Modified ITU-R Rain Attenuation Prediction Model for a Tropical Station

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Abstract—**Most satellite communication takes place above the 10 GHz frequency bands, a direct consequence of over-congestion of lower frequency bands. A dearth of database along the slant path in the tropical regions for use in rain propagation studies at microwave frequencies, made further studies at millimeter wave band quite attractive. Rain height data were sourced from the Tropical Rainfall Measuring Mission (TRMM) 3B43 V6 and NigComSat-1 satellite for 37 stations in Nigeria as reported in the literature. Terrestrial attenuation measurement data at 0.01% of time, sourced from the Universiti Teknologi Malaysia's Wireless Communication Centre (WCC) were transformed to slant path attenuation values using a transformation technique. Attenuation exceeded for other percentages of time were obtained using statistical methods. The ITU-R model is modified to suit the results. Further analysis at 12 GHz suggested that the proposed modified ITU-R model show good performance when compared with other models of interest.**

Index Terms—**prediction model, TRMM, rain attenuation, rainfall rate, tropical region**

I. Introduction

The distribution of rain along the radio propagation path is inhomogeneous. The non-uniformity of rainfall in both the horizontal and vertical directions makes the estimation of slant path attenuation complex. At frequencies above 10 GHz, the effects of attenuation and noise induced by atmospheric gases and rain are quite significant. The result of these is evidenced in satellite-earth microwave signal amplitude's fading (slow or rapid), scintillations (amplitude or/and phase), depolarization, and receiver antenna noise. Heavy rain is usually confined to a smaller area than lighter rain, and the rain cells, may take any shape [1]. If rainfall rate is measured only at a single point, it is difficult to know enough about the structure of a rain cell at some distance away from the observation point, the non- homogenous nature of rainfall may lead to incorrect estimates of the specific attenuation. The structure of rain drops can assume various shapes. It is spherical for small size cells, while it is considered oblate spheroidal or oblate distorted for medium and large size rain drops respectively [1]. This information is needed to indicate the best distribution model of rain falls within tropical climate, which is a very important factor in the rain attenuation model simulation. Consequently, the relation between the rainfall rate and the attenuation is a function of the effective path length.

However, there is a dearth of data on direct attenuation measurement due to rainfall along with appropriate precipitation data for estimating attenuation due to rainfall in the tropical regions of the world [2]. This is because most of the studies reported in the literature have been carried out in temperate regions where solid precipitation is common, therefore there is need to supplement the meager data available for the tropical regions in view of the importance accorded it in the classical picture of global electrification [3].

Again, these studies are required to assist microwave system engineers in link budget planning and for design of reliable communication systems.

University Teknologi Malaysia (UTM) is a station with geographical latitude of 1.45^0N and Longitude of 103.75^0E, and with an altitude of 37 m above mean sea level and mean annual rainfall of 2357 mm. It experiences Convective, Stratiform, Tropical Storm and Monsoon Precipitation rainfall types like as other tropical and sub-tropical regions.

II. Literature Review

The International Telecommunication Union – Radio communication Sector (ITU-R) model was adjudged the most widely accepted internationally for the prediction of rain effects on communication systems [4]; for this reason, most emerging models are compared against it for conformity and reliability, most importantly for cases where measured data are not available.

However, recent researches have shown that some ITU-R models are only suitably reliable in certain geographical areas [5]-[7].

The following rain attenuation prediction models were investigated and their results were compared with the measured and that proposed in this work. Two tropical locations (Johor and Penang) were used in this investigation.

A. International Telecommunication Union-Recommendation

The Recommendations ITU-R Rec. P.618-10 rain attenuation model [8] is the most widely accepted international method for the prediction of rain effects on satellite communication systems.

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The specific attenuation $\gamma_{0.01}$ (dB/km) for 0.01 % of time is given by:

$$\gamma_{0.01} = k\ R_{0.01}^{\alpha} \tag{1}$$

Parameters k and α can also be obtained from ITU-R P.838-3 [9].

Therefore, the predicted slant-path attenuation exceeded for 0.01 % of an average year is:

$$A_{0.01} = \gamma_{0.01} L_{eff} \tag{2}$$

The predicted attenuation exceeded for other percentages $\%p$ of an average year may be obtained from the value of $A_{0.01}$ by using the following extrapolation [8]:

$$A_{P\%} = A_{0.01}\left(\frac{p}{0.01}\right)^{-[0.655+0.033\ln p-0.045\ln A_{0.01}-z\sin\theta(1-p)]} dB \tag{3}$$

where p is the percentage probability of interest and z is given by:

$$For\ \ p \geq 1.0\%, z = 0 \tag{4}$$

$$For\ \ p < 1.0\%,\ z = \begin{cases} 0;\ for\ /\phi/ \geq 36^0 \\ z = -0.005(/\phi/-36)\ \ for\ \theta \geq 25^0 and\ /\phi/ < 36^0 \\ z = -0.005(/\phi-36/)+1.8-4.25\sin\theta,\ \ for\ \theta < 25^0 and\ /\phi/ < 36^0 \end{cases} \tag{5}$$

B Mandeep, SAM and DAH Models

Ku-band beacon signal measurements were conducted at USM as discussed in [10] and [11]. The specific attenuation,

(γ) was defined as the attenuation that is caused by rain over a distance of 1 km, and was given by:

$$\gamma\ (dB/km) = k\ R_p^{\alpha} \tag{6}$$

The total attenuation was determined as:

$$A(dB) = \gamma\ (dB/km) * L_{eff}\,(km) \tag{7}$$

To estimate γ, for linear and circular polarization, and for all path geometries the ITU-R recommendation P-838-3 was used to obtain the statistical regression coefficients k and α using the equations (8) and (9) as follows:

$$k = [k_H + k_V + (k_H - k_V)\cos^2\theta\cos 2\tau]/2 \tag{8}$$

$$\alpha = [k_H\alpha_H + k_V\alpha_V + (k_H\alpha_H - k_V\alpha_V)\cos^2\theta\cos 2\tau]/2k \tag{9}$$

where θ is the path elevation angle, and τ is the polarization tilt angle relative to the horizontal ($\tau = 45$ for circular polarization).

To calculate the effective length path, $Leff$ the calculation that was used in the Simple Attenuation Model (SAM) [12] was adopted. He proposed effective path length as a power-fitting function of rain rate:

$$Leff = 13.367 * R_p^{-0.21}\ \text{(km)} \tag{10}$$

The SAM model is one of the most widely used slant-path attenuation prediction models, which incorporates the individual characteristics of the stratiform and convective types of rainfall. In convective rainstorms, when R>10 mm/h, the effective rain height, H_R depends on the rain rate because strong storms push rain higher into the atmosphere, and thereby lengthening the slant path [11]. To determine the slant path attenuation, a modified value of effective path length must be used, as follows:

$$A = \gamma\ \frac{1-\exp\left[-\alpha b\ln\left(\frac{R_{\%p}}{10}\right)\right]L_S\cos\theta}{\alpha b\ln\left(\frac{R_{\%p}}{10}\right)\cos\theta};\ R_{\%p} > 10\text{mm/h} \tag{11}$$

where the empirical constant $b = 1/22$ and $\gamma = k\,R_{\%p}^{\alpha}\ \ (dB/km)$ ·

Dissanayake *et al*. [13] model is based on log normal distribution of rain rate and rain attenuation. The model is approximately similar to the ITU-R model since the rain related input to the model is the rain intensity at 0.01 % of the time. The model is applicable to both terrestrial and slant paths within the frequency range 4 - 35 GHz, and the percentage probability range of 0.001 – 10%. The behaviour of the localized DAH model can be modelled by the expression:

$$A_{P\%} = A_{0.01}\left(\frac{p}{0.01}\right)^{-[0.655+0.033\ln p-0.045\ln A_{0.01}-z\sin\theta(1-p)]} dB \tag{12}$$

where $A_{P\%}$ and $A_{0.01}$ are attenuation exceeded for P % and 0.01% of the time respectively.

C Proposed Model

Monthly data for 37 stations in Nigeria were extracted from the Tropical Rainfall Measuring Mission (TRMM) 3B43 V6 satellite and the NigComSat-1 satellites data as employed by [14]. The data from TRMM data were reported to show good correlation with the and the rain gauges one-minute average rainfall rates for 0.01% of the time in all the 14 locations, using ITU-RP SG3 (2008) digital map-based data and work on contour map data for Nigeria by [15].

Furthermore, the effective path length, L_{eff} through rain at Ku (11 GHz) downlink frequency at 0.01% of the time was extracted from [4]. The attenuation exceeded for other percentages of the time was obtained using statistical interpolation and extrapolation methods. However, the data for Ku-band downlink were used for obtaining the statistical relationship between L_{eff} and rain rate. The effective path length is a function of rain rate and has a direct correlation with the measured rain rate [11]. The effective path length has been found by using statistical method based on the direct relationship between L_{eff} and rain rate. The proposed effective path length is also a power-fitting function of rainfall rate and is given by the expression:

$$Leff = 19.4919 * R_{0.01}^{-0.373}\ \text{(km)} \tag{13}$$

With regression coefficient, $R^2 = 0.9117$ as shown in Fig. 1.

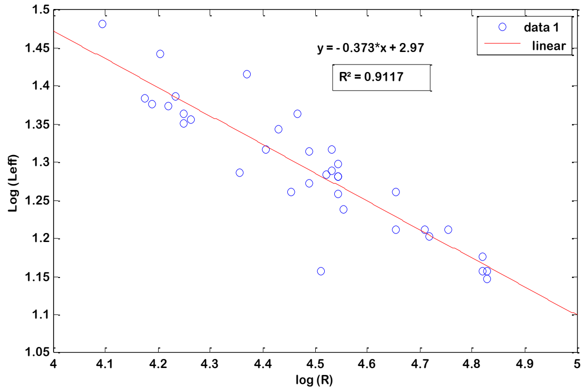

Figure 1. Correlation plot for L_{eff} and rainfall rate at 12 GHz downlink frequency from NigComSat-1 satellite

In effect, the proposed total attenuation can then be expressed as:

$$A = kR^{\alpha} * 19.4919 * R_{0.01}^{-0.373} (\text{dB}) \quad (14)$$

where k and α are regression parameters for estimating specific attenuation as proposed by [16].

The exprimental data were terrestrial attenuation at 15 GHz data obtained from the UTM WCC for 0.01% of the time. The terrestrial attenuation data were thereafter transformed to slant path attenuation using transformation technique proposed for Ku band by [17]. The transformation was validated with 15 GHz DIGI MINI-LINKs at UTM WCC. The propagation path (the distance between the transmitting and receving stations) used by UTM WCC were at 4.58km, 11.33km etc. The standard deviation σ_{ei} of the error distribution can be defined from:

$$\sigma_{ei} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} e_i^2 - (\mu_{ei})^2} \quad (15)$$

where e_{ei} is the percentage error and μ_{ei} is the mean square error for each exceedance of time percentage; and is given by:

$$\mu_{ei} = \frac{1}{N}\sum_{i=1}^{N} e_i \quad (16)$$

where i is the individual test variable and N is the total number of test variables.

The mean square error μ_{ei} and standard deviation σ_{ei} are then used to calculate the Root Mean Square (RMS) D_{ei}; which is defined as follows:

$$D_{ei} = \left[(\mu_{ei})^2 - (\sigma_{ei})^2\right]^{1/2} \quad (17)$$

III. Results and Analysis

The percentage attenuation error was determined using the expression:

$$\% \; Attenuation \; error = \left(\frac{predicted - Measured}{Measured}\right) * 100\% \quad (18)$$

At 12 GHz, SAM prediction model was observed to show the least performance by producing negative attenuation values (large under-estimations) for all percentages of time, using the same measurement data. Furthermore, it was observed that there is high degree of correlation between DAH and ITU-R models for 0.01% percentages of time exceeded. This may be due the fact that the rain related input to both models is the rain intensity at 0.01 % of the time. The result of the simulation plots of local data for all the models under investigation (except for SAM) shows that higher percentage unavailability translates to higher rainfall attenuation as depicted in Fig. 3 and Fig. 4.

The relationship between slant path length and rain rates at Ku-band is shown in Fig. 2.

The SAM and Mandeep prediction models underestimate and overestimate the measurements for all the percentages of time respectively The ITU-R model slightly underestimated for $p \geq 0.003\%$, while DAH model matches the measurement for only at $p = 0.005\%$ and underestimated at $p \geq 0.01\%$. It was also observed to overestimate the measurement for $p \leq 0.003\%$.

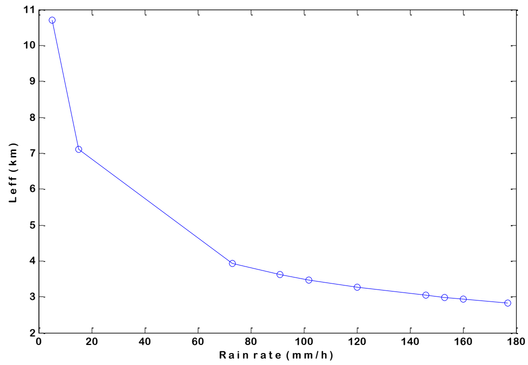

Figure 2. Relationship between L_{eff} and rainfall rate at 12 GHz

Equally, the ITU-R model matches the measurements for $p \leq 0.002\%$, while the proposed model prediction closely matches the measured values for all percentages of the time.

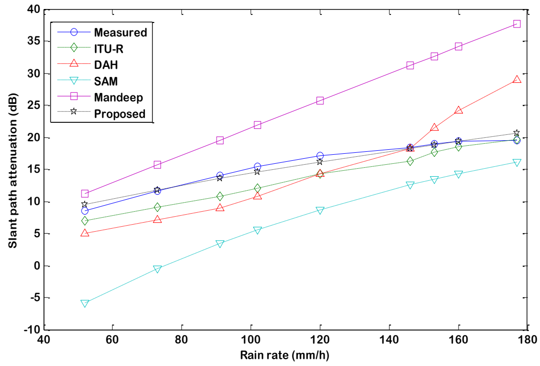

Figure 3. Comparison of the slant path attenuation exceedance at 12 GHz for UTM, Malaysia

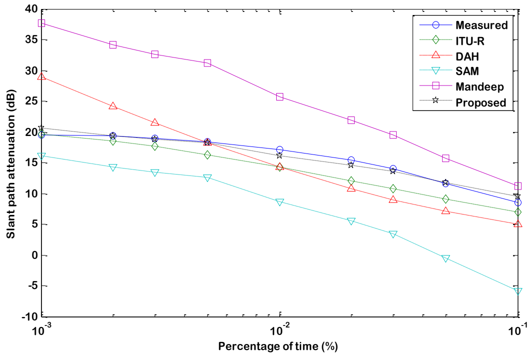

Figure 4. Equal Probability plots of rain rate and slant path attenuation at 12 GHz for UTM, Malaysia

Table I compares the parameters mean square error (μ_{ei}), standard deviation (σ_{ei}) and root mean square (D_{ei}) for the measured slant path attenuation data with the predictions of ITU-R, DAH, SAM, Mandeep and proposed model. According to the evaluation procedures adopted by the Recommendations ITU-R P.311-13 [18], in the comparison of prediction methods, the best prediction method produces the smallest values of the statistical parameters.

In effect, the proposed model was observed to produce the best prediction compared to other prediction of interest since it has the lowest values of e_{ei}, D_{ei}, for the whole range or for the majority of time percentages of interest. The validation results at 12 GHz clearly suggests that the proposed model's estimates seem to provide fairly more accurate results than the other models of interest, even though slant path measurement data are not available at higher frequencies.

TABLE I. PERCENTAGE ERROR AND RMS COMPARISON FOR SLANT PATH AT 12 GHZ

Parameter	Prediction Models	Time percentage ($\%p$)									
		0.001	**0.002**	**0.003**	**0.005**	**0.01**	**0.02**	**0.03**	**0.1**	**0.5**	**1.0**
μ_{ei}	**ITU-R**	0.0008	-0.0045	-0.0073	-0.0116	-0.0168	-0.0222	-0.0231	-0.0173	-0.0149	-0.0147
	DAH	0.0482	0.0250	0.0133	-0.0008	-0.0168	-0.0306	-0.0357	-0.0416	-0.0387	-0.0147
	SAM	0.3083	0.3279	0.3447	0.3678	0.4490	0.5551	0.6682	1.3233	20.3851	-28.0366
	MANDEEP	0.0936	0.0762	0.0720	0.0693	0.0502	0.0414	0.0400	0.0327	0.0050	-0.0220
	PROPOSED	0.0062	0.0001	-0.0008	-0.0007	-0.0056	-0.0059	-0.0031	0.0118	0.0371	0.0496
σ_{ei}	**ITU-R**	0.1502	0.1501	0.1500	0.1497	0.1492	0.1485	0.1484	0.1492	0.1494	0.1495
	DAH	0.2970	0.2999	0.3006	0.3009	0.3004	0.2994	0.2988	0.2980	0.2984	0.3006
	SAM	109.7613	109.7613	109.7612	109.7611	109.7608	109.7604	109.7597	109.7538	107.8522	106.1207
	MANDEEP	0.5575	0.5601	0.5607	0.5610	0.5630	0.5638	0.5639	0.5643	0.5652	0.5648
	PROPOSED	0.2021	0.2022	0.2022	0.2022	0.2021	0.2021	0.2021	0.2018	0.1987	0.1960
D_{ei}	**ITU-R**	0.1502	0.1500	0.1498	0.1493	0.1483	0.1469	0.1466	0.1482	0.1487	0.1487
	DAH	0.2931	0.2988	0.3003	0.3009	0.3000	0.2978	0.2967	0.2951	0.2959	0.3002
	SAM	109.7609	109.7608	109.7607	109.7605	109.7599	109.7589	109.7577	109.7458	105.9082	102.3501
	MANDEEP	0.5496	0.5549	0.5560	0.5567	0.5608	0.5622	0.5624	0.5634	0.5652	0.5644
	PROPOSED	0.2020	0.2022	0.2022	0.2022	0.2020	0.2020	0.2021	0.2015	0.1952	0.1896

IV. CONCLUSIONS

The TRMM satellite data for Ku-band downlink, which was used to obtain the statistical relationship between the effective slant path length and rainfall rate, showed that there was good correlation between the two, with a correlation coefficient factor of 0.9117. The results of the proposed model estimates at 12 GHz was observed to closely match the measurement data. Prediction models can quite easily (and safely too) be extrapolated to other sites with relatively good degree of accuracy, in contrast to adopting the physical (or direct measurement) approach. Attenuation values for other percentages of time were subsequently obtained using statistical methods.

In effect, proposed model's estimates suggest reasonably accurate results when compared with other models of interest.

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