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Fade Margin Estimations for Malaysian Armed Forces Military X-Band Satellite Communication Links

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Abstract

The satellite communication (satcom) operating in X-band frequencies has the potential to enhance communication capabilities of Malaysian Armed Forces (MAF) and the Malaysian National Security Council (NSC). The satcom can be deployed during catastrophic instances, crisis incidences and certainly for the use of military operations. The satcom can facilitate the delivery of critical high-speed data, voice and video services between military bases, headquarters and also military detachments. The paper highlights the predicted fade margin requirements by the Malaysian Military satellite communication in order to accomplish specific operational quality of services (QoS). This is of utmost importance considering that both the uplink and the downlink will be facing severe rain attenuation due to copious heavy rainfall events, typically endured by tropical region countries. A prediction technique, recommendation ITU-R P.618-12 with value proposed by ITU-R P.637-6 had been employed in order to generate the desired results. Local data acquired from the Department of Irrigation and Drainage Malaysia had also been utilized in the generation of the fade margin estimations. The findings from the studies can offer insight of how to ensure/enhance the satellite communication links reliability.

Keywords: *Rain attenuation, X-band, satcom, tropical region*

1. Introduction

The communication operation of Malaysian Armed Forces (MAF) has been enhanced with the use of new satellite communication (satcom) links system operating at X-band frequencies. MAF previously leased satellite communication services from Telekom Malaysia Berhad operating at C-band frequencies. The high bandwidth requirement of MAF was facilitated by the MEASAT-3b satellite, built by Airbus Defence and Space SAS formerly known as Astrium. The MEASAT-3b was successfully launched on 12 September 2014. The satellite was launched into space using Ariana 5 ECA launch vehicle from the European Space Port located in Kourou French Guiana [1]. The satellite carries four dedicated X-band transponders including one with operating frequency of 8.12GHz. The X-band payloads accommodate two coverage beams which are global and regional that offer peculiar advantages to MAF during their strategic and tactical operations. The satcom provides an improve long distance communications with adequate capacities to support effective operations of MAF. The system is controlled and monitored by the satellite Earth station designated as *Pusat Komunikasi Satelit ATM* which is located at Paya Jaras, Sungai Buloh, Selangor [2].

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2. The Significance of Military X-band Satellite Communication

The X-band frequencies have been traditionally reserved for military satcoms, in most countries around the world. The associated equipment for X-band satcom are expected to be designed specifically for military operations in term of improved mobility as well as their robustness. All communication links including the military are acutely subjected on sufficient access to the radio spectrum i.e. bandwidth. The bandwidth offered by X-band frequencies to date can sustain the interoperability requirement of multiple uniformed forces. At any time military utilization of the specific bandwidth facilitated by X-band frequencies must be safeguarded under joint effort campaign of both the civilian and military agencies. In Malaysia, Malaysian Communication and Multimedia Commissioner (MCMC) shoulders the role as the regulatory body for the whole nation. MCMC is the central regulatory body that overseeing communications and multimedia industry based on the authority warranted by the Malaysian Communications and Multimedia Commission Act passed by the parliament in 1998 [3] and another passed act in 2010 known as the Strategic Trade Act [4].

The conventional X-band satcom equipment are tactically designed to support smaller, low powered, easy to be assembled terminals intended to be deployed in all kind of operation theatres. The real push for X-band link is due to its wider bandwidths in contrast to the precursor S-band and C-band links. With wider bandwidths X-band frequencies can certainly offer a more substantial increased capacity for the communication links. There are however, concerns regarding realization of X-band link in the tropics especially when taken into consideration specifications that particularly designed for operation in temperate climates. X-band frequencies operating in tropical regions will certainly have to endure higher attenuation because of atmospheric propagation losses and much more severe signal fading due to heavy rain [5]. On that note, accurate appraisal on challenges of an X-band link the case of tropical regions has to be carried out by satellite designers and engineers [6].

3. System Location and Geographical Information

The beacon signals are transmitted from MEASAT-3b satellite operating from its orbital slot at 91.5° E. The overview scenario of MEASAT signal performance prediction is shown in Figure 3.1 above. The Earth station is located at Paya Jaras, Sungai Buloh Selangor at the longitude of 101.551°E and latitude of 3.206°N. The above sea level height for the Earth station is approximately 0.063km. With reference to MEASAT-3b satellite, the earth station yields an antenna elevation angle of 77.55°. The rainfall rate readings are measured by an online monitoring system operated by Department of Irrigation and Drainage Malaysia (DID) at Kampung Paya Jaras Tengah, Sungai Buloh, Selangor installation site with the longitude of 101.32° E and latitude of 3.11° N.

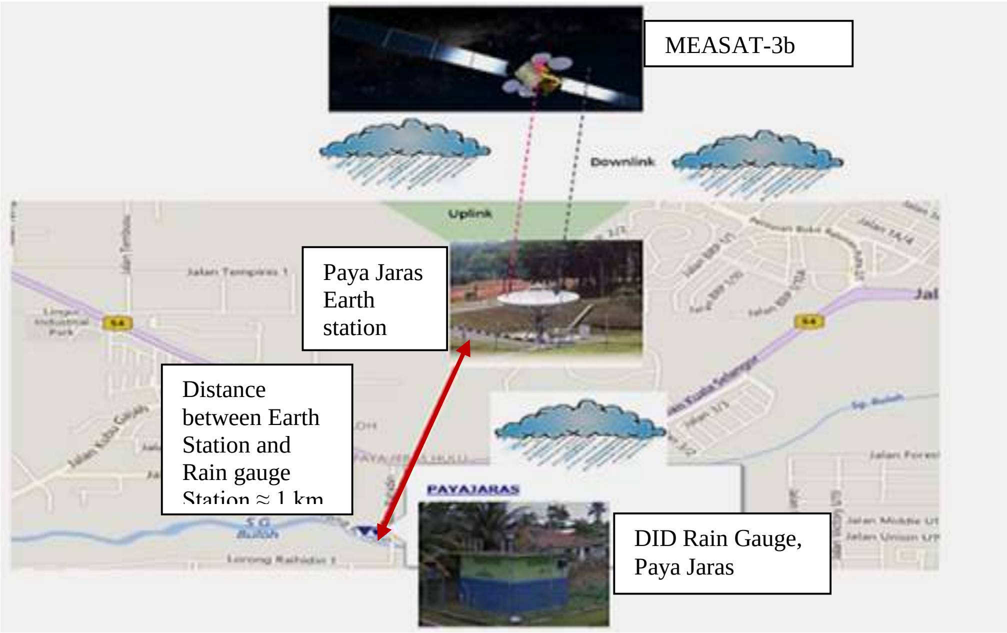

Figure 3.1. System Scenario

4. Estimation Procedures

The prediction of the attenuation experienced by beacon signal of X-band required diverse propagation parameter in the planning of Earth to space system operation or vice versa as shown in Table 4.1. The theoretical assessment for the newly established Earth station in Paya Jaras Selangor can be achieved using the following procedure.

Table 4.1. Earth Station and Satellite Information

Paya Jaras Terminal Description	MEASAT-3b Satellite Location
Longitude (degree), l_{es} : 101.551° E	Longitude (degree), l_{st} : 91.5°E
Latitude (degree), φ : 3.206° N	Frequency (GHz), f : 8.12
Above mean sea level's station height (km), h_s : 0.063	Polarization : vertical

Rain fade margin at specific availability can be derived from predicted attenuation statistics for an average year. The rainfall rate $R_{0.01}$, exceedance at 0.01% of an average year, both theoretically according to Recommendation ITU-R P.837-6 and locally measured had been applied in the ITU-R Model according to steps outlined in ITU-R P.618-12 [7][8]. Applicable local rainfall rates, $R_{0.01}$ with an integration time of 1 min had also been determined. Local measured rainfall rates at 5 minute integration was converted into values at 1 minute integration time using formulations by Segal and Burgueno [9]. The steps in generating the predicted attenuation levels are summarized below:

1) The rain height, h_R was adopted using the proposed value in Recommendation ITU-R P.839-4 [10]:

$$hR = h0 + 0.36 \text{ km} \quad (1)$$

2) If $\theta \geq 5°$, the slant-path below the rain height length, L_s, was computed using equation:

$$L_s = \frac{(h_R - h_s)}{\sin\theta} \quad \text{km} \tag{2}$$

Where rain height, h_R was obtained from ITU-R P.839-4.

3) The slant-path length horizontal projection, L_G was calculated as below:

$$L_G = L_s \cos\theta \quad \text{km} \tag{3}$$

4) The specific attenuation, γ_R was obtained by using the frequency-dependent coefficients made available by Recommendation ITU-R P.838-5 [11] and the rainfall rate, $R_{0.01}$, was determined from the previous step, by using:

$$\gamma_R = k\,(R_{0.01})^{\alpha} \quad \text{dB/km} \tag{4}$$

5) The horizontal reduction factor, $r_{0.01}$, for 0.01% of the time was calculated as below:

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\frac{L_G\ \gamma_R}{f}} - 0.38\left(1 - e^{-2L_G}\right)} \tag{5}$$

6) The vertical adjustment factor, $v_{0.01}$, for 0.01% of the time was calculated as below:

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

For $\zeta > \theta$,

$$L_R = \frac{L_G\ r_{0.01}}{\cos\theta} \quad \text{km}$$

Else,

$$L_R = \frac{(h_R - h_s)}{\sin\theta} \quad \text{km}$$

If $|\varphi| < 36°$, $\chi = 36 - |\varphi|$ degrees

Else, $\chi = 0$ degrees

$$\nu_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}\left(31\left(1 - e^{-(\theta/(1+\chi))}\right)\frac{\sqrt{L_R\ \gamma_R}}{f^2} - 0.45\right)} \tag{6}$$

7) The effective path length was determined:

$$L_E = L_R\ \nu_{0.01} \quad \text{km} \tag{7}$$

8) The predicted rain fade exceeded for 0.01% of an average year was obtained from:

$$A_{0.01} = \gamma_R\ L_E \quad \text{dB} \tag{8}$$

9) The estimated rain fade at other percentage exceedances of the average year, in the range 0.001% to 5%, was ascertained from the rain fading to be exceeded for 0.01% for an average year:

If $p \geq 1\%$ or $|\varphi| \geq 36°$: $\beta = 0$

If $p < 1\%$ and $|\varphi| < 36°$ and $\theta \geq 25°$: $\beta = -0.005(|\varphi| - 36)$

Otherwise: $\beta = -0.005(|\varphi| - 36) + 1.8 - 4.25 \sin\theta$

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{?\ 0.655 + 0.033\,1n(p) - 0.045\,1n(A_{0.01}) - \beta(1-p)\sin\theta} \quad \text{dB} \tag{8}$$

Parameters were determined in accordance with the ITU-R's recommendation except with the inclusion of the rainfall rates generated using local measured values as shown in Figure 4.1. The parameters are listed in Table 4.2 below:

Table 4.2. Calculated Parameter Using ITU-R Recommendations

Parameter	Values
$R_{0.01}$(mm/hr) 5min	136
$R_{0.01}$(mm/hr) 1min	Segal[9], 156.4 Burgueno [9], 157.8
θ (°)	77.58
τ (°)	72.21
h_R (km) : ITU-R P.839-3	5.083
L_s (km)	5.14
L_G (km)	1.11
k_H : ITU-R P.839-3	0.00754
K_V : ITU-R P.839-3	0.00670
α_H : ITU-R P.839-3	1.3155
α_V : ITU-R P.839-3	1.2895
A	1.303
K	0.0071
γ_R(dB/km)	4.23346
$r_{0.01}$ (mm/hr)	0.7980
ζ (°)	80.03316
χ (°)	32.7939
$v_{0.01}$ (mm/hr)	0.4371
L_R (km)	4.1021
$A_{0.01}$ (dB)	6.38
B	0.1639

4.1. Rainfall Rate at Paya Jaras Earth Station

The monthly cumulative distributions functions (CDF) are grouped together for twelve consecutive months in 2016 shown in Figure 4.1. It can be observed that for measured rainfall rate, $R_{0.01}$ exceed for 0.01% of an average year is 136 mm/hr based on the annual CDF for 2016.

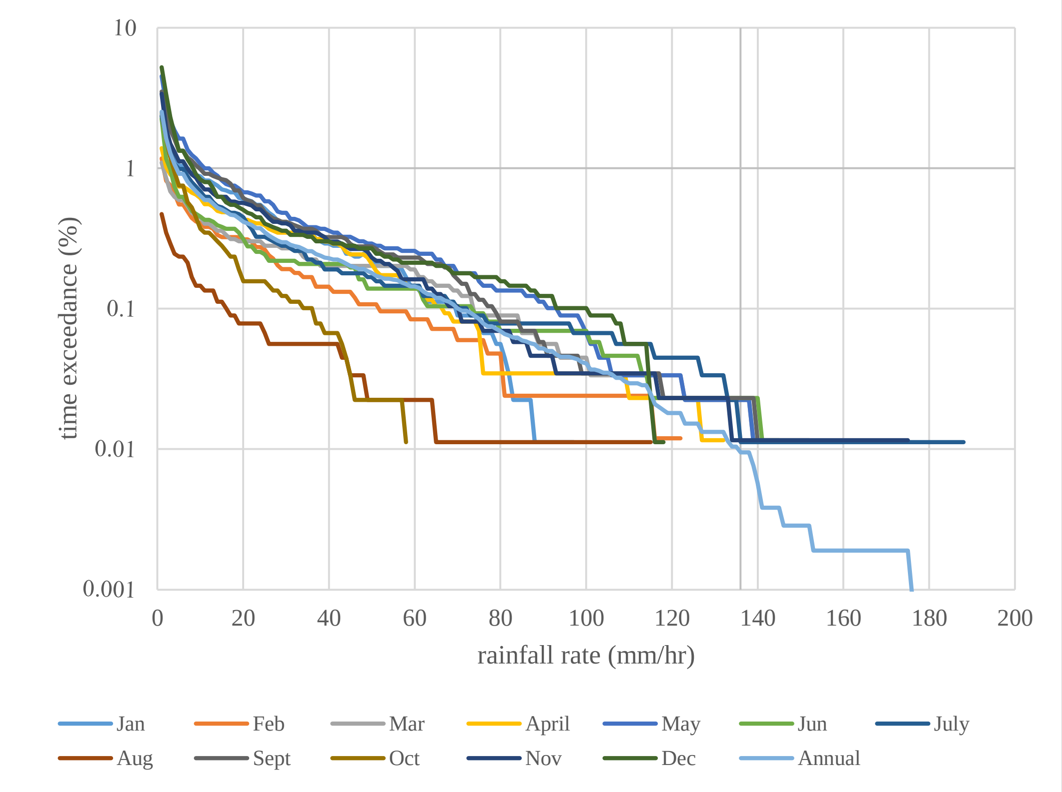

Figure 4.1. Monthly Distribution and Annual Distribution of Rainfall Rate at Paya Jaras Earth Station for the Year 2016

5. Finding and Observations

The communication links establishment should be planned based on the cumulative distributions. Cumulative distributions or annual statistic maybe the most practical presentation layout for the long-term data. The desired link performance can be achieved by incorporating applicable/suitable rain attenuation margin. The cumulative distribution functions of rain attenuation to be experienced at Paya Jaras Earth station were generated. The rain fade annual statistic produced using the ITU-R recommendation; with ITU-R rain value as well as local data can be viewed from Figure 5.1. Table 5.1 shows select attenuation values for the X-band satellite-Earth link for specific MAF required QoS (broadcast- 0.3%, communication – 0.03%).

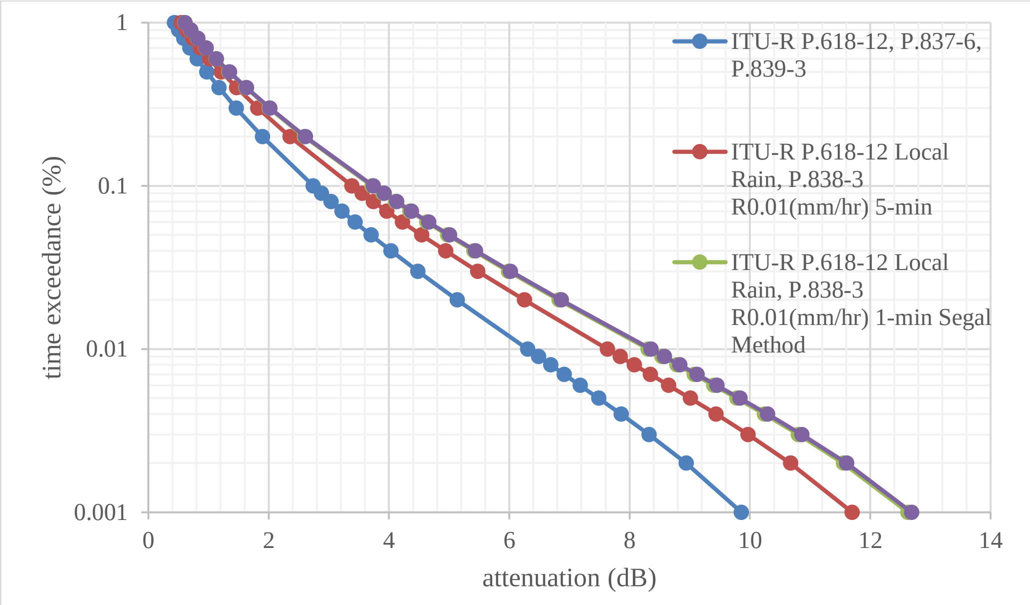

Figure 5.1. Plot of ITU-R Predicted Attenuation Statistics

Table 5.1. Selected Time Percentages and Predicted Values

Time exceedance (%)	ITU-R Predicted Attenuation (dB)	ITU-R with local data Predicted Attenuation (dB)	ITU-R with local data, $R_{0.01}$ (mm/hr) Segal Method, Predicted Attenuation (dB)	ITU-R with local data, $R_{0.01}$ (mm/hr) Segal Method, Predicted Attenuation (dB)
1.000	0.4316	0.6024	0.6061	0.6065
0.300	1.4581	1.8175	2.0174	2.0174
0.100	2.7377	3.3804	3.7355	3.7355
0.030	4.4772	5.4714	6.0165	6.0165
0.010	6.3016	7.6285	8.3502	8.3509
0.001	9.8557	11.6970	12.6849	12.6853

6. Conclusion

The military X-band satellite communication for Malaysian Armed Forces are in operation. The reliability of X-band link is indeed becoming very critical where high-speed data, voice and video transmission can be affected by the rain fade. The feasibility studies on the impairment identify that consequences are indeed quite damaging due to the fact that Malaysia experiences tropical climate. Preliminary results of possible rain induce-attenuation signal degradation to be experienced by the X-band satcom link at Paya Jaras had been predicted. In general, the X-band satellite operation in Malaysia may have difficulties to achieve the 99.99% availability (equivalent to 0.001% time exceedance) this is due to the fact that considerable substantial margin of more than 10 dB; has to be incorporated in order to cope with rain fading in such severe climate. The differences between ITU-R prediction and with local data is approximately 2dB. For future works, annual CDF generated using 24 months or two years of rainfall rate will be pursued.

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