Free Space Attenuation Analysis for X -band and S-band Satellite Link using Meteorological Radar Data in the Tropics

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***Abstract*—Free space fading for satellite link propagation studies in the equatorial regions are indeed particularly scarce, complicated and expensive to venture upon. Most of satellite propagation studies done in temperate climate are not reasonable for countries in the equatorial region due to its huge climate differences. In equatorial regions, the future stratospheric and space-based telecommunications systems are expected to operate with high elevation angle slant paths and high frequency of operation from the Earth stations' point of view. These systems will also be sharing frequency bands with other terrestrial and space services. From this standpoint, a precise modelling of the vertical variation of free space path loss parameters will be of great interest for improving the prediction of the clear sky margin along the slant path in the tropics. In this paper, the Free Space Path Loss (FSPL) propagation link for X-band and S-band RazakSAT satellite will be analysed using a Terminal Doppler Weather Radar (TDWR) data. Both links will be evaluated and the assessment of the link's fade margin will be suggested. An accurate estimation of the satellite fade margin will evidently save power from the satellite perspective and better transmission can be estimated. The outcome of this research will be very useful for future implementation of satellite link fade margin improvement during non-rain weather, both during clear sky and cloudy weather in the tropical region. This research will facilitate the key decision makers and the satellite designers to progress business, availability, and throughput proficiently. Therefore, hopefully, the spending is well reasonable with a better return on investment (ROI) and attracts more investors in satellite industries.**

***Index Terms*—X-band; S-band; Satellite Link; TDWR Radar.**

I. INTRODUCTION

Satellites communication play a vital role in the growth of global communications, media and technology industries. A communications satellite system is a setup of microwave receiver, repeater and regenerators placed in orbit around the Earth that receives, amplifies and redirects analogue and digital signals contained within a carrier frequency [1]. It is one of the most indispensable growth from the space programs and has made a core contribution to the trends in worldwide communications. Satellite for past 50 years played a key factor for global economic growth in communications, broadcasting technology and media industries [2]. During these years, satellite communication enables many breakthroughs in global telephony, intercontinental live television, global positioning system (GPS), secure military-grade encrypted communication, internet data networks for consumers and private companies [3]. Assessment of radio signal attenuation, the key element in satellite link propagation, will allow satellite designer to adjust fade margin accordingly. Thus, a satellite with standard availability of 99.7% throughout the year is achievable. The information transferred most often include voice (telephone), video (television) and digital data. The essential component of a communications satellite system is the two attribute of the space segment and ground segment. The space segment consists of the spacecraft and launch mechanism while the ground segment typically comprises the Earth station and network control center of the entire satellite system [3]. Satellite Free Space Path Loss (FSPL) or Free Space Attenuation is an important aspect to contemplate before satellite launching due to the very soaring cost of its pre-and post-operation and the grounding itself.

Propagation studies in the tropical region are quite recent as most of the tropical countries are in the categories of developing countries. The propagation phenomena concerning Earth-space links mainly originate in the troposphere and the ionosphere. Respectively, propagation effects are separated into two categories: ionospheric effects, influencing systems operating below 3GHz, and tropospheric effects, influencing systems operating above 3GHz. In tropical regions, the future stratospheric and space-based telecommunications systems are expected to manoeuvre with high elevation angle slant paths and high frequency of operation from the Earth stations' standpoint. This is due to the fact that the corresponding spaceborne transmitters are likely to be orbiting along the equator. These systems will also be initially sharing frequency bands with other terrestrial and space services. The available FSPL included only frequency, distance and the gain from the transmitter and receiver. From this standpoint, an accurate modelling of the vertical variation of free space path loss parameters will be of great interest not only for improving the prediction of the clear sky margin along the slant path in the tropics but also for cloud and wind interference calculations [4].

II. FREE SPACE PATH LOSS

In telecommunication, Free-Space Path Loss (FSPL) is the loss in signal strength of an electromagnetic wave that would affect from a line-of-sight (LOS) path through free space (usually air), with no obstruction nearby to cause reflection or diffraction. It is defined in "Standard Definitions of Terms for Antennas", IEEE Std 145-1983, as "The loss between two isotropic radiators in free space, expressed as a power ratio." Generally, it is expressed in unit decibels (dB), although the IEEE standard does not say that. It does not include any loss related to hardware deficiency or the effects of any antennas gain. International Telecommunication Union (ITU) elucidate the Free Space attenuation standard calculation in ITU-R P.525-2; Calculation of Free Space Attenuation [9].

Free-space path loss is relative to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal. Signal scatter with distance. Therefore, an antenna with a fixed area will receive less signal power the farther it is from the transmitting antenna. For satellite communication, this is the primary mode of signal sources of attenuation or destruction are implicit, a transmitted signal attenuates over distance because the signal is being stretched over a larger and larger area. This form of attenuation is known as express in terms of the ratio of the radiated power to the power received by the antenna or, in decibels, by taking 10 times the log of that ratio. For any type of wireless communication, the signal disperses with distance. Therefore, an antenna with a fixed area will receive less signal power the farther it is from the transmitting antenna. For satellite communication, this is the primary mode of signal loss. Even if no other causes of attenuation or impairment are assumed, a transmitted signal attenuates over distance because the signal is being spread over a larger and larger area. This form of attenuation is known as free space loss press in terms of the ratio of the radiated power to the power received by the antenna or, in decibels, by taking 10 times the log of that ratio. It is preferable to calculate the free-space attenuation between isotropic antennas, also known as the free-space basic transmission loss (symbols: L_{bf}, free-space basic transmission loss or A_0, Free Space Attenuation in dB, is as follows:

$$L_{bf} = 10\log\left(\frac{P_t}{P_r}\right) = 20\,log\left(\frac{4\pi d}{\lambda}\right) \quad \text{dB} \tag{1}$$

where: Pt = Transmitted Power
Pr = Received Power
d = distance
λ = wavelength
d and λ are expressed in the same unit.

Equation (1) can also be written using the frequency instead of the wavelength.

$$L_{bf} = 32.4 + 20\,log\,f + 20\,log\,d \quad dB \tag{2}$$

where: f = frequency (MHz)
d = distance (km)

Theoretically, the existing free-space path loss equation is proportional to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal. In this research, the effect of clouds, wind and the atmospheric layer will be included in the newly derived formulation to further improve the margin of a satellite link during clear sky using the radar data. Another known fading factor is ionospheric scintillation [5]. This attenuation will cause irregular variations in the received signal level and angle of arrival [6]. The intensity of this type of attenuation increases with rising frequency and decreasing elevation angle (increasing the distance). Ionospheric scintillation attenuation is also significant for frequency below 3GHz especially for non-geostationary satellite [7]. Maximum effect of this attenuation is observed during the summer season in temperate climate region. However, for a tropical region, the weather is always hot and humid throughout the year as the region is near to the equator. Therefore, scintillation attenuation will absolutely be an exciting study to be done for RazakSAT satellite. It is known this satellite is a non-geostationary satellite operating at S-band which is below 3 GHz. In addition, the satellite elevation angle changes as it travels by its orbit. Figure 1 shows the illustration of the FSPL measurement setup using TDWR radar data and received signal at National Space Centre, Malaysia

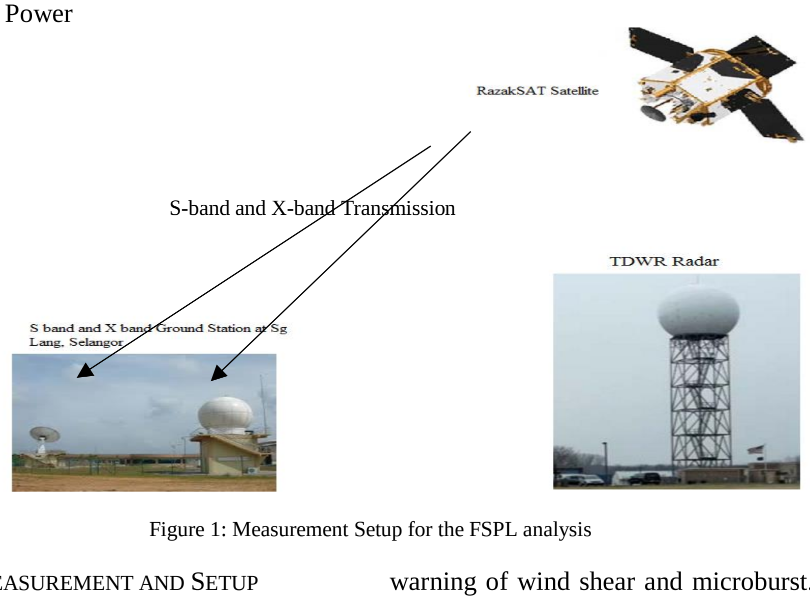

Figure 1: Measurement Setup for the FSPL analysis

III. SYSTEM MEASUREMENT AND SETUP

A. TDWR Radar System

A Terminal Doppler Weather Radar (TDWR) is currently positioned at Bukit Tampoi, about 10 km north of Kuala Lumpur International Airports (KLIA) for the detection and warning of wind shear and microburst. The S-band radar is located at 2° 45' 0" N / 101° 42' 0.1" E and operates at a frequency of 2.85 GHz (S-band). The radar system is automatically activated in two scanning approaches; Airport and Aerial mode. The radar mechanically shifts from Aerial mode to Airport mode when its sensor detects rain of more than 0.1 mm hour–1 within the 20-square km vicinity from KLIA. Each mode consists of three different volume scans called TASKs. Volume A (Vol-A) is for long-range surveillance at low elevation angle. Volume B (Vol-B) is for medium range observation and Volume C (Vol-C) is for short-range surveillance at high elevation angle. Both the Pulse Repetition Frequency (PRF) and antenna scan rate is different for each task. Higher PRF is used in the short-range mode.

Approximately 300 volume raster scans are attained per day in which each scan is generated within the duration of about 5 minutes to validate the clear sky events. Both transmitted and received signal power are verified with the use of test instruments namely oscilloscope, power meter, power sensor, frequency counter, signal generator, spectrum analyzer, attenuators and crystal detectors. Data acquired were from 1 January 2009 to 31 December 2009. Ideally, radar scans of 1-minute should be used. However, the present system requires 10 sweeps i.e. 5 minutes in order to be able to generate a full volume scan. This is the only available data option that can be acquired from Malaysia Meteorology Department (MMD). Should 1-minute scanning time data are available in the future, a more refined technique can be attempted. Table 1 lists the radar's characteristics. An IRIS software system by Vaisala is used to generate and display TDWR information. Reflectivity, Z can vary from extremely large values for heavy rain to very small values for mist. To make this extensive range of Z viewable on processor display, the software translates values into logarithmic quantity which are expressed in units of decibels (dBZ). The reflectivity, Z in unit dBZ is calculated from (3):

$$dBZ = log_{10}\, Z\ (mm^6\ m^{-3}) \qquad (3)$$

B. *RazakSAT Satellite System*

The signal from RazakSAT transponders are using X-band (8.21 GHz) and S-band (2.4 GHz) with QPSK modulated transmission. The ground station located at 2° 47' 3" N / 101° 30' 27" E received, monitored, and tracked the signal transponder using the Hexapod antenna. RazakSAT satellite was activated and managed from its Earth segment situated in Banting, Selangor, Malaysia. The Earth segment infrastructure is expanding its operation for space activities with the purpose to spur on the country into becoming a centre for operation, test, research and development in Asia region. Some of the core infrastructures that have been developed at the centre are the Mission Operation Centre (MOC) and Optical Calibration Laboratory. Upcoming facilities include the Assembly, Integration and Test (AIT) Facility and Data Centre. The facility is owned and operated by ANGKASA that handles the communications for both uplink and downlink with orbiting spacecraft. It has two antenna systems which are 5.0 meter antenna which can provide Tracking, Telemetry & Control (TT&C) support operating in S-band and 7.3 meter antenna for Image Receiving and Processing System (IRPS) operating in X-band. The RazakSAT's mission plan, command generation and telemetry receiving, archiving and analysis were accomplished at the MOC by a committed team of engineers. The satellite orbited the Earth in an exclusive positioning recognized as Near Equatorial Orbit (NEqO) at an altitude of approximately 684.5 km. This was especially considerable because Malaysia is commonly covered by equatorial cloud bands. Normal sun-synchronous optical satellites, which may re-visit an area only every 7 days, will approximately never be able to observe the ground during their pass ("RazakSAT" 2006). In contrast, RazakSAT revisited parts of Malaysian vicinity at almost every 1 hour and 28 minutes. The elevation angles implicated range from 0° up to 89° [10].

The satellite was in connection with the ground station for about 20 minutes and pass through the Malaysian atmosphere 14 times daily. During these crucial hours, the signal power level received at the ground station was computed. The elevation angle, latitude and longitude were then brought out to find the mean values. Then, the values of signal power received at the same elevation angle, latitude and longitude during clear sky were calculated. The signal power received during clear was then deducted from the power transmitted from the satellite as the other parameters remain constant. The divergence from these two values was implied as the free space attenuation as in Equation (1). Dataset acquired is for the period of measurements of 3 years instigation from 1 June 2009. Figure 2 shows one of the examples of the received power level during clear sky. The graph shows time series variation from 8:24:00 to 8:38:24 during one of the transmissions of the S-band events. The received power signal variation measured in dBm demonstrate the variation of the received signal due to different elevation angle and path length of the satellite path. The event examined in this paper is between 16th July 2009-31 July 2009 during the RazakSAT operation.

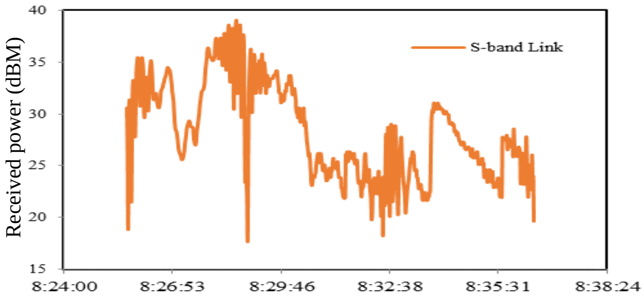

Figure 2: RazakSAT Received Power for S-band Link

IV. Results and Discussion

The data of power received at the Sg. Lang Ground Station was recorded every second. The radar data from MET Dept is investigated to confirm the clear sky condition at the Ground Station. Figure 3 shows the Constant Altitude Plan Position Indicator (CAPPI) from TDWR Radar Data to authenticate the free space environment.

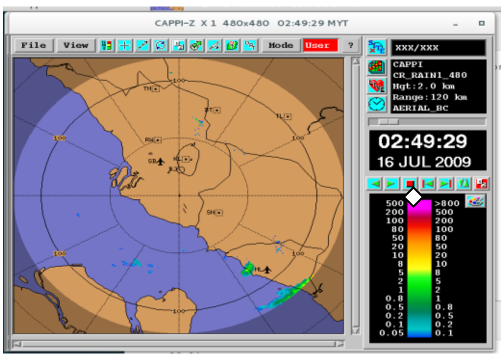

Figure 3: CAPPI Radar Data during the analyzed events showing clear sky condition at the Ground Station (mark)

The data from IRPS at RazakSAT's Sg. Lang Ground Station such as the satellite latitude, longitude, elevation angle, and received power is analyzed to calculate the Free Space Attenuation. Table I shows the important criteria to be observed for the analysis of S-band and for X-band. It is shown that the increasing elevation angle will increase the distance and hence increase the assessment of FSPL. The X-band values indeed averagely increase about 5.2% from the S-band values. The calculation results of FSPL for each angle during RazakSAT's transmission is shown in Figure 4. The longer the distant, more path loss is experienced during the events. The recommended time to best transmit the data/signal is during the shortest path which is at zenith angle.

Table 1
FSPL measurement for RazakSAT satellite link for S-band and X-BAND

Date & Time	Azimuth Ang (ϕ)	Elevation Ang (θ)	Power (dBm)	Sat Latitude (°N)	Sat Longitude (°E)	Sat Dist (km)	FSPL (S-band) (dB)	FSPL (X-band) (dB)
28/7/09 23:41:31	280	0	16	7	72	3301	149	161
25/7/09 23:42:31	277	1	21	5	77	2718	149	158
31/7/09 01:39:10	115	1	22	-7	123	2640	149	159
16/7/09 06:08:01	283	3	25	8	80	2466	149	156
30/7/09 12:48:26	117	4	19	-7	120	2314	147	157
18/7/09 05:33:49	287	5	28	8	82	2263	147	155
31/7/09 23:48:33	314	29	26	9	95	1061	145	149
17/7/09 08:34:43	358	48	34	7	101	523	142	143

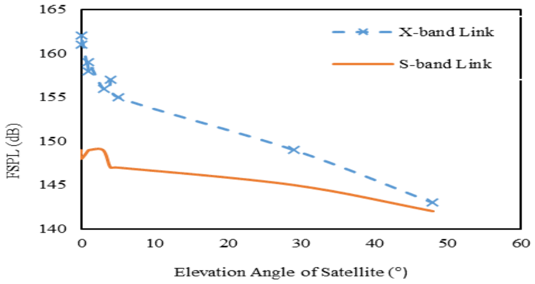

Figure 4: FSPL Estimation values for S-band and X-band link

In the tropics, satellite-space based telecommunications systems are predictable to operate with high elevation angle slant paths and higher frequency of operation from the Earth stations' perspective. Therefore, higher elevation angle will have lesser FSPL but a higher frequency of operation will incur higher FSPL. NEqO orbiting satellite such as RazakSAT that having different elevation angle provide the opportunity to investigate the available FSPL formulae. In the future, the study will reveal and improve the FSPL formulae suitable for tropical region and propose a correction factor for the FSPL accessible for client in tropical region environment

V. Conclusion

The cost for pre- and post-operation of satellite launching is very high, therefore it is hoped that this research will help the key decision makers and the satellite designers to improve cost, availability and throughput efficiently. These studies suggested the best location of the satellite to transmit its signal to transmit data. The outcome of this research will be very useful for future implementation of satellite link fade margin improvement during non-rain weather in the tropical region. Thus, hopefully the spending is well justified with a better return on investment (ROI) and attracts more investors.

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