclusion and as well as recommendations of future works.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter introduces the overview of satellite communications. The chapter discusses description of radio wave propagation mechanisms in space communication. It also further discusses on the definition of the tropospheric scintillation, the scintillation parameters and also the theoretical background of the scintillation prediction models that have been proposed by other researchers.

2.1 OVERVIEW OF SATELLITE COMMUNICATIONS

A satellite is an active transmission relay, which has the same function as relay towers used in terrestrial microwave communications (Jr., 2008). In less than 50 years, the commercial satellite communications industry has advanced from an unconventional exotic technology to a mainstream transmission technology which can be used in all elements of the global telecommunications infrastructure. Nowadays, satellite communications are able to provide humongous services which involving data, voice, video and even offers services to fixed, broadcast, mobile, personal communications and private network users (Jr., 2008). A number of features are available and offered by satellite communications which cannot be offered by the alternative modes of transmission, for instance terrestrial microwave, cable or fiber networks. The advantages of satellite communications are: