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Research Article

Earth-Space Rain Attenuation Prediction: Its Impact at Ku, Ka and V-band Over Some Equatorial Stations

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Abstract. Attenuation due to rain predictive models have been used to calculate the impact of rainfall on satellite communication for six stations in Malaysia. The impact of rainfall is very important for designing a modern satellite system for heavy rainfall climatic regions like Malaysia, with large annual rainfall accumulation exceeding 3000 mm and rainfall rate exceeding 150 mm/h at Ku (12/14 GHz), Ka (20/30 GHz) and V (40/50 GHz) bands. The present result shows that the avalibility of link for 99.99% at the three bands for uplink and downlink to Malaysian Communication Satellite (MEASAT-3a) is not practicable. The results suggest link availability of 99.9% for Ku-uplink and Ka downlink, while 99% for Ka uplink and 99% for V band uplink and downlink due to high annual rainfall rates for most of the stations. The overall result shows that the impact of heavy rainfall on satellite communication will be more severe in the Eastern part than the Western of Malaysia.

Keywords. Rain accumulation; Rainfall rate; Rain attenuation; Ku, Ka and V bands; Satellite communication; Earth space link

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1. Introduction

The attenuation of transmitted signals by rain is a well known effect that becomes very severe at frequencies above 10 GHz as the wavelength of the transmitted signal become comparable to the size of the raindrop. The advance in technology and the demand for more communication channels or larger bandwidth for both terrestrial and earth-space communication has led to frequency-spectrum congestion at C (4/6 GHz) and Ku (12/14 GHz) band. The enormous bandwidth and frequency channels available at Ka (20/30 GHz) and V (40/50 GHz) band for wireless telecommunication services such as Multipoint Video Distribution Systems (MVDS), Digital Multimedia Applications (DMA), Local Multipoint Distribution Systems (LMDS), satellite networks, and fast internet access. These results for Ka and V bands are to be vital for the exploitation of new services [5]. Despite the above advantages rain causes the signal transmitted to fade causing a reduce in the signal strength at the receiver. This effect significantly reduces the availability if signal strength of satellite communication operating at Ka and V bands. The level of the signal strength depends strongly on the fall speed of raindrops, size distribution and temperature [17]. The impact of attenuation due to rain can be predicted by measuring the heaviness of the rain often described by the “rain rate” which is measured in millimeters of accumulation per hour. This paper study and predict the impact of rain at Ku, Ka and V bands for earth-space communication for six stations that covers the Western Peninsula and the Eastern Part (EP) of Malaysia.

1.1 Climate of Malaysia

Malaysia is located between Latitude 1° to 7°N near the equator and longitude 99° to 120 °E. The climate type is categorized as equatorial, being hot and humid throughout the year. The average annual rainfall accumulation and temperature is about 2500 mm [22] and 27 °C respectively [16]. Western Peninsula (WP) and the Eastern Peninsula (EP) differs from each other, whereby the WP is influenced by the flow of wind from the mainland. Malaysia experience two monsoon seasons, which is the Southwest Monsoon (SWM) that occurs from May to September and the Northeast Monsoon (NEM) from November to March. The two inter monsoons in the months of April and October bring heavy rainfall to this region in the form of convective rain. The SWM is the driest period throughout the whole country and NEM influence the country with heavy rainfall due to the gusty winds from the South China Sea. The *Titiwangsa* mountain range which is the backbone of Malaysia, divides the country into lowlands, coastal region and the highlands. The coasts rainfall ranging from 100 mm to 300 mm in a month. The lowlands show very high humidity levels and follow a more typical rainfall pattern. The highlands are covered with large amounts of cloud cover with high relative humidity above 75% [18]. Figure 1 presents the Map of Malaysia and the six stations used in the study which consist of lowlands, coastal region and the highlands.

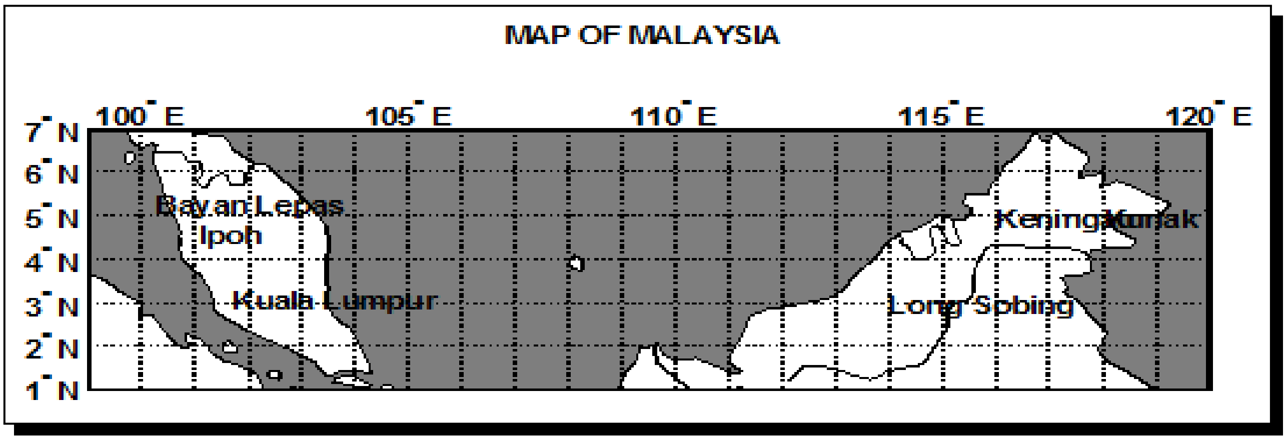

Figure 1. The Six Locations in Malaysia

2. Methodology

2.1 Rainfall Rate Prediction Models

Many models exist to predict the cumulative distribution of rain rate which most of them are influenced by the International Telecommunication Union Radiowave Propagation (ITU-RP). Other rainfall rate models are the works of Rice-Holmberg [21], Crane [2], Segal [23], Moupfouma and Martins [19], Chebil's and Rahman [1] Ito and Hosoya [10], Dutton-Dougherty model [4] to mention but a few. The current literature review suggests that rain rate distribution is better described by a model which is closer to a log-normal distribution at the lower rainfall rates, and a gamma distribution at the higher rainfall rate. Emiliani *et al.* [5] in his literature clearly states that the Ito and Hosoya [10] model was found to be applicable worldwide. Ito and Hosoya, the proposed model is based on global databases and introduces a thunderstorm ratio β coefficient as a meteorological input.

Therefore, Ito and Hosoya model was used to estimate the 1-min point rain rate for six stations in Malaysia. The input parameters needed for the model are, the annual rainfall accumulation M, in mm, thunderstorm ratio β, and percentage of time unavailability Pin %. The rainfall accumulation data used in this study starts from 1950 to 2010, from various data sources such as; National Oceanic and Atmospheric Administration (NOAA) global summary of the day, Global Precipitation Climatology Centre (GPCC), NASA and Tropical Rainfall Measuring Mission (TRMM) satellite sensors, the Microwave Imager (TMI, 3A12 V6), and Data Precipitation Product (3B43 V6) were used to derive the thunderstorm ratio.

The Ito and Hosoya [10] model is divided into mode 1 rain ($M1$) which consists of rainfall other than convective and thunderstorm rainfall events and mode 2 rain ($M2$) relates to high rainfall rates associated with strong convective activity and thunderstorms. The total average rainfall accumulation M is given as

$$M = M1 + M2 \quad (\text{mm}). \tag{1a}$$

β is the ratio of thunderstorm rain accumulation to the total rainfall accumulation given as

$$\beta = \frac{M1}{M}. \tag{1b}$$

Based on the equations, the rain rate for different percentages of time, R_p (mm/h) is give below. The model uses coefficients a_p, b_p, c_p with $x = \log(p)$ given in equations (3) to (5) that was based on data collected from 290 data sets from 84 locations in 30 countries, and a databank of different integration time rain rates, which contains data sets from 54 locations in 23 countries.

$$R_p = a_p M^{bp} \beta^{cp} \tag{2}$$

$$\log(a_p) = 0.1574155x^4 + 1.348171x^3 + 3.528175x^2 + 1.479566x - 2.302276, \tag{3}$$

$$b_p = -0.004583266x^4 - 0.4098161x^3 - 1.162387x^2 - 0.8261178x + 0.911857, \tag{4}$$

$$c_p = 0.002574688x^4 + 0.1549031x^3 + 0.1747827x^2 - 0.2846313x + 0.001255081. \tag{5}$$

2.2 Rain attenuation Prediction Models

About sixteen attenuation due to rain models published in COST 255 reports [9] that claims global applicability. Out of these sixteen models, three rain attenuation prediction methods namely; Crane Global [3], Garcia [7] and Karasawa [15] models were used to estimate the impact of rain at Ku, Ka and V bands for the six stations. Among the three models, the ITU RP.618-9 model [11] has been reported to be among the best rain attenuation prediction model by Restrepo et al., [20] in tropical and equatorial climates [20]. The procedure for step-by-step calculation of the four models are given below.

2.2.1 The ITU-R Model

The input parameters needed for the ITU-R model are point rainfall rate data for the station for 0.01% of an average year (mm/h), height of the station above sea level (km), the dish elevation angle, latitude of the Earth station (degree), transmitting or receiving frequency (GHz) of the earth station, effective radius of the Earth (8500 km) and the frequency- polarization dependent coefficients given in ITU-RP 838 [13].

Step 1: Determine the rain height, h_R, as given in Recommendation ITU-R P.839 [14].

Step 2: For q^3 5° compute the slant-path length, L_s, below the rain height from:

$$L_s = \frac{(h_R - h_s)}{\sin\theta} \text{ km}. \tag{6}$$

For $q < 5°$, the following formula is used:

$$L_s = \frac{2(h_R - h_s)}{\left(\sin^2\theta + \frac{2(h_R - h_s)}{R_e}\right)^{1/2} + \sin\theta} \text{ km}. \tag{7}$$

If $h_R - h_s$ is less than or equal to zero, the predicted rain attenuation for any time percentage is zero and the following steps are not required.

Step 3: Calculate the horizontal projection, L_G, of the slant - path length from:

$$L_G = L_s \cos q \ \text{ km}. \tag{8}$$

Step 4: Obtain the rainfall rate, $R_{0.01}$, exceeded for 0.01% of an average year (with an integration time of 1 min). If this long-term statistic cannot be obtained from local data sources, an estimate can be obtained from the maps of rainfall rate given in Recommendation ITU-R P.837 [12]. If $R_{0.01}$ is equal to zero, the predicted rain attenuation is zero for any time percentage and the following steps are not required.

Step 5: Obtain the specific attenuation, g_R, using the frequency-dependent coefficients given in Recommendation ITU-R P.838 and the rainfall rate, $R_{0.01}$, determined from Step 4, by using:

$$g_R = k(R_{0.01})^a \ \text{ dB/km}. \tag{9}$$

Step 6: Calculate the horizontal reduction factor, $r_{0.01}$, for 0.01% of the time:

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\frac{L_G \gamma_R}{f}} - 0.38\left(1 - e^{-2L_G}\right)}. \tag{10}$$

Step 7: Calculate the vertical adjustment factor, $v_{0.01}$, for 0.01% of the time:

$$\zeta = \tan^{-1}\left(\frac{h_R - h_s}{L_G r_{0.01}}\right) \ \text{ degrees}.$$

For $z > q$, $L_R = \dfrac{L_G r_{0.01}}{\cos\theta}$ km

Else, $L_R = \dfrac{(h_R - h_s)}{\sin\theta}$ km

If $|j| < 36°$, $c = 36 - |j|$ degrees

Else, $c = 0$ degrees

$$v_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}\left(31\left(1 - e^{-(\theta/(1+\chi))}\right)\frac{\sqrt{L_R \gamma_R}}{f^2} - 0.45\right)}.$$

Step 8: The effective path length is:

$$L_E = L_R n_{0.01} \text{ km}. \tag{11}$$

Step 9: The predicted attenuation exceeded for 0.01% of an average year is obtained from:

$$A_{0.01} = g_R L_E \text{ dB}. \tag{12}$$

Step 10: The estimated attenuation to be exceeded for other percentages of an average year, in the range 0.001% to 5%, is determined from the attenuation to be exceeded for 0.01% for an average year:

If p^3 1% or $|j|^3$ 36°: $b = 0$

If $p < 1\%$ and $|j| < 36°$ and q^3 25°: $b = -0.005 \ (|j| - 36)$

Otherwise: $b = -0.005\ (|j| - 36) + 1.8 - 4.25 \sin q$

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{-(0.655+0.033\ln(p)-0.045\ln(A_{0.01})-\beta(1-p)\sin\theta)} \text{ dB}. \tag{13}$$

2.2.2 The Crane Global Model

The input parameters required for the Crane global model are;

f: the frequency of operation, in GHz,

θ: the elevation angle to the satellite, in degrees

φ: the latitude of the ground station, in degrees N or S,

hs: the altitude of the ground station above sea level, in km and

τ: the polarization tilt angle with respect to the horizontal, in degrees.

Step 1: Determination of the rain rate distribution

Determine the global model rain climate region, Rp, for the ground station of interest from the long-term measured rain rate distributions available for the location of interest preferably not less than 10-years average data.

Step 2: Determination of rain height

The rain height, $h(p)$, used for the global model is a location dependent parameter based onthe 0° isotherm (melting layer) height. The rain height is a function of station latitude φ and percent of the year p.

Step 3: Determine the surface projected path length

The horizontal (surface) path projection of the slant path, D, is found from the following:

For $\theta \geq 10°$

$$D = \frac{h(p) - h_s}{\tan\theta} \tag{14}$$

For $\theta < 10°$

$$D = R\sin^{-1}\left[\frac{\sin\theta}{h(p)+R}\left(\sqrt{(h_s+R)^2 sin\theta + 2R(h(p)-h_s) + h^2(p) - h_s^2} - (h_s+R)\sin\theta\right)\right] \tag{15}$$

where R is the effective radius of the earth, assumed to be 8500 km.

Step 4: Determine the specific attenuation coefficients

The specific attenuation is based on the relationship

$$g_R = a(R_P)^b \tag{16}$$

where γ_R is the specific attenuation in (dB/km) and a and b are frequency dependent specific attenuation coefficients. These are the same coefficients that are used in the ITU-R Rain Attenuation Model. They were defined as k and α in that model, in keeping with the ITU-R designations. The a and b coefficients are found from the regression coefficients from

$$a = [k_H + k_V + (k_H - K_V)\cos^2\theta\cos 2\tau]/2$$

$$b = [k_H\alpha_H + k_V\alpha_V + (k_H\alpha_H - k_V\alpha_V)\cos^2\theta\cos 2\tau]/2a \tag{17}$$

where θ is the path elevation angle and τ is the polarization tilt angle with respect to the horizontal.

Step 5: Determine empirical constants

Determine the following four empirical constants X, Y, Z, U for each probability p of interest:

$$X = 2.3R_P^{-0.17},$$
$$Y = 0.026 - 0.03\ln R_P,$$
$$Z = 3.8 - 0.6\ln R_P,$$
$$U = \frac{\ln(Xe^{YZ})}{Z}, \tag{18}$$

where Rp is the rain rate at the probability $p\%$, obtained from Step 1.

Step 6: Mean slant path attenuation

The mean slant-path rain attenuation, $A(p)$, at each probability of occurrence, p, is determined as follows:

for $0 < D \le d$:

$$A(p) = \frac{aR(p)^b}{\cos\theta}\left[\frac{e^{UbD}-1}{Ub}\right]$$

for $d < D \le 22.5$:

$$A(p) = \frac{aR(p)^b}{\cos\theta}\left[\frac{e^{UbD}-1}{Ub} - \frac{X^b e^{Ybd}}{Yb} + \frac{X^b e^{YbD}}{Yb}\right] \tag{19}$$

For $D > 22.5$, calculate $A(p)$ with $D = 22.5$, and the rain rate $R'(p)$ at the probability value:

$$p' = \left(\frac{22.5}{D}\right)p \tag{20}$$

Step 7: Upper and lower bounds

The Crane global model provides for an estimate of the upper and lower bounds of the mean slant path attenuation. The bounds are determined as the standard deviation of the measurement about the average and are estimated from the table given in [3] for percentages exceedance 0.001%, 0.01%, 0.1% and 1% of an average years are ±39, ±32, ±32, and ±39, respectively.

2.2.3 The Garcia Model

The input parameters required for the Garcia model are; point rainfall rate data for the station for $R(P)$, for $P\%$ of an average year (mm/h), height of the station above sea level (km), the dish elevation angle (θ), latitude of the Earth station (degree), transmitting or receiving frequency (GHz) of the earth station, and the frequency-polarization dependent coefficients given in ITU-RP 838. The proposed method for satellite radio links is an extension of that proposed for terrestrial links [8, 6].

Rain attenuation A_s (dB) in a satellite link is obtained by

$$A_s = kR_p^{\alpha}L_s/\{a + [L_s(bR + cL_s + d)/e]\} \tag{21}$$

where Ls is the equivalent path length, in km for $\theta \geq 5^\circ$, given by

$$L_s = (H_r - H_s)/\sin\theta \tag{22}$$

with

$$H_r = \begin{cases} 4 \text{ [Km]} & 0 < |\lambda| < 36^\circ \\ 4 - 0.075(|\lambda| - 36^\circ) \text{ [Km]} & |\lambda| \geq 36^\circ \end{cases} \tag{23}$$

The coefficients a, b, c, and d are constants depending, in general, on the geographical area and can be determined easily by regression techniques based on simultaneous rain attenuation and rain intensity. Coefficient e is only a scaling factor. Taking $e = 10^4$, the "worldwide" coefficients are: $a = 0.7$, $b = 18.35$, $c = -16.51$, $d = 500$.

2.2.4 The Karasawa Model

The input parameters required for the Karasawa model are exactly the same as ITU-R model except $R_{0.1}$ is needed. The step by step procedure for calculating the attenuation distribution is given below.

Step 1: Calculate the effective rain height, H_r, as follows:

$$H_r[Km] = \begin{cases} 4 - 0.075(|\lambda| - 36^\circ) & \text{for } |\lambda| \geq 36^\circ \\ 3 + 0.028 * |\lambda| & \text{for } |\lambda| < 36^\circ \end{cases} \tag{24}$$

Step 2: Calculate the vertical reduction factor, r_v:

$$r_v = \frac{H_r}{h_R} \tag{25}$$

Step 3: Compute the slant-path length, $Ls[km]$, from:

$$\begin{aligned} L_s &= \frac{r_v(H_R - H_s)}{\sin\theta} & \theta \geq 5^\circ \\ L_s &= \frac{2r_v(H_R - H_s)}{\sqrt{\sin^2\theta + \frac{2r_v(H_R - H_s)}{R_e}} + \sin\theta} & \theta < 5^\circ \end{aligned} \tag{26}$$

Step 4: Calculate the horizontal projection, $L[km]$, of the slant path length from:

$$L = L_s\cos\theta \tag{27}$$

Step 5: Calculate the horizontal reduction factor, rh, 0.01, from:

$$r_{h,0.01} = \frac{1}{1 + L/L_O}, \tag{28}$$

where

$$L_O = 35\exp(-0.015R_{0.01})R_{0.01} \leq 80 \text{ [mm/h]},$$

$$L_O = \frac{94}{\sqrt{R_{0.01}}} R_{0.01} > 80 \text{ [mm/h]}. \tag{29}$$

Step 6: Obtain the specific attenuation, $\gamma_{0.01}$, from:

$$\gamma_{0.01} = KR_{0.01}^{\propto} \tag{30}$$

Step 7: The predicted attenuation exceeded (dB) for 0.01% of an average year is obtained from:

$$A_{0.01} = \gamma_{0.01} L_s r_{h,0.01} \tag{31}$$

Step 8: The predicted attenuation exceeded (dB) for 0.1% of an average year is obtained from:

$$A_{0.1} = [0.38\left(\frac{R_{0.1}}{R_{0.01}}\right) + 0.23]A_{0.01} \tag{32}$$

Step 9: Calculate the rain attenuation, As, as a function of time percentage, p:

$$A_s = \begin{cases} 10^{m+sq(p)} & 0.01 \le p \le 1 \\ A_{0.01} - 1.74s10^{m+3.1s}(\log_{10} p + 2) & 0.001 \le p \le 0.01 \end{cases} \tag{33}$$

where

$$q(x) = 2.33 - 0.847x - 0.144x^2 - 0.0657x^3,$$

$$x = 1 + \log_{10} p,$$

$$m = 4.03\log_{10} A_{0.1} - 3.03\log_{10} A_{0.01},$$

$$s = 1.30\log_{10}(A_{0.01}/A_{0.1}). \tag{34}$$

Four programs were written for the computation of the rain attenuation A(dB) models, namely; "*ITUR*", "*Crane*", "*Garcia*", and "*Karasawa*" in Matlab for equations (6) to (34). Each program can be invoke as a function from Microsoft Excel, taking all the input parameters listed above.

3. Results and Discussion

The geometrical and climatic input parameters for the six stations and for links to Malaysian Communication Satellite (MEASAT-3a) launched in 2009 is placed on geostationary orbit position 91.5°E, presently it carries only a Ku spot beam antenna power of 120W. An hypothetical spot beam antenna was assumed to also be on MEASAT-3a for Ka and V band, therefore the impact of rain at Ka and V bands for exceedance probabilities of 0.001 to 1% of an average year is also investigated.

The results of rainfall accumulation and the rainfall rate for 0.01% exceedance is generally high for five of the six stations (104 to 154 mm/h) except Bayan Lepas (85 mm/h). This is because of higher annual rainfall accumulation at the five stations (> 2500 mm) while Bayan Lepas accumulation is < 2500 mm. The calculated satellite look angles to MEASAT-3a for the six stations is between 58° to 78° and the rain height from ITU-R data base is between 4.85 to 4.89 km.

Figures 2a to 2f present the results of rain attenuation for the four models at the three bands for exceedance probabilities of 0.001 to 1% of an average year. Garcia model is consistent but underestimate rain attenuation at the three bands, this is because of the "worldwide" coefficient a, b, c, d used in equation (21), which may not be applicable in all geographical area. The Crane global model overestimate rain attenuation between 10 GHz to 30 GHz and underestimate above 30 GHz, this is because the model was designed based on data from the North America (USA) a temperate climate. Karasawa model prediction of rain attenuation is moderate and consistent for frequency between 10 to 50 GHz. ITU model was only consistent between 10 GHz to 30 GHz, but above 30 GHz it overestimates rain attenuation, this is because the model was design base on rain attenuation data base from most climatic regions of the world for frequencies between 9 GHz to about 35 GHz.

Therefore, in this study the ITU model will be used as the standard to predict rain attenuation for frequencies between 10 and 30 GHz for the six stations. The Karasawa prediction model (as stated in Section 2) is similar with ITU model only that the point rainfall rate at 0.1% for the station is needed as one of the input parameters to estimate rain attenuation for other percentages of time. Therefore because of the consistency of the Kasarawa model in predicting rain attenuation at all the frequencies and not over predicting at higher frequency, it will be used in this paper to estimate the impact of rainfall for frequencies between 40 to 50 GHz for the six stations in Malaysia. At 1% exceedance, the results presented in Figure 2a to 2e shows that the predicted rain attenuation by Kasarawa and Crane models are very close with a difference of about 0.5 dB to 1 dB, while ITU model underestimate rain attenuation up to about 12 dB for the same frequency between 40 to 50 GHz.

Using the ITU-model, at Ku band downlink (12 GHz) 99.99% availability of signal may be possible as the power loss in rainfall is between 12 to 18 dB (15 to 63 W) in all the six stations. But for Ku uplink (14 GHz) it may not be practicable in Kuala Lumpur, Ipoh and Long Sobing, because the attenuation in the three stations is between 22 to 25 dB (158 to 300 W). The power loss in rain for Bayan Lepas, Keningau and Kunak is between, 18 to 20 dB (63 to 100 W), since MEASAT-3a carries a Ku spot beam antenna power of 120W, 99.99% availability of signal may be possible at the latter three stations this fulfill the ITU-R standard of 53-minute outage of signal in an average year or 0.01% unavailability.

At Ka uplink (30 GHz) Figure 2d suggest that a system design of 53-minute to 8.8 hours outage (0.01 to 0.1% unavailability) in a year may not be practicable in Kuala Lumpur and Long Sobing, because the attenuation in rainfall for the two stations is greater than 35 dB. A Ka spot beam antenna power greater than 1000 W (30 dB) is required to overcome the impact of rain. The loss in rainfall for Bayan Lepas, Keningau and Kunak at 30 GHz is between 23 to 25 dB. The only achievable system design for Ka-uplink in all the six stations is 99% availability in an average year (or 88 hours outage in a year) due to heavy rainfall.

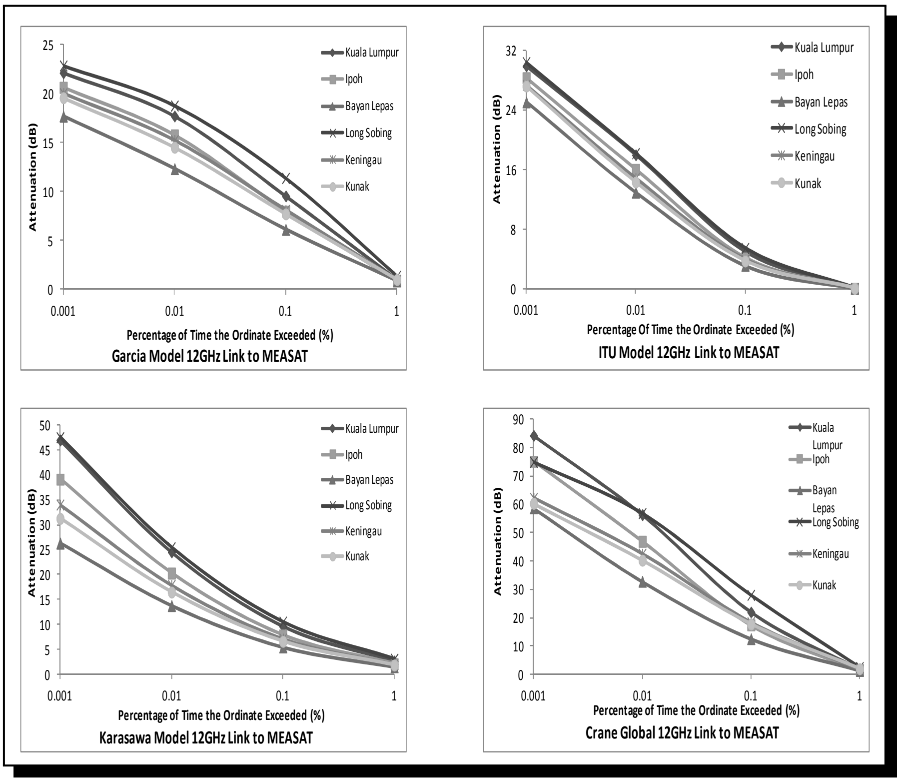

Figure 2a. Rain attenuation (dB) at Ku, (12 GHz) for exceedence probabilities of 0.001-1% of an average year

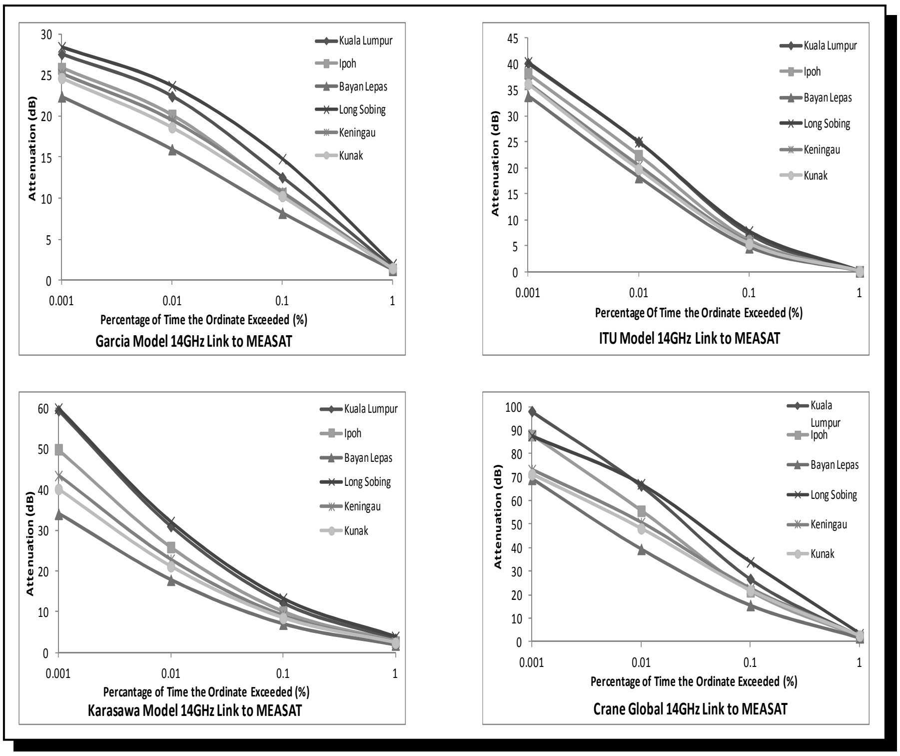

Figure 2b. Rain attenuation (dB) at Ku, (14 GHz) for exceedence probabilities of 0.001-1% of an average year

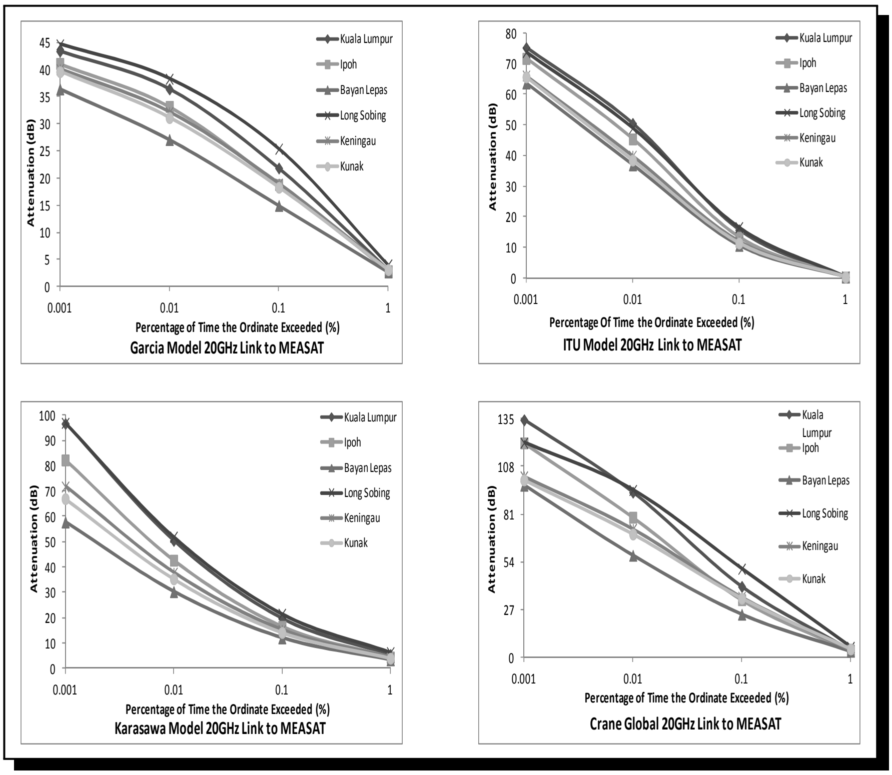

Figure 2c. Rain attenuation (dB) at Ka (20 GHz) for exceedence probabilities of 0.001-1% of an average year

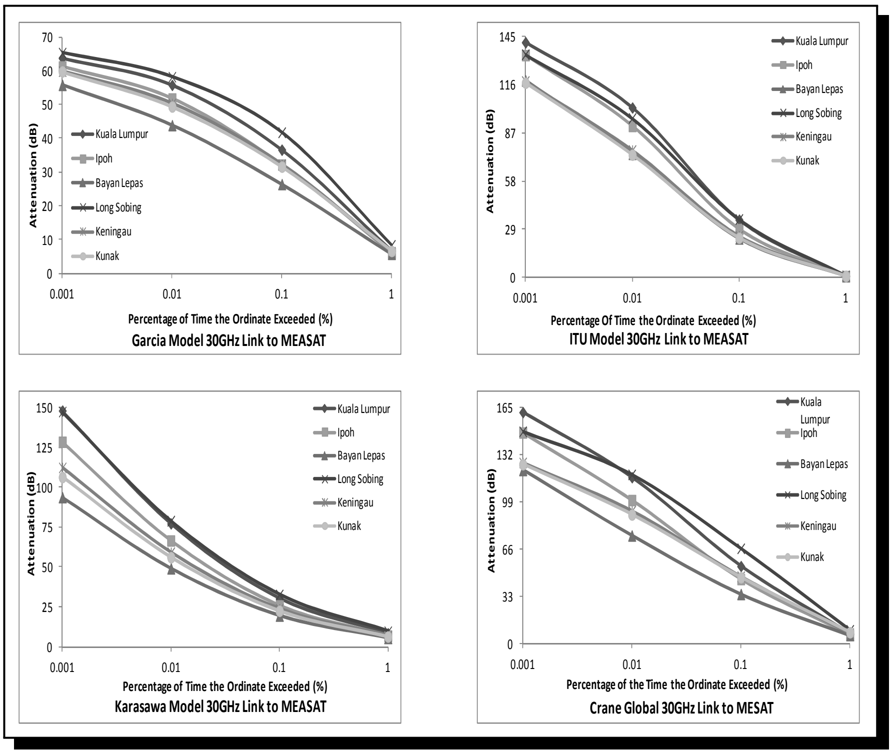

Figure 2d. Rain attenuation (dB) at Ka (30 GHz) for exceedence probabilities of 0.001-1% of an average year

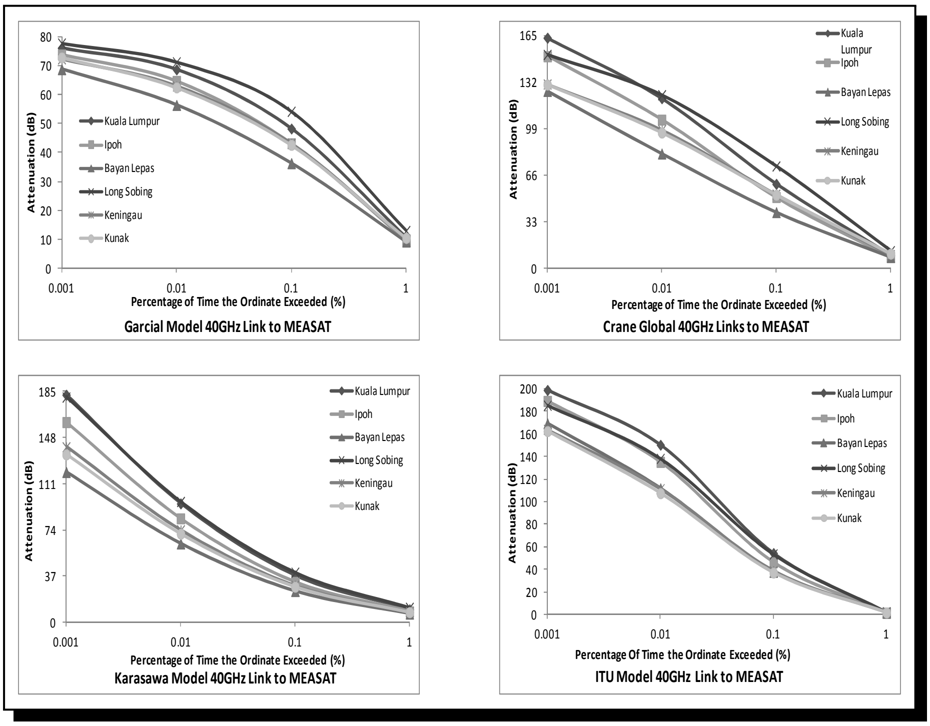

Figure 2e. Rain attenuation (dB) at V (40 GHz) for exceedence probabilities of 0.001-1% of an average year

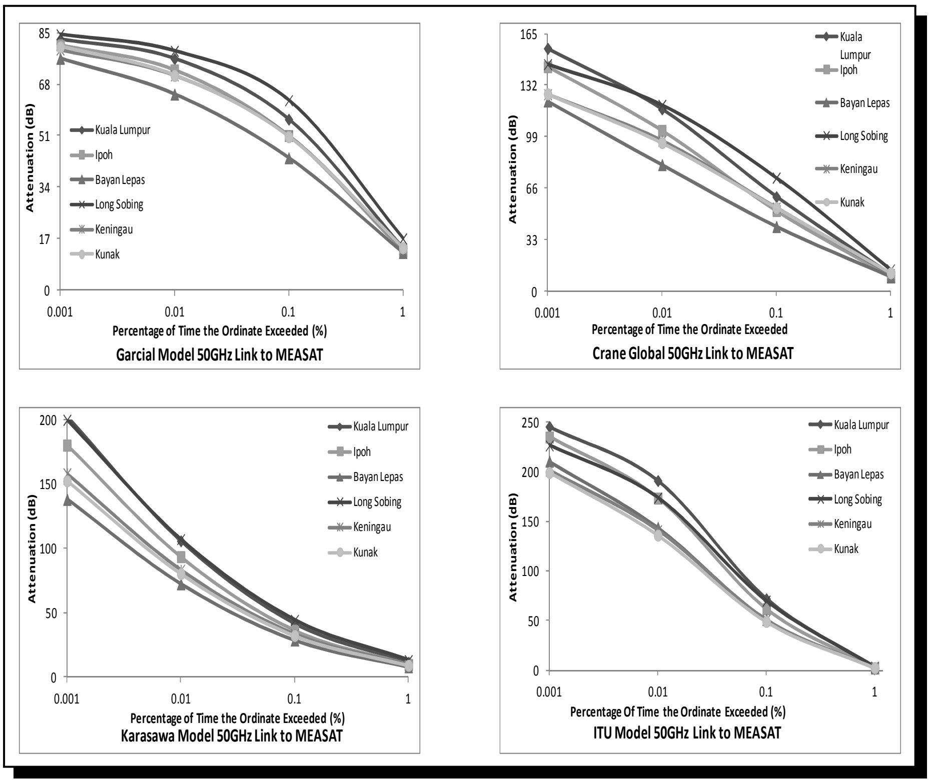

Figure 2f. Rain attenuation (dB) at V (50 GHz) for exceedence probabilities of 0.001-1% of an average year

At Ka-downlink (20 GHz) the results in Figure 2c shows that at 0.01% exceedance in a year (or 99.99% availability of signal) is not practicable due rain, the loss is between 38 to 50 dB. A system design of 99.9% availability is achievable (8.8 hours outage per year), because rain attenuation at 0.1% exceedance is between 11 to 17 dB.

Using the Karasawa model at V-band uplink and downlink (50/40 GHz) the result in Figures 2e and 2f suggest that a system design from 0.001 to 0.1% exceedance is not practicable because rain attenuation is between 32 to 200 dB in five stations except at 40 GHz in Bayan Lepas (25 dB). A V-band spot beam antenna power of about 1.5 KW will be needed to overcome 32 dB loss in rainfall to achieve 99.9% availability of signal at Ipoh. The result suggests a system design of 1% exceedance (99% availability) in an average year (equivalent to 14.5 minutes outage of signal per day) is practicable as rain loss will be between 7 dB to 15 dB in all stations. Heavy rainfall will severely affect the performance satellite communication at the three bands in all the six locations.

4. Conclusion

The impact of rainfall takes on a new significance when designing a modern satellite system at the Ku (12/14 GHz), Ka (20/30 GHz) and V (40/50 GHz) bands for heavy rainfall climatic regions like Malaysia with large annual rainfall accumulation exceeding 3000 mm. The present result shows that link availability for Ku, Ka and V-band uplink and downlink is no longer in the realm 99.99%. Using four rain attenuation models, for six stations in Malaysia, the study suggests that 99.9% for Ku-uplink, 99% for Ka uplink and 99.9% for Ka downlink and 99% for V band uplink and downlink. The overall result shows that the impact of rain attenuation at Ku, Ka and V-band will be more severe in the Eastern Part than the Western part of Malaysia.

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Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

References

[1] J. Chebil and T.A. Rahman, Rain rate statistical conversion for the prediction of rain attenuation in Malaysia, *Electronics Letters* **35** (12) (June 1999), 1019–1021.

[2] R.K. Crane and P.C. Robinson, ACTS propagation experiment: Rain-rate distribution observations and prediction model comparisons, *Proc. IEEE* **85** (6) (1997), 946.

[3] R.K. Crane, Prediction of attenuation by rain, *IEEE Trans. Comm. COM-28* **9** (Sept. 1980), 1717 – 1733.

[4] E.J. Dutton, H.T. Dougherty and R.F. Martin, *Prediction of European rainfall and link performance coefficients at 8 to 30 GHz*, NTIS, U.S. Department of Commerce, 1974, Rep. AD/A-000804.

[5] L.D. Emiliani, L. Luini and C. Caposni, Analysis and parameterization of methodologies for the conversion of rain-rate cumulative distributions from various integration times to one minute, *IEEE Antennas and Propagation Magazine* **51** (3) (June 2009), 70 – 84.

[6] J.A. García-López and J. Peiró, Simple rain-attenuation-prediction technique for terrestrial radio links, *Electronics Letters* **19** (1983), 879 – 880.

[7] J.A. García-López, J.M. Hernando and J.M. Selga, Simple rain attenuation prediction method for satellite radio links, *IEEE Transactions on Antennas and Propagation* **36** (3) (1988), 444 – 448.

[8] J.A. García-López, J.M. Hernando and J.M. Selga, Simple rain attenuation prediction method for satellite radio links, *IEEE Transactions on Antennas and Propagation* **36** (3) (1988), 444 – 448.

[9] R.A. Harris (editor in chief), *COST Action 255, Radiowaves propagation modeling for SATCOM services at Ku-Band and above*, European Space Agency publication Division Noordwijk, Netherlands (2002).

[10] C. Ito and Y. Hosoya, Proposal of a Global Conversion Method for Different Integration Time Rain Rates by Using M Distribution and Regional Climatic Parameters, *Electronics and Communications in Japan*, Part 1, **89** (4) (2006), 1 – 9.

[11] ITU-R Recommendation, *Propagation data and prediction methods required for the design of Earth-space telecommunication system, Geneva*, International Telecommunications Union, Radiocommunications Sector, 2009, 618-9.

[12] ITU-R Recommendation, *Characteristics of precipitation for propagation modelling Geneva*, International Telecommunications Union, Radiocommunications Sector, 2007, 837-5.

[13] ITU-R Recommendation, *Specific attenuation model for rain used in prediction methods Geneva*, International Telecommunications Union, Radiocommunications Sector, 2005, 838.

[14] ITU-R Recommendation, *Rain height model for prediction methods, Geneva*, International Telecommunications Union, Radiocommunications Sector, 2001, 839-3.

[15] Y. Karasawa, M. Yamada and J.E. Allnutt, A new prediction method for tropospheric propagation on earth-space paths, *IEEE Trans. Antennas Propagation* **AP-36** (11) (1988), 1608 – 1614.

[16] Malays Travel Guide: "Climate of Malaysia Circle of Asia", `http://www.circleofasia.com/Geography-and-Climate-Malaysia.htm`, retrieved 2008-07-28.

[17] J.S. Mandeep and S.I.S. Hasssan, Slant-path rain attenuation predictions in tropical regions, *Journal of Atmospheric and Solar-Terrestrial Physics* **68** (2006), 865 – 868.

[18] Marshall Cavendish Corporation, *World and Its Peoples: Malaysia, Philippines, Singapore, and Brunei, New York*, Marshall Cavendish Corporation, p. 1156, 1158 – 1161, 1164, 1166 – 1171 (2008).

[19] F. Moupfouma and L. Martin, Point rainfall rate cumulative distribution function valid at various locations, *Electronic Letters* **29** (17) (August 1993), 1503 – 1505.

[20] K.L. Restrepo, D. Emiliani and C. Fradique-Mendez, Rain attenuation prediction in tropical zones, theoretical analysis, measurement campaigns and model comparisons, *20th ICSSC*, Montreal, Canada (2002).

[21] P. Rice and N. Holmberg, Cumulative time statistics of surface-point rainfall rate, *IEEE Transactions on Communications* **21** (10) (October 1973), 1131 – 1136.

[22] Saw and Swee-Hock, The population of Peninsular Malaysia, *Singapore: Institute of Southeast Asian Studies* (2007), 1 – 2.

[23] B. Segal, The influence of rainguage integration time on measured rainfall-intensity distribution functions, *J. Atmospheric and Oceanic Technology* **3** (December 1986), 662 – 671.

[24] *Weather phenomena*, Malaysian Meteorological Department, archived from the original on 2008-03-20, `http://web.archive.org/web/20080320105546/`, `http://www.kjc.gov.my/english/education/weather/monsoon01.html`, retrieved 2008-07-31.