

Rain Attenuation Prediction Model for Tropical V-band Satellite Earth link

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Abstract. Radiowave propagation plays a very important part in the design and eventually dictates performance of space communication systems. The requirements of today's satellite communication have grown extensively where higher capacity communications systems are needed. The escalating demands for microwave and millimetre wave communications are causing acute frequency spectrum congestion. Hence, existing and future satellite system operators are planning to employ frequency bands as high as the V-band. The challenge in operating at such high frequencies for communication purposes is that there exist stronger electromagnetic interaction between the radio signals and atmospheric hydrometeors. These instances will without doubt degrade the performance of such high frequency satellite communication systems. The development of a model capable of accurately predicting the V-band signal propagations is considered very important particularly for systems operating in tropical region. Researchers and engineers alike can employ the model to estimate the availabilities of effectively the future high frequencies satellite services.

Keywords: rain attenuation prediction model, V-band, tropical region

1. Introduction

The development of a modified rain-induced attenuation model for tropical V-band satellite- Earth link was inspired from the notable inconsistencies of the existing models including the ITU-R P618-9 [1]. Prominent researchers namely Ippolito [3] and Ajayi [4] do believe that most available models may not be directly applicable for predicting rain attenuation in tropical region. Specific consideration and attention at V-band frequency are now eminent since there are escalating usages of the lower bands. The key concern now is that the commonly adopted ITU-R model may also not be appropriate, as can be observed in [2]. Afterall, the ITU-R model is based on among the earliest developments of specific attenuation $\gamma = aR^b$ by Olsen and Rogers somewhat way back in 1976 [5]. The issues are:

a) Most experiments in deriving the model were carried out in temperate climate. Temperate climate characteristics are completely different from tropical climate that requires profound attention on the issues of rain fade.

b) Olsen and Rogers [5] clearly stated that the possibilities of more than 10% error will occur if the frequency used and rain rate experienced are outside the specified limits of;

i) $f > 34$ Ghz and $R = 5$ mm/hr

ii) $f < 11$ GHz and $R = 25$ mm/hr

iii) $f < 3$ GHz and $R = 100$ mm/hr

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c) The development of high frequency asymptotic expansion for attenuation, A is indeed more difficult and complex due to the volatile varying rain drops size distribution especially the case of tropical rain.

d) The calculations for water spheres involved only 41 frequencies but then manipulated for the whole range from 1 to 1000GHz.

e) The values for the rain rates stated by the Laws and Parson [6] for the higher rain rates; 101.6 and 152.4 mm/h were obtained by mere extrapolation and must therefore be viewed with extreme caution since the actual sizes and velocities of the rain drops may vary radically.

It is of utmost importance to acknowledge that some parameters proposed within ITU-R models are based on the measurements of a specific region and may not be universally applicable. The proposed model comprises of new parameters; is configured in order to achieve a model capable of replicating the measured data and to be measured data. The model does have a higher and greater reliability in estimating the likelihood of availabilities and the required margins for future V-band satellite services in tropical region.

2. Configuration of the Prediction Model

2.1. Relevancy of ITU-R Prediction Model

The ITU-R 618-9 slant path rain attenuation prediction is based on the estimation of the attenuation exceeded at 0.01% of the time $A_{0.01}$. The attenuation is derived using the rainfall rate exceeded at the same time percentage ($R_{0.01}$) [7]. ITU-R concept of equiprobability is not consistent with meteorological information and not entirely satisfactory from the theoretical point of view. ITU-R somehow claims that the accuracy obtained using the prediction method is consistent with the quality and variability of available rain intensity data [8]. Such argument can be quite true since the environment that they experimented does not have serious issues about the rainfall intensity.

2.1.1. On-Site Tropical Rain Measurements

For a given value of rain rate $R_{0.01}$ the specific attenuation (γ_R) is multiplied by an effective path length (L_{eff}) to produce the corresponding value of $A_{0.01}$. The effective path length is the product of a path reduction factor ($r_{0.01}$) and the slant path length L_s :

$$A_{0.01} = \gamma_R \cdot L_{eff} = \gamma_R \cdot L_s \cdot r_{0.01} \quad (1)$$

An empirical expression is used for scaling to other time percentages in order to provide the complete rain attenuation distribution.

Rainfall fade at each rate percentage will have different effects due to absorption and scattering properties. ITU-R proposed 120mm/hr at $R_{0.01}$. The typical tropical sizes of the rain drops at this rate can be about 5mm [9, 10]. While the rainfall rate at $R_{0.01}$ in tropical region has been measured by Ismail [10] at about 160mm/hr and will be used in the new prediction model. It has been commonly generalized that the effects of absorption at $R_{0.01}$ is higher than scattering. The same applies when predicting at other percentages of time where absorption effects monopolized the signal energy losses. It is now eminent that scattering effects have to be considered accordingly due to reduced wavelength at frequencies such high as the V-band.

2.1.2. Tropical Effective rain height

For vertical paths, the effective path length coincides with the effective rain height which, at any latitude, may differ from the 0°C isotherm height h_{FR} ; as specified in Recommendation ITU-R P.839. No information is available on the behavior of the ratio h_R/h_{FR} for various other latitudes. Recent work by Study Group 3 suggests that it may be appropriate to use h_{FR} as the effective rain height in the model. Mandeep [11] proposed the new rain height for satellite communication in Malaysian environment. The experiment carried

out in Malaysia was using radiosonde readings observed at four different stations. Based on his findings, the related measurement in south of Malaysia; the rain height varies from 3.4km to 7.1km over the probability range 99.99% to 0.01% which offers an average of 5.25km. The value is adopted in the new prediction model to emulate a more realistic environment i.e. a tropical region.

2.1.3. Specific attenuation

Many researchers had proposed various approximations of k and α values. It is believed that the one that measured in the tropical region itself [12] should offer better predictions values. The reported derived values of k and α can be 42% higher when compared to ITU-R's. These values are to be included in the suggested prediction model in the later subsections.

2.2. The Proposed Prediction Model

A new prediction model has been considered. The possibility of developing a – a new prediction model for V-band satellite link applicable for tropical region now exists by using the local measurements of rain height, rainfall rate and specific attenuation by Mandeep [11] Ismail [10] and Islam and Tharek [12] respectively. The new model can be considered as an adaptation of the ITU-R recommendation. The associated parameters are from tropical region measurements and a correction factor, C had been configured accordingly. The new proposed model is shown in the equation below:

$$A_{p(\text{new})} = A_{0.01} * (p/0.01)^{-(0.655+0.033 \ln(p)-0.045 \ln(A_{0.01}) - \beta(1-p)\sin \theta)^2} \pm C \quad (2)$$

The * sign shows that the values will be using tropical on-site measurement.

2.2.1 Determination of the Correction factor, C

The correction factor was calculated using the regression analysis. The difference of the measured value and the ITU-R P618-9 prediction (using local parameters) was analyzed and the output is shown below;

Table 1: Regression output for the correction factor, C.

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	0.4562	0.0585	7.7967	0.0000	0.3374	0.5750
Difference	0.0062	0.0110	0.5696	0.5726	-0.0160	0.0285

The t -Stat or t statistics is the regression coefficient (of a given independent variable) divided by its sample standard deviation for a normal random variable with zero mean. In testing the null hypothesis that the statistics data mean is equal to a specified value μ_0 , one uses the statistic;

$$t = \frac{\bar{x} - \mu_0}{\frac{s}{\sqrt{n}}}$$

Where s is the sample standard deviation of the sample and n is the sample size. The degrees of freedom used in this test is $n - 1$. The correction factor C then assumes the t -stat value 7.8 as can be seen in the table 1. The correction factor is believed to be the possible answer for the limitation in the earlier ITU-R P618 prediction model.

3. Calculation of Rain Induced Attenuation Statistics Using New Prediction Model

Figure 1 shows the comparison of the modified prediction model, ITU-R prediction and measure values.

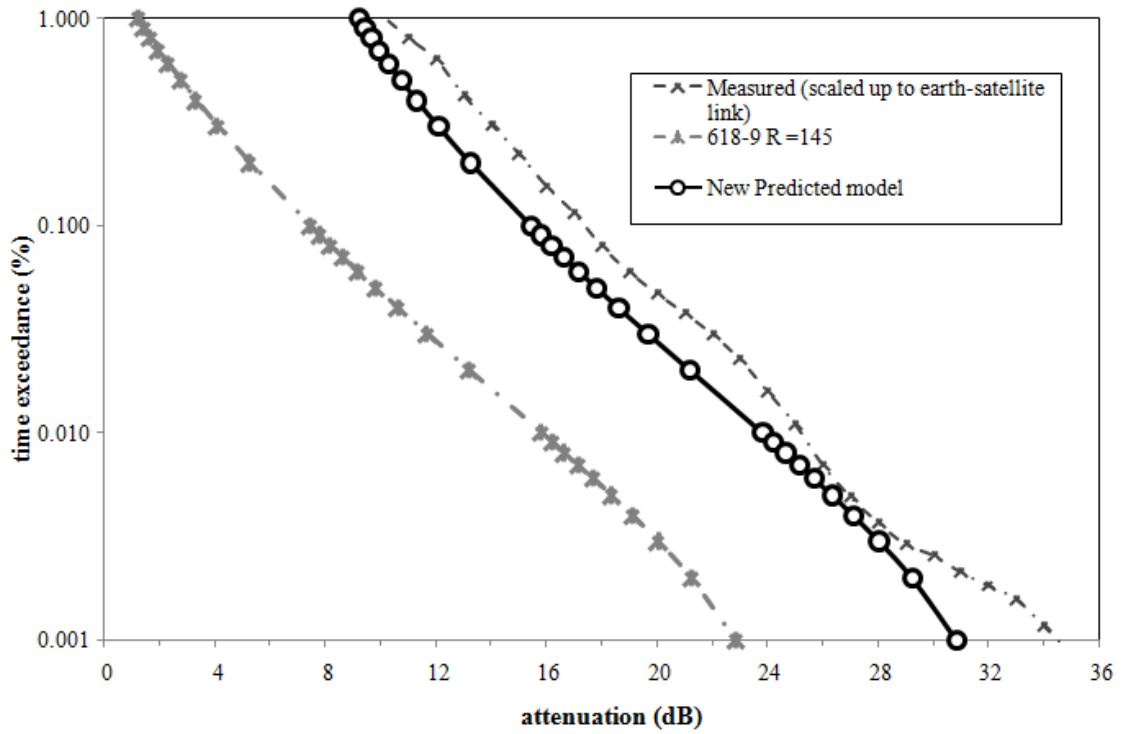


Fig. 1: Plots of statistics.

Table 2 below summarizes the differences of parameter values between the ITU-R P 618-9 and the new proposed model

Table 2: Differences in ITU-R and Modified Proposed Characteristics Values

	ITU-R P.618-9	Modified Prediction Model
$R_{0.01}$ (mm hr ⁻¹)	145	164
h_s (km)	0.05	0.05
θ (°)	77.42	77.42
φ (°)	3.08	3.08
τ (°)	72.65	72.65
f (GHZ)	38	38
R_e (km)	8500	8500
H_R (km)	5.000	5.25
L_S (km)	5.072	5.32
L_G (km)	1.106	1.16
k	0.641	0.763
α	0.465	0.863
γ_R (dB/km)	6.475	26.3
$r_{0.01}$ (mm hr ⁻¹)	0.930	0.735
ξ (°)	84	84
L_R (km)	4.720	3.908

4. Validation on Proposed Model

The V-band frequency satellite links measured at another tropical country; Nigeria, was evaluated. Comparisons were then made against the current ITU-R Recommendation 618-9 and the newly proposed model. Figure 2 shows the plots of the measured value, ITU-R P618-9's prediction and the new model's prediction. The ITU-R model severely overestimated the measured value in Abakaliki, Nigeria. Table 3

shows the percentage error differences between the ITU-R's and new model's prediction values when compared to the measured values.

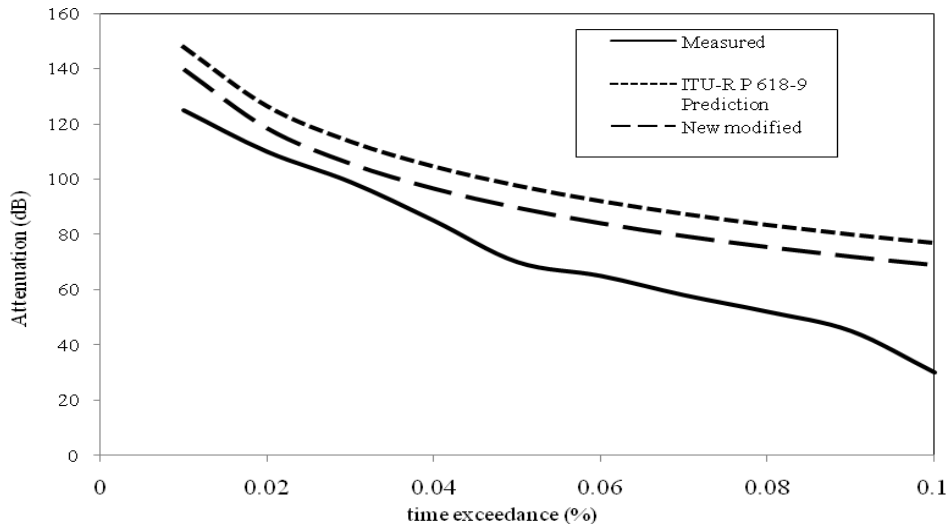


Figure 2: Measured values, ITU-R prediction and new modified model at Abakaliki, Nigeria.

Table 3: Comparison of Prediction Model, ITU-R model and measured values

Nigeria (38GHz)					
Time exceedance	Measured	ITU-R Prediction	% of error	New prediction	% of error
0.01	125	148.00	18.40	140.00	12.00
0.02	110	126.51	15.01	118.51	7.74
0.03	99	113.65	14.80	105.65	6.72
0.04	85	104.57	23.02	96.57	13.61
0.05	70	97.61	39.44	89.61	28.01
0.06	65	92.00	41.53	84.00	29.23
0.07	58	87.32	50.55	79.32	36.76
0.08	52	83.33	60.24	75.33	44.86
0.09	45	79.85	77.44	71.85	59.67
0.1	30	76.78	155.93	68.78	129.27
Malaysia (38GHz)					
Time exceedance	Measured	ITU-R Prediction	% of error	New prediction	% of error
0.01	11.00	7.45	32.25	15.45	40.47
0.02	12.00	7.80	34.99	15.80	31.68
0.03	13.00	8.20	36.95	16.20	24.59
0.04	14.00	8.65	38.20	16.65	18.94
0.05	15.00	9.19	38.75	17.19	14.58
0.06	16.00	9.83	38.56	17.83	11.44
0.07	17.00	10.64	37.44	18.64	9.62
0.08	18.00	11.69	35.03	19.69	9.41
0.09	19.00	13.22	30.44	21.22	11.67
0.10	20.00	15.84	20.80	23.84	19.20

It is evident that the new proposed prediction model does offer better estimation values than ITU-R Recommendation 618-9. Reduced error percentage can be observed in the above table.

5. Conclusion

Based on data analyses and scientific concerns on millimetre waves propagation in the tropic, a new rain attenuation prediction model had been developed. It can be concluded that most prediction models including the ITU-R - did not manage to offer good estimations when compared to measured values of V-band in tropical region. A new proposed prediction model had been configured; and capable of offering higher accuracy in predicting the V-band link rain attenuation in tropical region

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7. References

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