INTERFERENCE BETWEEN TERRESTRIAL, HIGH-ALTITUDE PLATFORM AND SATELLITE SYSTEMS AT 28 GHz

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This thesis is dedicated to my wonderful, my ***mother,*** *who raised me to be the person who I am today.*

To my Beloved ***wife, brothers*** *and* ***sisters***

To my sons, ***Ibrahim****,* ***Osama****,* ***Abdul Malik and ALezz***

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ABSTRACT

As a result of increasing demand of wireless communication services, the use of the same radio communication channel for different services is inevitable. Therefore, radio frequency interference is a major cause of telecommunication service interruption. Rain attenuation increases the interference by scattering signal or attenuating the carrier signals. The affirmative impact of rain attenuation is when the rain attenuation gives harmful interference and does the same negative impact, but over the interfering links. The aim of this thesis is to analyse the interference in a wireless network consists of terrestrial, receiving satellite ground station, and High Altitude Platform (HAP), under clear sky and rainy condition at 28 GHz. This study is divided into two sections: the first section is the analysis of three interference scenarios, based on the link budgets and data obtained from Maxis Communication Bhd, one of the mobile operators in Malaysia, in three scenarios. First and second scenarios, the interference from terrestrial and HAP to satellite ground station separately. The third scenario when the interference from both systems to satellite ground station. The contour maps of Carrier to Interference ratio (C/I) at satellite ground station are drawn. The results demonstrated that only the third interference has a severity and requires great separation distances. The second section is analysis of the impact of rain attenuation on the interference. The measurements of rain are used from several local measuring sources. Radar database is used to distribute the rain rate using the cell exponential profile, Excell model. The C/I contour maps when satellite ground station exposed interference from both terrestrial and HAP is used to identify the location of the three systems. The impact of the rain attenuation computed from excel model when it affects over the interfering path is analysed. It is showed that there was a significant improvement in the interference to noise ratio when rainfall on the interfering link. The improvement in interference to noise ratio reached 11.14 dB. Received Signal Level (RSL) is measured for one year over terrestrial sites operated by Maxis, provides 15-minute integration time attenuation statistics obtained from a digital microwave. ITU-R models are used to extract 1-minute rain rate and 1-minute rain attenuation from measured 15-minute rain attenuation. Furthermore, coefficients are proposed to convert rain attenuation from 15-minute to 1-minute integration time directly. The impact of the rain attenuation computed from Maxis database and ITU-R model when it affects over the interfering path was analysed. The results clarified that improvement in the interference to noise ratio was more than 15 dB. Moreover, results showed that the rainfall estimation from received signal level measurement over terrestrial links has a great potential. Next, the commercial microwave links' network of an arbitrary geometry could be considered as a widely distributed source of rainfall observation network with high resolution and minimum supervision. Designers can benefit from the positive impact of the rain when designing wireless networks.

ABSTRAK

Hasil daripada permintaan yang semakin meningkat perkhidmatan komunikasi tanpa wayar, penggunaan saluran komunikasi radio yang sama untuk perkhidmatan yang berbeza tidak dapat dielakkan. Justeru gangguan frekuensi radio adalah salah satu punca utama gangguan perkhidmatan telekomunikasi. Pelemahan hujan meningkatkan gangguan melalui penyerakan isyarat atau melemahkan isyarat pembawa. Kesan afirmatif pelemahan hujan apabila ia menyebabkan gangguan dan kesan negatif yang sama turut memberi kesan kepada hubungan yang mengganggu. Tujuan tesis ini adalah menganalisis gangguan dalam rangkaian tanpa wayar terdiri daripada daratan, stesen satelit bumi, dan platform altitud tinggi (HAP), di bawah keadaan cerah dan keadaan hujan pada 28 GHz. Kajian ini terbahagi kepada dua bahagian: bahagian pertama merupakan analisis tiga senario gangguan, berdasarkan bajet talian dan data yang diperolehi dari Maxis Communications Bhd, salah satu pengendali talian mudah alih di Malaysia. Senario pertama dan kedua, adalah gangguan dari daratan dan HAP ke atas stesen satelit bumi berasingan. Senario ketiga adalah gangguan dari kedua-dua sistem ke atas stesen satelit bumi. Peta kontur nisbah pembawa kepada gangguan (C/I) di stesen satelit bumi telah dihasilkan. Keputusan menunjukkan bahawa hanya gangguan ketiga memberi kesan amat teruk dan memerlukan jarak pemisahan yang besar. Bahagian kedua adalah analisis kesan pelemahan hujan pada gangguan. Pengukuran hujan digunakan dari beberapa sumber pengukur tempatan. Pangkalan data radar digunakan untuk mengagihkan kadar hujan menggunakan profil sel eksponen, model Excel. Peta kontur C/I apabila stesen satelit bumi terdedah kepada gangguan dari kedua-dua daratan dan HAP digunakan untuk mengenal pasti lokasi ketiga-tiga sistem. Kesan pelemahan hujan yang dikira daripada model Excel apabila ia memberi kesan ke atas laluan yang mengganggu dianalisa. Ia menunjukkan bahawa terdapat peningkatan yang nyata dalam gangguan kepada nisbah bunyi apabila hujan pada pautan yang mengganggu. Peningkatan dalam nisbah gangguan kepada bunyi sehingga 11.14 dB. Tahap isyarat yang diterima (RSL) diukur selama satu tahun di lokasi daratan yang dikendalikan oleh Maxis, menyediakan integrasi masa 15-minit statistik pelemahan yang diperolehi daripada gelombang mikro digital. ITU-R model digunakan untuk mengekstrak 1-minit kadar hujan dan 1-minit pelemahan hujan dari 15-minit pelemahan hujan yang diukur. Tambahan pula, kami mencadangkan pekali untuk menukar secara terus pelemahan hujan dari integrasi masa 15-minit kepada 1-minit. Kesan pelemahan hujan dikira dari pangkalan data Maxis dan ITU-R model apabila ia memberi kesan atas laluan yang mengganggu turut dianalisa. Keputusan menunjukkan bahawa peningkatan dalam nisbah gangguan kepada hingar adalah lebih daripada 15 dB. Selain itu, keputusan menunjukkan bahawa anggaran hujan dari pengukuran tahap isyarat yang diterima atas talian daratan mempunyai potensi yang besar. Seterusnya, rangkaian talian gelombang mikro komersil geometri arbitrari boleh dianggap sebagai sumber meluas rangkaian pemerhatian hujan dengan resolusi tinggi dan penyeliaan minimum. Pereka boleh mendapat manfaat daripada kesan positif hujan apabila mereka bentuk rangkaian tanpa wayar.

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LIST OF SYMBOLS

C	–	The received desired signal power
P_{St}	–	The transmitted power from the desired station
L_{fst}	–	The desired transmitter losses
G_{St}	–	The transmitter antenna gain
L_{se}	–	The free-space loss between the desired transmitter station and desired receiver station path
d	–	The distance between the transmitter station and the receiver station
λ	–	The wavelength
A	–	The atmospherics attenuation between desired transmitter station and receiver station
G_{er}	–	The receiver antenna gain
L_{fer}	–	The receiver losses
I	–	The received interfering signal power
P_{tI}	–	The transmitted power from the interfering station
L_{fIt}	–	The interfering transmitter losses
G_{tI-er}	–	The antenna gain of the interfering transmitter station in the direction of the desired receiver
N	–	Thermal noise receiver signals
K	–	Boltzmann’s constant
T	–	Temperature
B	–	The bandwidth
I_a	–	The interference adjustment factor
I_{total}	–	The total received interfering signal power
ρ_o	–	The radius of rain cell
R_M	–	The rain rate peak
ρ	–	The distance from the cell centre
p_{max}	–	The distance from the cell center to the rain profile reach zero

R_{low} – The rain cell lowering

γ – The specific attenuation due to rain

R – The rain rate in mm/h

k – Frequency-dependent coefficients

$\propto$ – Frequency-dependent coefficients

A_{001} – Rain attenuation that has exceeded about 0.01% of the time

$R_{0.01}$ – The one-minute rainfall rate exceeded for 0.01%.

r – The redaction factor

f – The frequency

h_s – The height above mean sea level

θ – The elevation angle in degrees

∅ – The latitude of the earth station

θ_t – The terrestrial side lobe angle

θ_{SGS} – The satellite ground station side lobe angle

θp – HAP side lobe angle

LIST OF ABBREVIATIONS

C/I	–	carrier to interference ratio
C/N	–	carrier to noise ratio
I/N	–	interference to noise ratio
HAP	–	High altitude platform
IPC	–	Interference protection criteria
RSL	–	The received signal level
Excell	–	The cell exponential profile
TS	–	Interference from terrestrial to satellite ground station
HS	–	Interference from the HAP to the satellite ground station
THS	–	Interference from the terrestrial and the HAP to the satellite ground Station
HT	–	The rain occurred over half of the interfering paths
FT	–	The rain occurred over entire of the interfering paths
MT	–	The rain occurred over entire of the interfering paths before system Outage
FWA	–	Fixed Wireless Access
GSO/FSS	–	GeoStationary Orbit Fixed Satellite Service
EESS	–	Earth Exploration Satellite Service
RAS	–	Radio Astronomy Services

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CHAPTER 1

INTRODUCTION

1.1 Overview

During the past two decades, wireless communications has changed the world more than any other technical achievement. Terrestrial and satellite systems are well-established methods for providing mobile communications services. Both technologies have many benefits, as well as they have disadvantages. An innovative way to overcome the limitations of both the terrestrial tower-based and satellite systems is to provide wireless communications via High Altitude Platform Station (HAPS) [1, 2].When these three systems operate in one area, the most problematic disruption to the services and quality that they provide is interference. As a result of the rapid increase in the demand for the telecommunication services that these systems provide, it is necessary to make more efficient use of the spectrum, which includes frequency sharing between different services. The main determination of an appropriate operation of frequency sharing between radio communications systems is mutual interference [3]. The interference problem represents a set of interrelated regulatory and legal problems. There are two categories of interference problems: internal and external. In an effort to help avoid interference, telecommunication administration is responsible for the organization and sharing of national frequencies. At the international level, the International Telecommunications Union facilitates this goal.

One of the main factors that affect the interference of terrestrial and satellite radio links working at frequencies higher than 10 GHz is rain attenuation. This is particularly noticeable in tropical climates. The intention of this thesis is to analysis the interference in a designed wireless network that consists of satellite, terrestrial, and high altitude platforms. This network will be used to study the interference from the terrestrial and high altitude platforms to the satellite ground station in both clear sky and rainy conditions and will be based on measured data and link budgets that were obtained from radar data and microwave received signal from Maxis communication Bhd one of the mobile operator in Malaysia.

1.2 Problem Statement

Today, there are many wireless communication systems, such as satellites and terrestrial systems. In the future, high-altitude platform (HAP) will be a part of the massive expansion in the communication world. As a result of this expansion, systems will be deployed in the same geographical areas and operate in the same frequency bands. The biggest challenge that faces these systems is the electromagnetic radiation from one system to another. This effect is known as radio frequency interference [4]. Compensating for this interference is one of the perquisites for the reliable design of a wireless communication system. In order to avoid situations of unacceptable interference levels and severe performance degradations, there is a strong need to use the appropriate frequency band and study the possible atmospheric attenuation [5].

The existing frequency band must be used as efficiently as possible. This can be accomplished by using a technique known as frequency reuse, which uses the same frequency several times within the same telecommunication system. This technique is based on the isolation between two links, such as a cellular radio system in a terrestrial network. Frequency sharing, which uses the same frequency of two or more radio communication systems and exploits higher-frequency bands, is one of the techniques that attempt to meet the increasing demand of telecommunications.

However, at these wavelengths, there are severe propagation losses in the atmosphere [6].

It is important to consider the atmospheric attenuation increase when the links are designed to work in the Ku, Ka, Q, and V bands. In such bands, rain attenuation is the main factor that limits the path's performance, especially in tropical regions. Rain attenuation aggravates the interference, due to the potentially existing rain attenuation [3]. The carrier-to-interference ratio degraded when the rain effect on the carrier link and increased when the rain effect on the interference link.

The aim of this thesis is to analysis the interference in a designed wireless network that consists of a satellite, terrestrial, and a high-altitude platform operating at 28 GHz. This system will be used to study the interference from the terrestrial and high-altitude platforms on the satellite ground station under clear and rainy conditions using Excell model and ITU-R model. This thesis will attempt to show how rain reduces the interference when it is affected by the interfered link by increasing the interference-to-noise ratio.

1.3 Objectives

The objectives of this research are analyzing the interference in a designed a wireless network that consists of satellite, terrestrial and high altitude platform in an attempt to study the following:

- To identify the separation distance between the satellite, HAP, and terrestrial systems using contour maps that depends on the carrier-to-interference ratio.

- To evaluate the impact of rain when it affects the interfering links.

- To propose recommendations to improve the performance of satellite, HAP, and terrestrial systems when they are coexistence with each other.

1.4.1 Scope of the Work

The scope of this project is to study the backhaul interference between the ground stations of satellite, high altitude platform, and wireless terrestrial systems when deployed in the same geographical area.

- The research begins with collecting information on the system specifications of High Altitude Platforms (HAPs), microwaves system specifications, frequency sharing between HAPs and terrestrial systems data, interference between HAPs terrestrial systems, and rain intensity and attenuation data from different sources, particularly Maxis Communications Bhd.

- Evaluation of the interference of satellite, terrestrial, and high altitude platform (HAP) with a ground station when the elevation angle at the HAPs ground station is 20°, which is the worst case elevation angle. The evaluation of interference is carried out in both clear-sky and rainy conditions. In rainy conditions, the Excel model is used to present the rain rate distribution matrix for different peak values and rain cell lengths.

- Development the contour maps to determine the separation distance of the satellite ground station, the high altitude platform, and the terrestrial systems depend on.

- Evaluate the rain attenuation impact on the interfering.

- Finally, propose a recombination to establish a coexisting network consisting of satellite, HAP, and terrestrial systems.

1.5 Outline of Thesis

The outline of this thesis as following:

Chapter 1: This chapter contains the introduction to this study, the problem statement, research objectives, and the scope of the study.

Chapter 2: This chapter discusses the theory and literature reviews that have been previously been completed. This chapter also reviews the major radio interference problem faced in wireless networks and reviews the practical interference problems between satellite, terrestrial, and high-altitude platforms.

Chapter 3: This chapter reviews the propagation mechanism that is related to interference. Furthermore, this chapter presented the survey of the rain attenuation prediction models that are required for slant path and terrestrial link's design: ITU-R predication model and exponential cell (Excel) rain attenuation model. Moreover, some methods that are used to convert various times of rain rate to one-minute rain rate are reviewed.

Chapter 4: In this chapter, the research methodologies of this work are discussed. The source of information and program which was used to analyze the interference is the major topic of this chapter. Interference from terrestrial and HAPS to satellite ground station are evaluated and optimized in this chapter.

Chapter 5: This chapter shows the contour maps that determine the threshold between the satellite, terrestrial, and high altitude platform when they operate in the same area to avoid interference, depending on the carrier-to-interference ratio as follows: the contour maps are drawn to determine the threshold location of the satellite ground station near the existing terrestrial site. The contour maps are then drawn to determine the threshold location of the high altitude platform near the existing terrestrial and the satellite ground station.

Chapter 6: This chapter contains the interference of evaluation and analysis of interference from the terrestrial and high altitude platform to satellite ground, as well as the charts for different cases that show the impact of rain attenuation on the interference using the measured rain when the Excell and ITU-R models are applied. Moreover it illustrates the positive impact of rain attenuation when the rain effect on the interference links to clarify their contribution to improve the interference-to-noise ratio at the satellite ground station.

Chapter 7: In this chapter, the main ideas and summarized results of this research are concluded and future areas of study are discussed.

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