Australian Journal of Basic and Applied Sciences, 8(24) Special 2014, Pages: 254-259

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

Assessment of X-band Earth-Satellite link Rain Attenuation Prediction in Malaysia

[1]Khairayu Badron, [1]Ahmad Fadzil Ismail, [1]Nuurul Hudaa Mohd Sobli, [1]Mohamad Kamrul Hasan, [2]Mazslan Ismail, [2]Ooi Sock Teng and [2]Terence Jerome Daim

[1]ECE dept, Kuliyyah of Engineering, International Islamic University Malaysia, Jln Gombak,53100, Kuala Lumpur
[2] National Space Agency Malaysia, Kg Sg Lang, Banting, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 30 September 2014
Received in revised form
17 November 2014
Accepted 25 November 2014
Available online 13 December 2014

Keywords:
X-band Satellite, radar, ITU-R prediction

ABSTRACT

Background: Predicted rain fade values for an Earth-satellite link operating at X-band frequency had been generated using the latest ITU-R Recommendation, P618-11. Rain fade values for the very same link were also estimated using the "radar-derived attenuation" technique. The radar technique involves the exploitation of vertical polarization S-band meteorological radar reflectivity information to calculate the possible rain attenuation along the satellite propagation paths. All estimated rain fade values were then compared with the actual measured signal of RazakSAT's X-band satellite transmission. The measured X-band (8 GHz) transmission signals were collected and analyzed at the Malaysian National Space Agency (NSA) space center. **Objective:** Preliminary findings concerning the feasibility of each estimation technique are presented in this paper. The research also attempts to investigate the validity of the mentioned rain attenuation estimation techniques. **Results:** Preliminary findings concerning the feasibility of each estimation technique are presented in this paper. The research also attempts to investigate the validity of the mentioned rain attenuation estimation techniques. **Conclusion:** Such knowledge can be considered critical for the design of reliable Earth-Space communication link and certainly can be used in the preliminary proposition plan for the link designers as well as engineers.

To Cite This Article: Khairayu Badron, Ahmad Fadzil Ismail, Nuurul Hudaa Mohd Sobli, Mohamad Kamrul Hasan, Mazslan Ismail, Ooi Sock Teng and Terence Jerome Daim., Assessment of X-band Earth-Satellite link Rain Attenuation Prediction in Malaysia. ***Aust. J. Basic & Appl. Sci.,*** *8(24): 254-259, 2014*

INTRODUCTION

In a tropical climate experienced by Malaysia, intense rainfall is a regular phenomenon all throughout the year. The detailed understanding of the rain fade characteristics at specific frequency of operation is a critical requirement for the design of a reliable terrestrial and Earth space communication link at a particular position. To mitigate the attenuation due to rain, several attenuation counter-measure techniques, for example, site diversity and transmit power control can be established. In this case, the rain fade value is a requirement as the applicable compensational amount. At this particular point in time, very limited studies have been launched to analyze the rain fade characteristics in tropical region. In situation where actual values are not available, several techniques have been proposed to offer estimation of such vital information. The International Telecommunication Union – Radio communication Sector (ITU-R) model is believed to be the most widely accepted globally for the prediction of rain effects on communication systems (Crane, R.K., 1980). However, recent investigators have highlighted that some ITU-R models may only suitably reliable in certain geographical areas such as temperate regions (Omotosho, T.V., C.O. Oluwafemi, 2009; Badron, K., 2013). It is of extreme importance to be able to accurately anticipate the possible impairment encountered on a given link. A number of alternative models have been developed and proposed, claimed to be capable of offering a thorough description of the main propagation impairments including rain attenuation, gaseous absorption, cloud attenuation, scintillation, depolarization and atmospheric noise (Hornbostel, A. and A. Schroth, 1995). These highlighted effects are particularly related within the tropospheric region. Among suggested techniques that can be used to measure rain attenuation is by conducting experiments; where the received signal strengths of a satellite beacon are monitored concurrently with radar observation (Allnutt, J.E. and P. Peregrinus, 1989). In this aspect, any available radar reflectivity data becomes an attractive option for the study of rain attenuation estimation and prediction. The radar reflectivity data can offer huge advantages in predicting rain attenuation

Corresponding Author: Khairayu Badron, ECE dept, Kuliyah of Engineering, International Islamic University Malaysia, Jln Gombak, 53100, Kuala Lumpur, Malaysia.
E-mail: khairayu@iium.edu.my

due to its wide volume area coverage. This was carried out by first adapting the radar reflectivity values into rainfall rate using the established Z-R relations of Marshall-Palmer equation and, afterwards, by evaluating the slant path attenuation through the assimilation of the specific rain attenuation derived at the rainfall rate. The renowned Z-R relation by Marshall and Palmer (Marshall, J.S. and W. McK Palmer, 1948) that relates the value of the measured reflectivity, *Z* to the value of the rainfall rate, *R* is according to;

$$Z = aR^b \quad (1)$$

Marshall and Palmer published the Z-R relation using a set of general parameters of *a* = 200 and *b* = 1.6. One of the concerns would involve convective rain events that are widespread over the tropical regions. These convective events experienced in the tropics are expected to have a different Z-R relation with respect to the stratiform rain events that typically experienced in the temperate regions and the sub-tropical regions. For the tropics, a selection number of *a* and *b* parameters have been proposed by previous researchers (Yeo, J.X., 2012; Wilson, C.L. and J. Tan, 2001). In the study, radar data corresponding to phase of RazakSAT operational campaigns were procured. The estimated attenuation evaluated from the radar reflectivity using data obtained from the Malaysian Meteorological Department (MMD) located at Sepang, Selangor was weighted against the measured satellite slant path rain attenuation.

Malaysian second remote sensing satellite RazakSAT was launched into the Near Equatorial Orbit (NEqO) on 14 July 2009. The received power signals of its X-band downlink were monitored and recorded by the telemetry, tracking and command (TT&C) center at NSA. Received signals during rain were compared to those of clear sky condition in the course of quantifying the attenuation measurements. The detailed recognition of the rain fade at the desired frequency of operation is critical for the design of a reliable terrestrial and/or Earth-space communication link. The displacement between the NSA and radar station is approximately 19 km. An introductory analysis pertaining to the rain attenuation assessment on the X-band satellite links is also included in this paper. One of the critical aims of the study is to guarantee as well as corroborating the reliability of the attenuation due to rain estimated / extrapolated from the Z-R relation models. In achieving such objective, the RazakSAT satellite link information were compiled and processed where the measured attenuation data were utilized to corroborate the results obtained from the radar modeled data.

2 Description of System and Data:

2.1 Radar System:

The radar data employed was attained from the Malaysian Meteorological Department's (MMD) terminal Doppler weather radar (TDWR) installed strategically in the vicinity about 10 km north of Kuala Lumpur International Airport (KLIA). The analysis of rain fade made use of single polarization S-band terminal Doppler weather radar data with an operating frequency of 2.75 GHz. The radar antenna rotates at the rate of 2 revolution per minute (RPM) with pulse repetition frequency (PRF) equals to 300 Hz for scanning elevation angles of less than 5°. The radar will be revolving at faster speed of 4 revolution per minute (RPM) with PRF equals to 1000 Hz for angles of elevation between 5° to 40°. The radar system is programmed to maneuver in two scanning modes. Each mode incorporate sweeps of the surrounding area at a predetermined elevation angles. Each elevation contains 360 rays of data corresponding to 360 azimuth angles with no interlock beams. The radar can view up to 120 km radius.

2.2. RazakSAT Satellite System:

The X-band (8.3 GHz) transmission signals from RazakSAT were received, monitored, and tracked by the Hexapod antenna. The signals were amplified and down-converted into Intermediate Frequency (IF) before ingested to the High-rate Data Receiver (HDR) for demodulation of QPSK signal and bit synchronization. RazakSAT can be considered as a small Low Earth Observation (LEO) weighing only at about 200 kg. The satellite orbits the Earth in a unique positioning identified as Near Equatorial Orbit (NEqO), at nominal altitude of 685 km. RazakSAT is operated and controlled from its ground segment located in Sungai Lang, Banting, Selangor, Malaysia. The ground segment i.e. Malaysian Space Center consists of a Mission Control Station (MCS) and an Image Receiving and Processing Station (IRPS). The RazakSAT mission plan, command generation and telemetry receiving, archiving and analysis was executed accordingly at the MCS by a dedicated team of satellite engineers. Fig. 1 offers the impression of the RazakSAT and the MCS system configuration.

2.3. Rain Gauge Data:

The rainfall rate data measurement were collected from a rain gauge situated within KLIA edge. The rain gauge operated by MMD is the standard capable tipping bucket type. The data is collected by hour and it will be use in the ITU-R rain attenuation prediction for rainfall rate values in the calculation so it will be using local measurement.

RESULTS AND DISCUSSION

3.1. ITU-R Rain attenuation prediction:

ITU-R P.618-11 [13] rain attenuation prediction were calculated using these steps:

1) Elevation angle, θ was obtained as follows:

$$\theta = tan^{-1}\left[\frac{cos(l_{st} - l_{es})cos\,\varphi - 0.45}{\sqrt{1 - cos^2(l_{st} - l_{es})cos\,\varphi}}\right] \qquad (2)$$

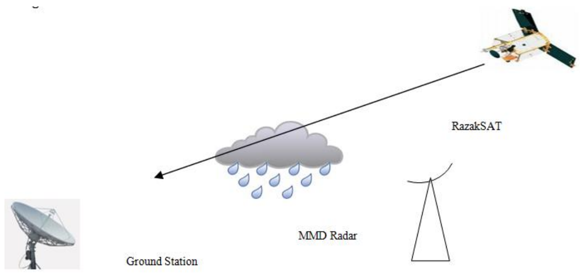


Fig. 1: Overview of RazakSAT System Configuration, the Ground Station located at Banting, Selangor and the MMD radar at Bukit Tampoi (right).

2) Polarization angle, τ was obtained as follows:

$$\tau = tan^{-1}\left[\frac{sin\,|l_{st} - l_{es}|}{tan\,\varphi}\right] \qquad (3)$$

3) If θ≥5°,slant path length, L_S was calculated as:

$$L_S = \frac{(h_R - h_s)}{sin\,\theta} \qquad (4)$$

where rain height, h_R was obtained from ITU-R P.839[14] or local measured value.

4) Horizontal projection, L_G was calculated as below:

$$L_G = L_S\,cos\,\theta \qquad (5)$$

5) The specific attenuation, γ can be obtained using k and α coefficients that was obtained from ITU-R P.838[15];

$$\gamma = kR^{\alpha} \qquad (6)$$

where R is the rainfall rate in mm/hr R was obtained from ITU-R P.837 or local measured value. In this analysis, R isb calculated using the rain gauge value collected at KLIA. The coefficients of specific attenuation, k and α, can be obtained from the ITU-R Rec. P.838–3 and are dependent on the link elevation angle, the radiowave frequency and polarization,

6) Attenuation prediction was obtained as below:

For ITU-R P.618 revision 6 to 11:

$$A = \gamma L_E \qquad (7)$$

where L_E is the satellite path effected by rain.

3.2. RazakSAT Satellite Link:

The signals received each time the satellite passes the ground station during clear sky and rain downpour were identified, measured and compared in the course of action of calculating the rain attenuation. Signal received from RazakSAT are available almost 14 times daily for duration of about 20 minutes each event. Fig. 2 shows the attenuated power received signal which is the difference during clear sky and during downpour condition. The X-band signals at 40°, 20° and 10 ° elevation angles were measured and the variations are listed in Table 1.

Table 1: RazakSat Data Comparison during Clear Sky and Rain events.

RazakSat Elevation angle	Power Received during clear sky (dB)	Power Received During Rain (dB)	Attenuation (dB)
40°	44.02	34.82	9.20
20°	41.33	34.91	6.42
10°	37.56	34.23	3.33

Australian Journal of Basic and Applied Sciences, 8(24) Special 2014, Pages: 254-259

3.2 Radar Derived Rain Attenuation:

The subsequent MMD S-band radar data of the said date and times were retrieved in order to authenticate that the RazakSAT slant path satellite-Earth link was indeed attenuated by heavy downpour. The radar image verifies the existence of rain events where Fig. 3a shows the Plan Position Indicator (PPI) snapshot at the stipulated time from radar data generated using IRIS software where convective rains existed as expected. In tandem, Fig. 3b portrays the display of Range Height Indicator (RHI) scan for the rain event on 1st September 2009 at the time 09:15:37. The vertical axis indicates the height above ground from the ground station site up to 15 km with clear indication of the rain height. The horizontal axis on the other hand shows the range distance from the radar position. In the approach of classifying the probable estimation using the radar information, a solid line was sketch emulating the slant path range distance from ground station to satellite site at Sg. Lang, Selangor at 40° elevation angle. The color bar in both figures indicates the reflectivity (dBZ) that was spotted by the radar.

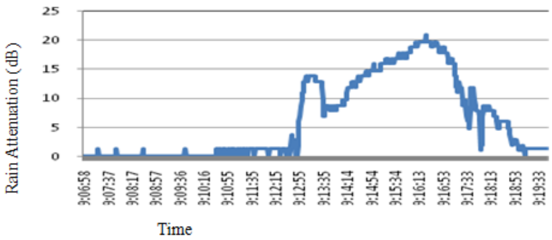
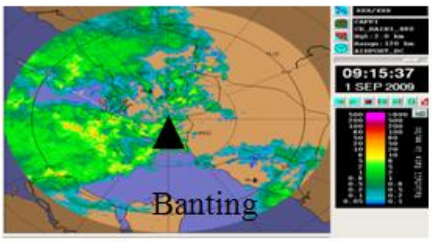


Fig.2 . RazakSAT's signal attenuation during 1/9/2009

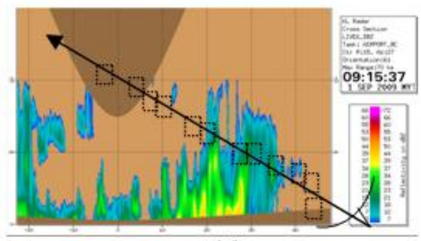
The amount of the slant path fading was then calculated through the numerically summation of;

$$\sum_{i=0}^{n} A = kR_i^{\alpha}.\Delta Li \qquad (8)$$



a)

Fig. 3a: Rain events confirmed using IRIS software on 1/9/2009.



b)

Fig. 3b: RHI scans from ground station towards RazakSAT path on 1/9/2009 for 40° elevation angle.

In (8), R_i is the rainfall rate value derived from the radar and ΔL_i is the path length at each Cartesian i^{th} pixel along the slant path between the Earth station and the satellite affected by rain. Therefore, from the RHI scan, the attenuation can be estimated using radar reflectivity, dBZ values based on each Cartesian grid or what is typically identified as bins/gates. The values of these bins is measured by converting the RHI views into raw data with reflectivity's values. Table 2 shows the conversion procedure.

After calculating each bins along the slant path at different elevation angles of interest (40°, 20° and 10°); subsequently, the *Z-R* relation relates the value of the measured reflectivity to the value of the rain rate according to the general formula given in (1) by Marshall and Palmer. Marshall and Palmer is a well-known *Z-R* relation that was somewhat optimized for stratiform type of precipitation thus $Z = 200R^{1.6}$ .Several angles of the satellite slant path length were assessed where each elevation angle offers different attenuation levels as tabulated in Table 3.

Table 2: Radar Derived Attenuation for each bin for 40° Elevation angle.

Bin No.	Reflectivity (Z)	Rainfall Rate (mm/hr)	Rain Attenuation (dB)
1	5.936723	0.111	0.00854
2	8.410785	0.138	0.00857
3	32.62867	0.322	0.00866
…	…	…	….
…	...	...	…..
600	5.104394	0.101	0.00853
Total Attenuation			8.12

Conclusion:

According on the elected rain event, it can be concluded that the values calculated from ITU-R calculation and the radar reflectivity estimation are found to be lower when compared to the actual RazakSAT satellite measurements. These indicate and suggest that an improvement in the ITU-R formulation and *Z-R* relationship should be thoroughly explored. The upcoming succeeding research undertaking will involve attempts of to accumulate the rain attenuation for a year using radar derived attenuation and devising a formula that can accurately predict the attenuation using the radar reflectivity information. At this particular point, it is observed that lesser elevation involves minor fading with minimal variation than higher elevation angle where longer path length is affected by rain. The Earth-space satellite performance is sturdily reliant on the path length affected by rain as well as precipitation characteristics along the slant path, where both affect the system performance significantly. The research will evidently attempt to constitute a new formula to derive rain fade estimation using radar information in tropical region.

Table 3: Estimated Attenuation Levels from Radar Reflectivity at Different Elevation Angle.

Elevation angle	ITU-R Prediction	Radar estimated values (dB)	Satellite Measurements (dB)	Variation of Sat and ITU-R	Variation of Sat & Radar Derived
40°	5.45	8.12	9.20	3.75	1.08
20°	2.56	4.31	6.42	3.86	2.11
10°	1.34	2.26	3.33	1.99	1.07

REFERENCES

Crane, R.K., 1980. “Prediction of attenuation by rain,” *IEEE Trans.Commun.*, vol. Com-28, 9: 1717-1733.

Omotosho, T.V., C.O. Oluwafemi, 2009. "Impairment of radio wave signal by rainfall on fixed satellite service on earth-space path at 37 stations in Nigeria,” Journal of Atmospheric and Terrestrial Physics, 71(8): 830-840.

Badron, K., A.F. Ismail, H.A.M. Ramli, M. Ismail, S.T. Ooi, S.F. Jamil, 2013. "Evaluation of RazakSAT's S-band link signal measurement with the radar derived rain attenuation," *Space Science and Communication (IconSpace), 2013 IEEE International Conference on* , 380-384: 1-3.

Hornbostel, A. and A. Schroth, 1995. “Comparison of radiometer, radar and rain gauge attenuation predictions with Olympus beacon measurements,” in *Proc. 9th Int. Conf. Antennas Propag. (Conf.Publ.No.407)*, Apr. 4-7.

Allnutt, J.E. and P. Peregrinus, 1989. “Satellite-to-ground radiowave propagation: Theory, practice, and system impact at frequencies above 1GHz,”.

Marshall, J.S. and W. McK Palmer, 1948. “The distribution of raindrops with size,” *J. Atmospheric Sci.*, 5(4): 165-166.

Battan, L.J., 1973. *Radar Observations of the Atmosphere*. Chicago: Univ. Chicago Press, 323.

Ulbrich, C.W., 1983. “Natural variation in the analytical form of the raindrop size distribution,” *J. Appl.Meteor*, 22(10): 1764-1775.

Yeo, J.X., Y.H. Lee, L.S Kumar, J.T. Ong, 2012. "Comparison of S-Band Radar Attenuation Prediction With Beacon Measurements," *Antennas and Propagation, IEEE Transactions on* , 60(10): 4892-4900.

Kumar, L.S., Y.H. Lee, J.X. Yeo and J.T. Ong, 2011. “Tropical rain classification and estimation of rain from Z-R (reflectivity-rain rate) relationships,” *Progr. Electromagn. Res. B*, 32: 107-127.

Wilson, C.L. and J. Tan, 2001. “The characteristics of rainfall and melting layer in Singapore: Experimental results from radar and ground instruments,” in *Proc. 11th Int. Conf. Antennas Propag.*, Apr. 17-20: 852-856.

www.atsb.my/razaksat [Online]

Recommendation ITU-R P.618-10, 2009. Propagation Data and Prediction Methods Required for the Design of Earth-space Telecommunication Systems.

Australian Journal of Basic and Applied Sciences, 8(24) Special 2014, Pages: 254-259

Recommendation ITU-R, 2005. Specific Attenuation Model for Rain for Use in Prediction Methods, Rec. ITU-R P. 838-3 Geneva.

Recommendation ITU-R, 2001. Rain height model for prediction methods", Recommendation ITU-R P.839-3, ITU-R P Sers., Int. Telecomm. Union, Geneva.