TIME DIVERSITY ANALYSIS FOR RAIN FADE MITIGATION IN SATELLITE LINKS BASED ON RAIN RATE DATA

BY

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ABSTRACT

Earth–to-satellite links are highly affected by propagation impairments by rain especially those operating at frequencies higher than 10 GHz. The satellite communication system performance suffers from severe degradation at high frequencies in tropical and equatorial climate. Time diversity is one of the workable technique with suitable time delay between successive transmissions which is proposed by many researchers to mitigate rain fade. However, time diversity analysis requires measured rain attenuation data. For future high frequency link design those data are not available at most of the places. Time diversity gain prediction model was proposed by the measured rain attenuation for time diversity improvement which is analyzed by the rest of researchers.

Rain rate data were measured using real-time rain gauge for one-year period at IIUM for 2014. A new concept of rain rate with and without time delay is introduced with appropriate equations. Based on the rain attenuation equation with time delay, the complementary cumulative distribution function of rain rate with time delay is presented. One month measured rain rate and rain attenuation is used to verify this concept. The rain attenuation prediction model proposed by ITU-R is used to estimate rain attenuation gain analytically. The analytically obtained gain is compared with measured gain and found close agreement. Hence, this concept has shown that attenuation gain can be easily estimated by using rain rate. A time diversity gain (G_A) model is derived based on 1 year measured rain rate in Malaysia. In proposed model, it is used three variables namely rain rate, time delay and frequency. Firstly, rain rate and time delay functions are used together, and constants are derived by regression from rain rate and rain rate gain. Secondly, constant for frequency function is derived from Cumulative distribution function of attenuation predicted by ITU-R and gain obtained analytically. These two functions are combined together and the proposed model of attenuation gain (G_A) is developed. The proposed model is validated using one-year rain rate and rain attenuation data measured at two locations in Malaysia and one location in Japan. The gain predicted by proposed model is almost same with measured gain for Malaysia and the maximum discrepancy is found 8%. It overestimates the measurement in Japan and the maximum error is 34%. However, the rain rate is 40 mm/hr measured in Japan, while it is 125 mm/hr in Malaysia at 0.01%. Analysis shows that the performance of proposed model is more accurate better than model proposed by Matricciani. Hence the proposed model is recommended to use in future for earth to satellite link design by using measured rain rate at any higher frequencies.

خلاصة البحث

تتأثر الوصلات الأرضية إلى الأقمار الصناعية تأثراً شديداً بضعف التوصيل والانتشار بسبب المطر بشكل خاص عندما تعمل بذبذبات أعلى من 10 ميكاهيرتز. ولهذا فإن أداء منظومة التوصيل للأقمار الصناعية تعاني من تدهور وضعف شديد في الذبذبات العالية في المناخ الاستوائي. إن اختلاف الزمن وتنوعه هو أحد التقنيات العملية مع زمن تأخير مناسب بين إرسالين متتاليين والتي تم اقتراحها من قبل عدة باحثين لتخفيف تلاشي المطر. ولكن تحليل اختلاف الزمن يتطلب بيانات مقاسة لتخفيف المطر. بالنسبة إلى تصميم وصلة التردد العالي في المستقبل فإن مثل هذه البيانات لا تتوفر في أغلب الأماكن. إن هذه الأطروحة تقترح نموذج تنبؤ كسب تنوع الزمان باستخدام معدل المطر عند أي ذبذبة عالية. إن تحليل تنوع الزمان والذي تم إجراؤه من قبل إسماعيل وآخرون ، فوكوجي وآخرون، فابر وآخرون، ماترجياني واخرون، و يودوفيا وآخرون عن الوصلات الأرضية بالقمر الصناعي تم استعراضه. اقترح ماترجياني وآخرون نموذج تنبؤ كسب لتنوع الزمن في حين أن تحسن تنوع الزمن المقاس قد تم تحليله لبقية مجموعة الباحثين الواردة أسماؤهم سابقاً.

تم قياس بيانات معدل الأمطار باستخدام الوقت الحقيقي لمقياس المطر لمدة سنة واحدة في الجامعة الإسلامية العالمية بماليزيا سنة 2014.

تم تقديم مفهوم جديد لمعدل المطر مع تأخر الوقت ومع عدم وجود تأخير للوقت مع تقديم المعادلات المناسبة لهذا المفهوم الجديد.

وبناءاً على معادلة تلاشي المطر مع وقت تأخير فإن دالة التوزيع المتجمعة التكميلية لمعدل المطر مع وجود وقت تأخير تم اقتراحها. وللتحقق من هذا المفهوم تم استخدام بيانات شهر واحد عن معدل المطر المقاس وبيانات تلاشي المطر. تم استخدام نموذج التنبؤ لتلاشي المطر والمقترح من قبل ايتو آر لتقدير كسب تلاشي المطر تحليلياً. إن الكسب الذي تم الحصول عليه تحليلياً قد تم مقارنته بالكسب المقاس وكانت القراءات متقاربة، بالتالي فإن هذا المفهوم قد برهن بأنه يمكن ايجاد كسب تلاشي المطر ويمكن حسابه باستخدام معدل المطر. تم اشتقاق نموذج اختلاف الزمن اعتماداً على بيانات مقاسة لمعدل الأمطار في ماليزيا لمدة سنة واحدة. في النموذج المقترح تم استخدام ثلاثة متغيرات وهي معدل الأمطار، وقت التأخير والذبذبات. تم أولاً استخدام دالة معدل الأمطار ووقت التأخير سوية وتم اشتقاق الثوابت بطريقة الانحدار مع استخدام معدل الأمطار ومعدل الأمطار المكسوب كعوامل في الانحدار. وثانياً تم اشتقاق ثابت دالة الذبذبة من ال سي دي اف التلاشي والتي تم التنبؤ بها من قبل ايتو آر والكسب المتحصل عليه تحليلياً. وتم دمج واشراك هاتين الدالتين سوية وتم تطوير نموذج كسب التلاشي المقترح. تم التحقق من صحة النموذج باستخدام بيانات سنة واحدة لمعدل الأمطار وتلاشي الأمطار المقاسة في موقعين في ماليزيا وموقع واحد في اليابان. إن الكسب المتنبأ به بالنموذج المقترح كان تقريباً نفس بيانات الكسب المقاس في المواقع الثلاثة ميكاهيرتز مع تناقض مقداره 8%. عند 12.57و12.0 و 12.225

وقد وجد تقدير مبالغ في القياس عند مستوى ذبذبة 19.45 ميكاهيرتز مع خطأ أعلى مقداره 34%. إن التحليل قد بيَّن بأن أداء النموذج المقترح هو أفضل بكثير من النموذج المقترح من قبل ماترجياني. إن نموذج التنبؤ المقترح قد أظهر توافقاً جيداً مع البيانات المستخدمة للذبذبات الأربعة والمقاسة في المواقع الثلاثة المختلفة. ولهذا فإن النموذج المقترح سيكون مفيداً في المستقبل لتصميم وصلات الأرض والأقمار الصناعية باستخدام معدل الأمطار المقاس عند الذبذبات الأعلى.

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 (Electronics 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.

Md. Moktarul Alam

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

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LIST OF SYMBOLS

R_m	Measured Rain Rate
R_p	Predicted Rain Rate
%p	Rain Rate variation at any percentage
T	Time Delay
P(A)	Probability of Attenuation
P (R)	Probability of Rain Rate
R_{TD}	Rain Rate Time Delay
ξ (A)	The Density Function
Γ	The Joint Probability Function
A	Rain Attenuation
G_A	Attenuation Gain

LIST OF ABBREVATIONS

ITU-R	International Telecommunication Union Radio Propagation
CDF	Cumulative Distribution Function
TDF	Time Diversity Function
TD	Time Delay

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The utilization of satellites for communication systems has expanded considerably in recent years. C and Ku-bands of frequencies are already congested because of high demand. Future directions of satellite communications are moving towards Ka and V-bands (Panagopoulos, 2008). Earth-to-satellite links that operate at frequencies higher than 10 GHz (Ku, Ka, and V bands) in the troposphere are strongly affected by propagation impairments especially by precipitation. Tropical and equatorial climates experience heavy precipitation all over the year. Therefore, the satellite communication system performance suffers from severe degradation at high frequencies. The most significant challenge in satellite-to-Earth signal transmission in tropical regions are attenuation caused by heavy rain.

The effects of rain attenuation on a transmitted radiowave is based on three assumptions describing the nature of radiowave propagation and precipitation. First, the intensity of the wave decays exponentially as it propagates through the volume of rain. Then the raindrops are assumed to be spherical water drops, which both scatter and absorb energy from the incident radiowave. And the contributions of each drop are additive and independent of the other drops. This implies a 'single scattering' of energy, however, the empirical results of the classical development do allow for some 'multiple scattering' effects (Ippolito, 1981).

Rain on the transmission path is the major weather effect of concern for frequencies of operation above 10GHz. Raindrops absorb and scatter radiowave energy, resulting in rain attenuation which can degrade the reliability and performance of the communication link (Pan, Allnutt, & Tsui, 2008). The non-spherical structure of raindrops can also change the polarization characteristics of the transmitted signal, resulting in rain depolarization (a transfer of energy from one polarization state to another). Rain effects are dependent on frequency, rain rate, drop size distribution, drop shape (oblateness), and to a lesser extent, ambient temperature and pressure (Pan et al., 2008).

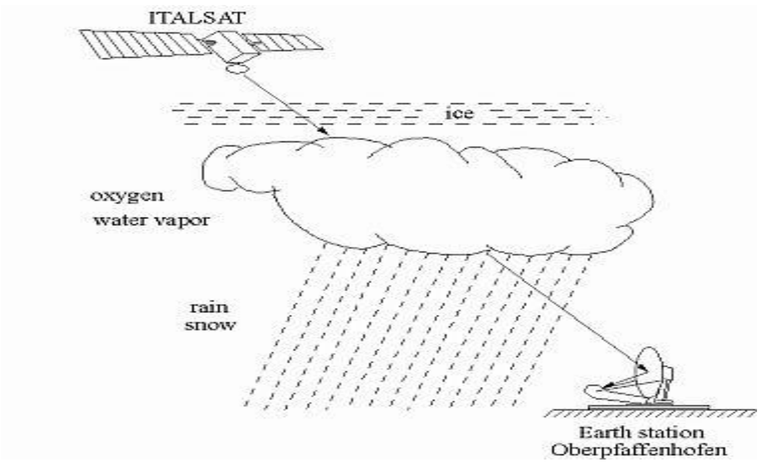

Figure 1.1. Example of Rain fade mitigation due to rain (Pan et al., 2008).

The calculation of excess attenuation due to rainfall is another, more complex matter. It has been common practice to express signal loss due to rain as a function of rate rate. The rate depends on water content and the fall velocity of the drops (Lam, Luini, Din, Capsoni, & Panagopoulos, 2014).

Therefore, the satellite communication system performance suffers from severe degradation at high frequencie (Livieratos, Kourogiorgas, Panagopoulos, & Chatzarakis, 2014). It is not practical to include very high fixed fade margins in link budgets as a compensation for the great propagation impairments due to effects of transmitter power limitations. In order to overcome such problems, implementation of

Fade Mitigation Techniques (FMTs) becomes significant to ensure the continuity of system availability (Kourogiorgas, Panagopoulos, Livieratos, & Chatzarakis, 2013).

FMTs have to take in consideration the system performance aims, the system architecture parameters and the frequency bands in operation (Livieratos et al., 2014). Time diversity is one of the best choice among FMTs in an Earth-satellite links to encounter severe channel fading in terms of cost and benefits. The performance of time diversity is generally evaluated using measured rain attenuation time series with and without delay of time (Kourogiorgas et al., 2013). It calculates the joint exceedance of rain attenuation probability both with and without delay. Time diversity gain is the indicator for improvement. An empirical model to predict time diversity gain function was derived in Malaysia based on measured data to estimate rain attenuation exceedance probability.

1.2 PROBLEM STATEMENT

Earth to satellite communications are moving towards higher frequency bands in future which are more sensitive to environment. Rain causes severe degradation in performances at higher frequency bands specially in tropical regions. Several mitigation techniques are proposed by researcher to design reliable system. Time diversity is one of the potential candidate for it. However, time diversity analysis requires measured rain attenuation data. For future high frequency link design those data are not available at most of the places. This thesis proposes a method to utilize 1-minute rain rate data to analyze time diversity technique at any desired frequency. A model is proposed to predict time diversity gain from annual measured rain rate statistics.

1.3 OBJECTIVES OF STUDY

The main objectives of this research are:

1. To investigate available time diversity prediction models in earth-to-satellite rain fade mitigation
2. To analyze time diversity method using rain rate distributions for earth-to-satellite rain attenuation mitigation
3. To develop a prediction model for time diversity gain based on measured rain rate distributions
4. To validate proposed time diversity gain model using measured rain rate and rain attenuation statistics

1.4 RESEARCH METHODOLOGY

For obtaining the desired objectives stated above, the following steps are taken into consideration:

Phase I: Investigation of Time Diversity Techniques

1. To develop the concept of time diversity technique from research papers of Ismail et al, Fukuchi et al, Fabbro et al, Matricciani et al and Udofia et al.
2. To analyse the research papers on time diversity gain by measured attenuation with time delay and Matricciani's proposed model on Time diversity gain.

Phase II: Rain Rate Data Collection

1. Collection of three years rain rate time series at IIUM
2. Processing of data with 1-minute integration time
3. Analysis of data for monthly, yearly and three-years average using cumulative distributions
4. Compare rain rate distributions with other prediction models.

The measurements started at International Islamic University Malaysia (IIUM) from 1st January 2014. Real-time Rain Gauge connected to PC to measure the rain intensity and save the data to a data logger (PC). The functions of the rain gauge are to measure rainfall intensity and determine rain events. The tipping bucket size is equivalent to 0.2 mm of rain.

Phase III: Analyze Time Diversity Technique Using Measured Rain Rate Data

1. To construct cumulative distribution function (CDF) for measured 1-minute rain rate time series.
2. To estimate time diversity, gain and improvement factor by delaying 1minute – 60 minutes based on measured 1-minute rain rate time series.
3. To develop time diversity gain model based on analysis

Phase IV: To Develop a Model for Time Diversity Gain

1. Derivate of a mathematical model.
2. Compare new time diversity gain model with analytically obtained gain

Phase IV: To Validate the Proposed Model.

1. To utilize measured one-year rain rate and rain attenuation data measured at two locations in Malaysia and one location in Japan from research papers.
2. To compare and validate time diversity gain predicted by proposed model with measured gain and that predicted by Matricciani.

The details flow chart of research methodology is presented in Figure 1.2.

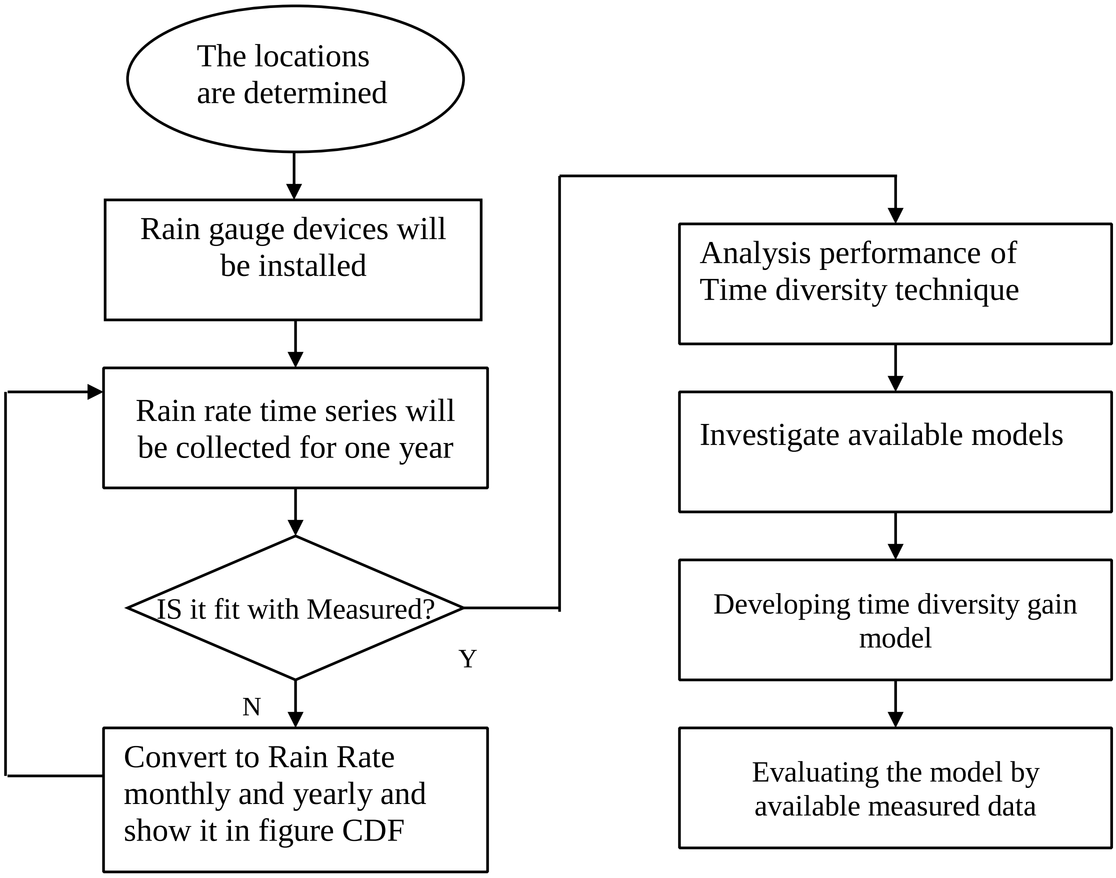

Figure 1.2. Flow chart of research methodology

1.5 RESEARCH SCOPE

The scope of this research is:

- The rain data was collected 3-years (2014, 2015 and 2016) from IIUM campus, but the year 2014 data is used because data availability is above 96% at 2014.
- One month measured rain rate and attenuation data is collected for validation of time delay technique.
- ITU-R predicted model is used for predicted attenuation. This model is globally accepted by the world.

- Validation is done by one-year rain rate and rain attenuation data measured at two locations in Malaysia and one location in Japan.

1.6 HYPOTHESIS

A model is developed to predict time diversity gain from annual measured rain rate statistics. In proposed method, it is assumed that rain rate with delay can represent rain attenuation with delay for same period of time at same location. This assumption is valid as long as the attenuation causes due to rain.

1.7 THESIS ORGANIZATION

The thesis consists six chapters. Chapter one coves the introduction. The updated literature review is presented in chapter two. The measured data and it's processing for cumulative distributions with and without time delay is explained in chapter three. The model for time diversity gain using rain rate distributions is developed step by step in chapter four. The validation of time diversity gain model is included in chapter five. Finally, conclusions of this research are presented in chapter six.

CHAPTER TWO

RAIN FADE AND ITS MITIGATION

2.1 INTRODUCTION

This chapter reports a study on propagation impairments for Earth–space communication links. The variation of effect was discussed in this chapter. The earth-space link was most effected by rain and rain attenuation also effected due to rain. Many researchers tried to mitigate rain fade. Diversity technique was found by them. The study used diversity as a technique for mitigating rain propagation impairments in order to rectify rain fade. Rain attenuation time series along earth-to-satellite link were investigated the level of possible improvement in system. Time diversity gain estimated to improve the rain fade which could predict as a function of rain attenuation levels and time delay.

2.2 PROPAGATION IMPAIRMENTS

In microwave link design, several effects are caused due to atmosphere propagation between earths to free space. The situations are caused by uncontrolled variation of signal's phase, amplitude, polarization and angle of arrival which efficacy lower rate of digital transmissions and the analogy transmission was reduced. The elevation angle to the satellite, local, climatology, local geography and type of transmission which are dependable on the frequency for space communications (Mandeep, 2007). For one thing, galactic noise and man-made noise are minimum. Atmospheric absorption and rainfall loss may generally be neglected. Finally, there is a mature technology with competitive pricing of equipment. On the other hand, Propagation of radio waves through the atmosphere above 10 GHz involves not only free-space loss but several other important factors (Paraboni, Capsoni, & Gabellini, 2010)For instance, are the gaseous contributions of the homogeneous atmosphere due to resonant and non-resonant polarization mechanisms and the particulate contributions due to rain, fog, mist, and haze, dust, smoke, and salt particles in the air (Grémont & Filip, 2004).

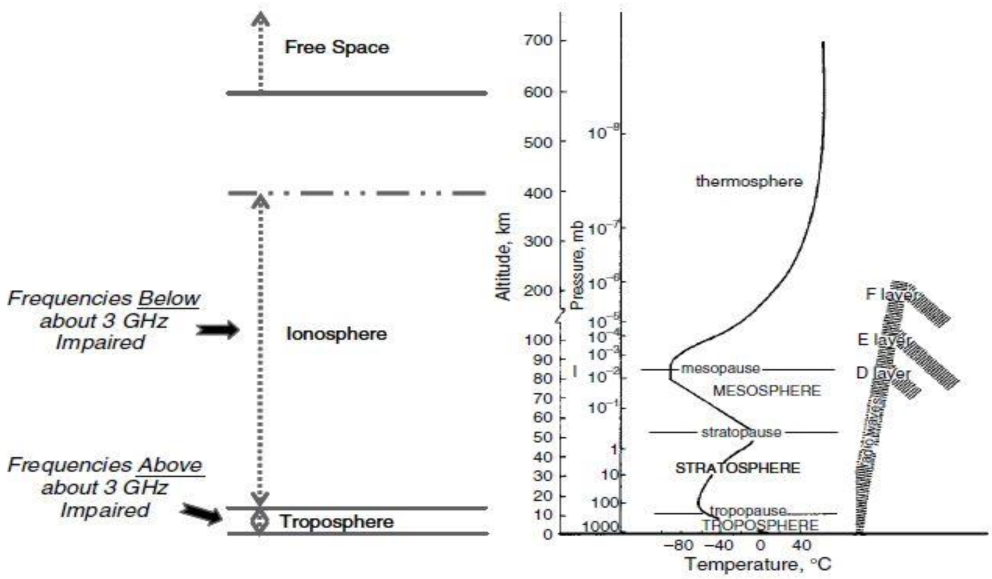

Figure 2.1 Components of the atmosphere impacting space communications (Louis J. Ippolito, 2008).

Figure 2.1 shows the particles of radio wave communications on free space communications in the earth's atmosphere. On the earth surface radio wave will propagate about 15km to 400 km due to applicable outer frequency. Ionosphere makes ionized extending region (Al-Saegh, Sali, Mandeep, & Ismail, 2013). Below 30 MHz of radio wave act as reflectors or absorbers, different places like as D, E and F layer; as a result, it is impossible for free space communications. Signal will be propagating when the thickness of E and F layers of reflection properties and increased frequency. 300 MHz frequency band of radio wave will propagate ionosphere, geographic location, day time and varying degrees depending on frequency. Effects of ionospheric effects,