Estimating losses at 40-GHz downlink using non-meteorological techniques in heavy rain areas

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Article Info

Article history:

Received Oct 20, 2022
Revised Dec 29, 2022
Accepted Feb 16, 2023

Keywords:

Rain attenuation
Satellite-earth link
Statistical frequency scaling
Tropical regions
V-band

ABSTRACT

The advancement of satellite communication has arisen tremendously where higher capacity communications systems are needed. Most satellite engineers are shifting to Ka, Q, and V-band upcoming since the low frequencies such as below 10 GHz are already congested. Actual measurement data at millimetre-wave frequencies in tropical regions are minimal. The prediction of rain attenuation at frequencies above 10 GHz is required to determine a reliable fade margin. In this paper, a statistical frequency scaling technique has been developed as an alternative way of estimating rain attenuation. The technique was derived based on the correlation between the attenuation ratio of a higher and lower frequency against the attenuation at a lower frequency. The attenuations from the proposed model were compared to the proposed frequency scaling by International Telecommunication Union-R (ITU-R) as well as the conventional ITU-R rain prediction model. To deliver a reliable model, validation methods have been done using a set of data with different years and locations in tropical regions. A dependent prediction technique with the lowest root mean square error (RMSE) value and error was produced. This technique is beneficial in applying suitable mitigation techniques to moderate rain fade in tropical regions.

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1. INTRODUCTION

Rain attenuation is the foremost factor of signal loss or signal fading over satellite and terrestrial links especially in tropical and equatorial regions such as Malaysia [1]-[5]. For application at millimeter-wave (mm-wave) frequency, rain attenuation is a serious problem as frequencies go higher, and the wavelength becomes shorter [6]. The shorter signal wavelength as approaches the size of the raindrops causes signal scattering and absorption [7]-[10]. As a result, the link availability is reduced and the quality of service (QoS) is degraded [11]. The development of a modified frequency scaling of rain attenuation model for tropical in the satellite-earth link was inspired by the overestimation of the frequency scaling model proposed by International Telecommunication Union-R (ITU-R) 618-13 [12]. An accurate prediction of rain attenuation is very essential in planning for satellite-earth microwave links [13]. Frequency scaling is a non-meteorological technique used to predict rain attenuation at desired frequency by deploying attenuation at the base frequency when there is no rainfall data acquired [2], [14], [15]. However, research on statistical frequency scaling in tropical regions for the satellite-earth link is not widely available. Most studies focus on the terrestrial system but the fade margin value found on terrestrial links is much lower than on satellite-earth links [16]-[20].

Thus, the research on frequency scaling focusing on the satellite-to-earth link in tropical regions should be performed. Statistical frequency scaling is the use of statistics from previous measurements at a based frequency to predict attenuation statistics at a desired higher frequency [21]. The statistical attenuation ratio (RAS) can be derived:

$$RAS\left(f_l, f_u, \%_p\right) = \frac{Attenuation\ (f_u, \%_p)}{Attenuation\ (f_l, \%_p)} \quad (1)$$

RAS is denoted as statistical attenuation at upper frequencies over statistical attenuation at lower frequencies at the same percentage time of exceedance, p [22]. When attenuation data measured at base frequency are available, the attenuation ratio in terms of frequency and attenuation is represented by an empirical formula. The formula used for the same path in the frequency range of 7 to 55 GHz is shown [12]:

$$A_2 = A_1\left(\frac{\varphi_2}{\varphi_1}\right)^{1-H(\varphi_1,\varphi_2,A_1)} \quad (2)$$

$$\varphi(f) = \frac{f^2}{1+10^{-4}f^2} \quad (3)$$

$$H(\varphi_1, \varphi_2, A_1) = 1.12 \times 10^{-3} \times \left(\frac{\varphi_2}{\varphi_1}\right)^{0.5} \times (\varphi_1 \times A_1)^{0.55} \quad (4)$$

Where A_1 and A_2 are the equiprobable values of the surplus rain attenuation at lower frequencies f_1 and upper-frequency f_2 (GHz), respectively. According to a previous study, Islam *et al.* [23] focus on the terrestrial link instead of the satellite-earth link. Islam concluded that the results from previous frequency scaling models show that not predict accurately in the tropical climate even though the predictions fit well the desert climate region [23]. In [2] use Boithias's model to apply the frequency scaling technique and there is no validation with measurement data made. De and Maitra [24] found that frequency scaling by ITU-R overpredicting the measurement attenuation at 31.4 GHz. Usha and Karunakar [25] applied ITU-R P.618-13 method for the frequency scaling technique and they highlighted that even though ITU-R frequency scaling can be used in India, there is a probability of getting higher error in other locations including Malaysia. Thus, more tests and analyses are required. Due to inadequacies in available models, new models of frequency scaling technique are proposed in this paper to more accurately reflect the measured data in tropical regions. The proposed model is based on rain attenuation in the year 2016 data and validated with rain attenuation data in the year 2015. After that, the attenuation values by proposed frequency scaling from 12 GHz (Ku-band) to 50 GHz (V-band) were plotted. The rain attenuation at V-band was validated by rain attenuation data in Nigeria, which is also a tropical region country.

2. METHOD

C-band and Ku-band rain attenuation was retrieved from the beacon signal at 4.198 GHz and 12.201 GHz from Malaysia East Asia Satellite-3 (MEASAT)-3. The Ka-band rain attenuation for the frequency of 20.199 GHz was retrieved from the MEASAT-5 or previously known as IPSTAR (Thaicom-4 satellite). The configuration of the measurement setup is shown in Figure 1.

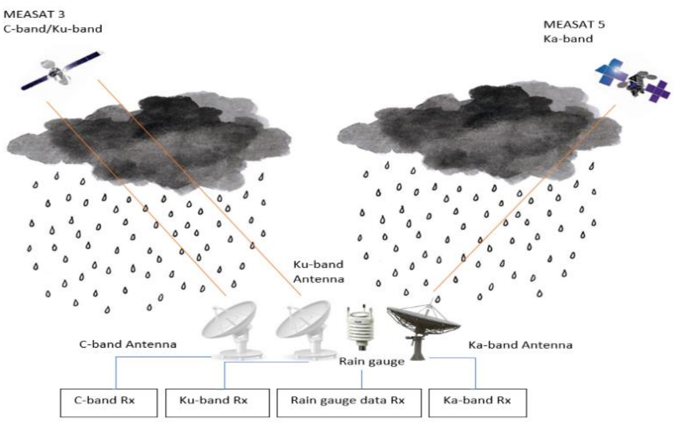

Figure 1. Configuration of the measurement setup

In this paper, the measured power levels during the rainy period of C, Ku, and Ka-band were collected for one year from January to December 2016. The rainfall data were retrieved from a rain gauge location at ASTRO Cyberjaya. The received power signals were processed to obtain statistical analysis data in this paper which is first-order analysis statistics, cumulative distribution function (CDF). From CDF, time exceedance at excess attenuation can be determined. The annual CDFs of rain attenuation at the C, Ku, and Ka-band are plotted with the ITU-R predicted frequency scaling in Figure 2. The figure exhibits significant variation between predicted frequency scaling by ITU-R values and measured values. The prediction of rain attenuation at Ka-band by using ITU-R's frequency scaling model shows that ITU-R underpredicts attenuation value at a time percentage interval of $0.1\% < P < 1\%$ and overpredict attenuation value for attenuation value at time percentage of at time percentage interval of $0.001\% < P < 0.1\%$.

Rain attenuation is the main parameter used in frequency scaling study in the satellite-earth path. Statistical attenuation of frequency scaling is based on the statistics of rain attenuation which is known as CDF. The CDF of rain attenuation from the year 2016 for C, Ku, and Ka-band with their mutual time base are plotted simultaneously with rainfall rate throughout the year 2016 in Figure 3. Figure 3 exhibits that rain attenuations at Ku-band and Ka-band are higher as the rainfall rate increases. From the figure, it can be said that rain attenuation at a higher frequency is proportional to the rainfall rate.

Rain attenuation at Ka-band is severe compared to rain attenuation at Ku-band. The C-band rain attenuation is less affected by rain and cannot be used as a rain attenuation at a base frequency in the frequency scaling technique. Figure 4 shows the graph of the RAS for the year 2016 as a function of the lower frequency attenuation for the frequency pair of Ka-band/Ku-band. A logarithmic equation was fitted to RAS within the percentage interval of $0.05\% < P < 0.4\%$ as shown in (5).

$$A_{fu}/A_{fl} = -1.425 \times \ln(A_{fl}) + C \quad (5)$$

The variable C is referred to as a coefficient which is 2 times of ratio of upper-frequency f_u, and lower-frequency f_l. The attenuation at upper frequency, $A_{(fu)}$ was plotted against attenuation at lower or base frequency, $A_{(fl)}$, as shown in Figure 5, and the following power equation was fitted to the plotted curve given:

$$A_{fu} = (\alpha \times A_{fl}{}^{\beta}) \quad (6)$$

α and β is variable coefficient related to upper and lower frequencies value where α was derived from (7) while β is a modified power model that fits the graph of attenuation at the Ka-band versus that at the Ku-band.

$$\alpha = \sqrt{f_u - f_l} + 1.38 \quad (7)$$

From (6) and (7) that correlate attenuation at upper and lower frequencies, this study proposed newly frequency scaling model. The model is useful for tropical regions which utilized Ku-band rain attenuation data from Cyberjaya as an attenuation at a base frequency to determine attenuation at the desired frequency at the Ka-band link. The proposed frequency scaling of rain attenuation for the Malaysia region is proposed by given (8), where $b = \frac{f_2}{f_1}$.

$$A_2 = (\alpha \times A_1{}^{0.669}) - (1.425 \times \ln b) + (2 \times b) \quad (8)$$

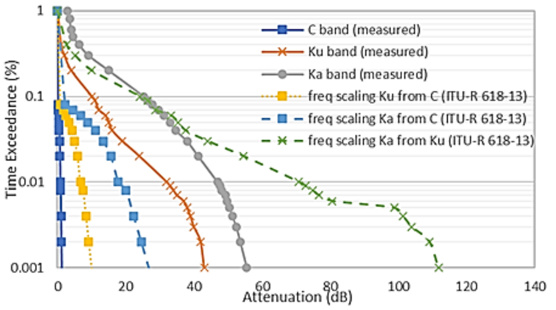

Figure 2. Comparison between predicted frequency scaling by ITU-R values and measured values

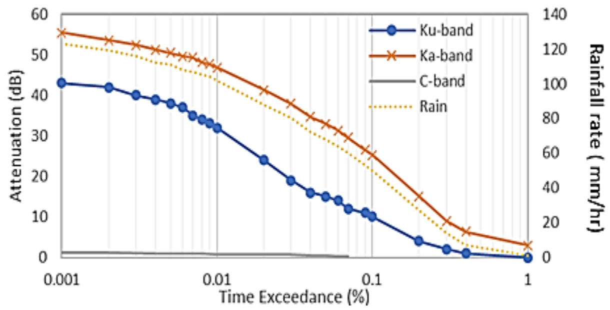

Figure 3. Measured beacon attenuation at C-band, Ku-band, and Ka-band for the year 2016 with rainfall rate

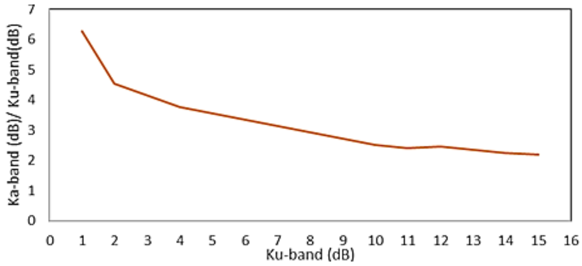

Figure 4. RAS for the year 2016 as a function of the lower frequency attenuation for the frequency pairs of 20/12 GHz

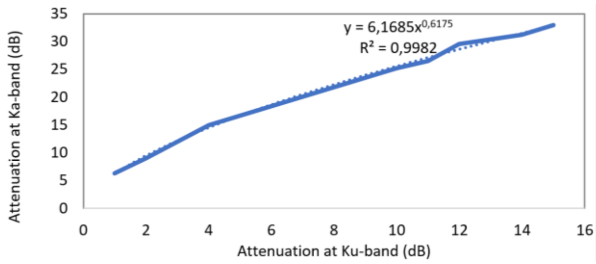

Figure 5. Graph of attenuation at 20 GHz versus that at 12 GHz

3. RESULTS AND DISCUSSION

Attenuation prediction by using the frequency scaling method such a best alternative way to determine rain attenuation at the desired frequency for which there is no data. The proposed model for year-wise estimation of rain attenuation for 20 GHz is depicted in Figure 6. The proposed model fits the measured rain attenuation of the Ka-band compared to the frequency scaling proposed by the ITU-R model.

The ITU-R frequency scaling models and proposed models are being analysed and evaluated by performing percentage error and root mean square error (RMSE) values. At the same probability level, the percentage errors, $\varepsilon(P)$, between measured rain attenuation data ($A_{\%p,}$ measured) and the model's predictions ($A_{\%p,}$ predicted) are evaluated within the percentage interval of 0.001% < P < 1%, is shown in (9).

$$Percentage\ error, \varepsilon = \left(\frac{A_{\%p,}Predicted - A_{\%p,}measured}{A_{\%p,}measured \times 100}\right) \quad (9)$$

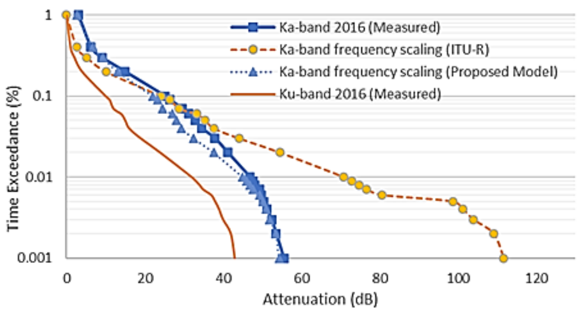

Figure 6. The proposed model compared with ITU-R's frequency scaling and measured rain attenuation at the Ka-band of the year 2016

The validation step is made to strengthen the proposed model. Thus, in this paper, the model is being validated with the Ka-band rain attenuation of the year 2015. Figure 7 represents the comparison of the frequency scaling of Ka-band rain attenuation of the year 2015 using the proposed model as well as using ITU-R's frequency scaling and measured rain attenuation at the Ka-band of the year 2015. The percentage error and RMSE values were also calculated to evaluate the model. The RMSE and percentage error for proposed frequency scaling for rain attenuation in the years 2015 and 2016 are presented in Table 1 in comparison with the frequency scaling model proposed by ITU-R for the years 2015 and 2016. From the table, the proposed model has lower RMSE and percentage error for rain attenuation at Ka-band in the year 2016 which are 2.8 and 11.3% error compared to rain attenuation at Ka-band that scaled by ITU-R which are 28.3 RMSE and 28% error. When validating the proposed model with the rain attenuation data for the year 2015, the RMSE value and percentage error are also lower than frequency scaling by ITU-R as shown in Table 1.

The derived attenuation values using the proposed frequency scaling from 12 GHz (Ku-band) to 50 GHz (V-band) were plotted in Figure 8 in the range of 0.01% < P < 0.1%. At 0.01% of time exceedance, the attenuation value predicted by the proposed model is 83 dB, while measured rain attenuation at V-band in Nigeria is 75 dB. The percentage error obtained is about only 10%. The proposed model fits well with the measured attenuation data of the V-band in Nigeria. Thus, this model can be an alternative technique to be applied for tropical regions in predicting rain attenuation at higher frequencies with no data provided.

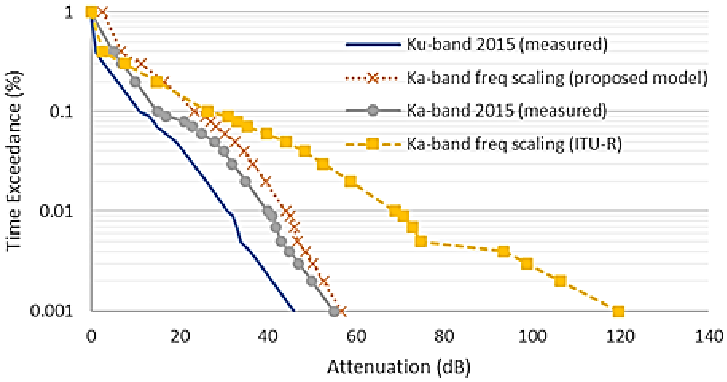

Figure 7. Frequency-scaled Ka-band rain attenuation of the year 2015 using the proposed model compared with ITU-R's frequency scaling and measured rain attenuation at Ka-band

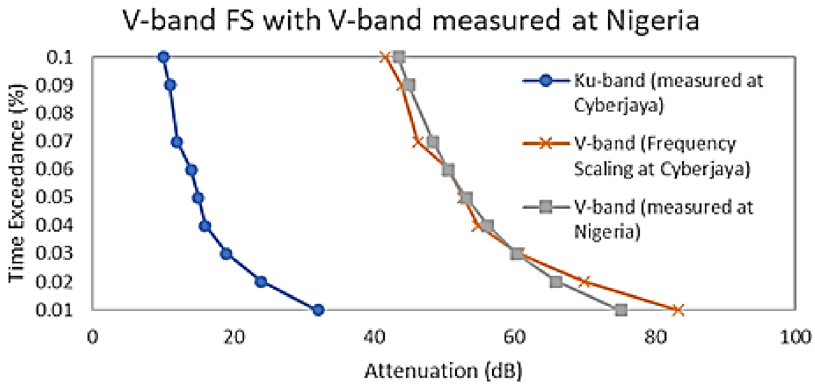

Figure 8. The attenuation value by proposed frequency scaling from 12 GHz (Ku-band) to 50 GHz(V-band)

Table 1. Comparison values of the RMSE value and percentage error proposed model with the rain attenuation data for the year 2015 and frequency model by the ITU-R

No	Model of frequency scaling	RMSE	Error (%)
1	Proposed model for Ka-band rain attenuation of the year 2016	2.8	11.3
2	Proposed model for Ka-band rain attenuation of the year 2015	4.9	31.7
3	ITU-R for Ka-band rain attenuation of the year 2016	28.3	28.0
4	ITU-R for Ka-band rain attenuation of the year 2015	30	58

4. CONCLUSION

Based on data analyses and scientific concern on millimetre-waves applied in tropical regions which experienced severe rainfall, the use of rainfall rate and attenuation at the base frequency as the main parameters for modelling frequency scaling that can be used in tropical regions. In this paper, the correlation between rainfall and attenuation has been observed as a major contribution to constructing a new model for statistical frequency scaling in tropical regions. The newly proposed frequency scaling model is capable of offering higher accuracy in predicting the V-band link rain attenuation in tropical regions. Furthermore, these analyses will provide a wide idea of rain attenuation at higher frequencies to satellite communication engineers for designing link budgets for improved signal propagation in equatorial regions specifically.

ACKNOWLEDGEMENTS

The acknowledgement goes to MEASAT Satellite System Sdn Bhd (MEASAT), and ASTRO Broadcast Centre (ASTRO) for providing data for this research project. The authors also acknowledge the Research Management Centre (RMC) of the International Islamic University Malaysia (IIUM) for the financial assistance for this study.

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