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Proposed Rain Attenuation Model Revised from ITU Used for Prediction in Tropical Climates

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Abstract: A model for predicting rain attenuation on earth-to-space is developed by using the measured data obtained from tropical and equatorial region. The proposed rain attenuation model uses the complete rainfall rate cumulative distribution as input data. It is shown that significant improvements in terms of prediction error over existing attenuation model are obtained.

Key words: Rain attenuation, tropical climate

INTRODUCTION

Rain attenuation modeling on satellite paths have been done by many researchers over the last three decades. With the introduction of Ku-band satellite communication services in the tropical and equatorial region, prediction of rain attenuation has become an important factor. Several empirical and non-empirical rain attenuation prediction models that have been developed are based on the measured data obtained from temperate regions. Most of these existing rain attenuation prediction models do not appear to perform well in high rainfall regions[1-3]. The ITU-R[4] model is currently being widely used by many researchers. Cumulative distribution empirical evidence[5] shows that the ITU-R model underestimates the measured rain attenuation cumulative distribution when applied to tropical regions, leading to a poor prediction. Therefore in this paper, a modified ITU-R model was developed using the complete rainfall rate cumulative distribution and the horizontal path length to calculate the cumulative distribution of rain attenuation for tropical and equatorial regions.

EXPERIMENTAL SETUP

The receiver sites are located at Universiti Sains Malaysia (USM), King Mongkut's Institute of Technology Ladkrabang (KMITL) and Indonesia Insitute Technologi Bandung (ITB). Descriptions of the measurement sites are presented in Table 1. The receiver antennas are pointed towards SUPERBIRD-C located at 144°E for USM and JCSAT-1B located at 128°E for KMITL and ITB. The SUPERBIRD-C and JCSAT-1B are highly reliable three-axis stabilized spacecraft with a transponder RF output power of 90W and 60W respectively at Ku-Band. The orientation of the receiver antennas is horizontal polarized. Simultaneous rain rate were measured by a tipping bucket rain gauge with a sensitivity of 0.5 mm per tip. The integration time used for computation of the rain rate is 1 min. The total acquisition time was above 96% during the 24 months of measurement.

RAIN ATTENUATION PROPOSED MODEL

The modified ITU-R model retains the concept of an equivalent rain cell. The horizontal projection of the slant path, L_G was modified based on the rain height, elevation angle, reduction factor and the rainfall rate at the measurement sites. Therefore this model was revised, so that it can be used at tropical countries with the antenna elevation angle varying from 40 to 70°. In the ITU-R model, the rainfall rate exceeded at 0.01% of time is used for predicting the correspondent value of rain attenuation.

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Table 1: Measurement sites characteristics

Measurement site	USM	KMITL	ITB
Earth Station Location	5.17°N	13.7°N	6.5°S
	100.4°E	100.8°E	107.4°E
Beacon Frequency, (GHz)	12.255	12.74	12.247
Antenna Elevation (deg)	40.1	54.8	64.7
Altitude (m)	57	40	700
Antenna diameter (m)	2.4	2.4	1.8

The extrapolation formula was also used to calculate the rain attenuation exceeded at other percentages of time between 1 and 0.001%. In the proposed model, the extrapolation formula was modified based on the rain attenuation data obtained from the measurement sites. The rain attenuation exceeded during P% of time is then given by:

$$A_P = A_{0.01} * 0.12 * P^{-(0.58569+0.061046\log(P))} \text{ dB} \quad (1)$$

where $A_{0.01}$ is the rain attenuation exceeded at 0.01% of time.

The specific attenuation, γ is a function of the rainfall rate, $R_{0.01}$ exceeded at 0.01% of time is given by:

$$\gamma = k(R_{0.01})^{\alpha} \quad \text{dB/km} \quad (2)$$

where k and α are frequency and polarization parameters, given by ITU-R recommendation[6].

The horizontal reduction factor, $r_{0.01}$ exceeded at 0.01% of time is given by:

$$r_{0.01} = [1 + L_G / L_o]^{-1} \quad (3)$$

where L_o is equivalent rain cell length and L_G is horizontal projection of the slant path calculate by using the rain attenuation data at the measurement site. This parameter is given by:

$$L_G = -3167.9714 + 2088.3369[L_S \cos(\theta)] - 66.345562[L_S \cos(\theta)]^2 - 2182.7255(\ln[L_S \cos(\theta)])^2 + 1229.5222 / [L_S \cos(\theta)]^2 \text{ km} \quad (4)$$

where L_S is the slant path length and θ is the antenna elevation angle.

The rainfall attenuation, $A_{0.01}$ exceeded at 0.01% of time is given by:

$$A_{0.01} = \gamma * r_{0.01} * L_S \text{ dB} \quad (5)$$

Figure 1, 2 and 3 shows the comparison between the proposed model and the ITU model for each measurement site. The proposed model lies in between the 95% confidence limits of the measured data for the entire measurement time compared to the ITU. This clearly shows that the proposed model cannot be rejected for prediction whereas the ITU model can be rejected for prediction at low percentage of time. ITU model has a roll-over effect at lower percentage of time due to the lack of high rainfall rate data used to develop the model. The proposed model was developed to overcome this problem.

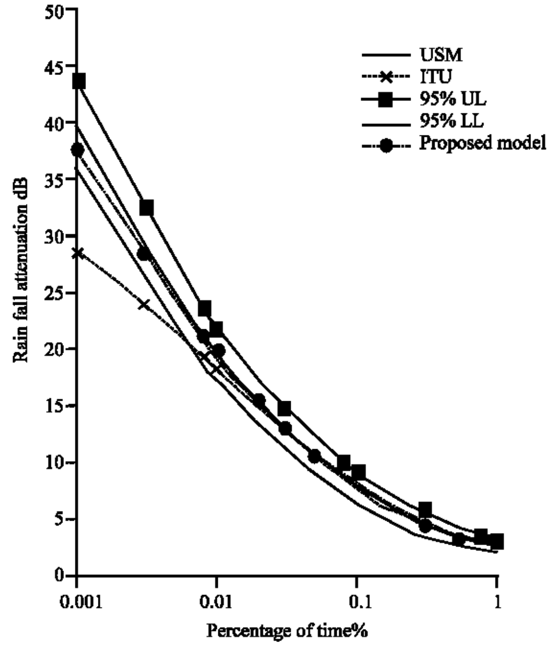

Fig. 1: Comparison of the proposed model and ITU with the measured data at USM

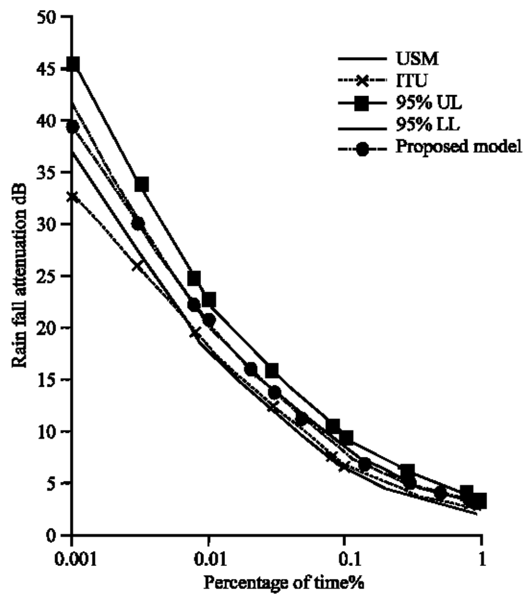

Fig. 2: Comparison of the proposed model and ITU with the measured data at KMITL

Table 2: Percentage error and rms values of test variable for USM, KMITL and ITB

	P%	0.001	0.003	0.01	0.03	0.1	0.3	1	%rms
USM									
	ITU	-27.9	-18.1	-6.4	0.4	6	9.1	-26.4	16.2
	Proposed	-5.1	-2.4	0.05	1.1	4.32	4.17	8.19	2.9
KMITL									
	ITU	-40.3	-33.4	-23	-18.1	-12	-15.1	-41.3	28.4
	Proposed	-6.09	-3.63	-0.49	-1.46	5.78	1.94	5.81	4.11
ITB									
	ITU	-35.5	-29	-23.3	-17.9	-22	-18.3	-48.1	29.9
	Proposed	9	6.19	-0.11	-4.92	-5.4	-1.56	6.79	6.14

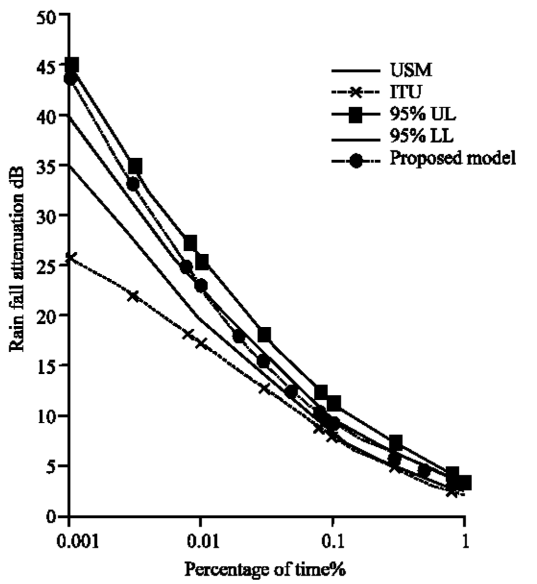

Fig. 3: Comparison of the proposed model and ITU with the measured data at KMITL

COMPARISON WITH ITU

The proposed model was tested against the ITU-R method using test suggested by ITU[7]. The test variable for percentage error and rms values are given by:

$$E_{rel} = [(A_{predicted} - A_{measured}) / A_{measured}]x100 \quad (6)$$

where $A_{predicted}$ and $A_{measured}$ are the predicted and measured rain attenuation values exceeded at a given percentage of time.

The mean error, μ_e and standard deviation, σ_e are used to calculate the Root Mean Square, D_e(RMS). The parameter is defined as follows

$$D_e = [(\mu_e)^2 + (\sigma_e)^2]^{1/2} \quad (7)$$

According to evaluation procedures adopted by the CCIR the preferred prediction method is the one producing the smallest RMS values[7]. Table 2 shows the comparison in terms of percentage error and rms values between the proposed model and the ITU model for USM, KMITL and ITB. It can be seen that the proposed model shows a significant improvement in terms of prediction error and rms values over the ITU attenuation model for all the three measurement sites.

CONCLUSION

The proposed rain attenuation model for earth-to-space performed better than the ITU-R model. The model can be used for different elevation angles and it is simply to use.

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