MEASUREMENT OF RAIN ATTENUATION FOR KU BAND SATELLITE SIGNAL IN TROPICAL ENVIRONMENT USING DAH, SAM MODELS

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ABSTRACT

Nowadays telecommunications and broadcasting services are in a rapid phase of expansion. There is an increasing demand for the multimedia services such as high-speed internet, on demand digital TV services, video conferencing and tele-education etc., which need high-speed data rates to cope with the demand whilst guaranteeing a high quality of service. The current microwave frequency spectrum allocated for telecommunication and broadcast services has become packed as the proposed broadband systems requires higher bandwidths. However, the attenuation due to atmospheric gases, clouds and rain increases significantly, for the frequencies above Ku-band. Though the attenuation is due to clouds and gases frequently, it is rain that causes the largest attenuation. In this paper three sophisticated models (ITU-R, DAH and SAM) have been explained to calculate rain attenuation. ITU-R model is the most widely accepted model by the international propagation community and is used for estimating long term statistics of rain attenuation at high frequencies in most of the regions. DAH stands for Dissanayake-Allnutt-Haidara Model. This is similar to and an extension of the ITU-R model. This model is also used at high frequencies. SAM stands for Simple Attenuation Model, which is suitable for tropical climate and heavy rainfall regions to calculate attenuation at point rainfall.

Keywords: specific attenuation, percentage exceedance, rain rate, attenuation.

INTRODUCTION

Generally satellite communication requires high band of frequencies i.e., ultra-high frequencies. At present, C, Ku band is used for satellite communication. It has band of frequencies in between 10-14 GHZ. But increasing the frequency range will also bring conflicts along with benefits. This is due to several factors like rain, snow, atmospheric gases etc. Among them, the major factor that leads the world of attenuation is RAIN. It is one of the most important factors which cause degradation of satellite signals in high frequency bands. Rain affects the transmitting signal in three ways: (1) It attenuates the signal; (2) It increase system noise temperature; and (3) It changes the polarization [1, 2].

EXPERIMENTAL SET UP AND LOCATION DETAILS

To study the Ku band attenuation over Indian region experimental setup was placed at K.L. University (Latitude-16.44’N, Longitude 80.62’E). Parabolic dish with size 96cm pointing towards INSAT 4A, GSAT-10 satellite for Rain attenuation studies. Received KU-band signal is given to down converter by using LNBF (9.5GHZ to 10.0GHZ) 950KHZ 2150 KHZ i.e., monitored by using spectrum analyzer, with the help of Data logging module (Lab-View(VI)), GPIB cable data a logged in to the PC with 10 sec interval. Simultaneously parallel experimental setup using OTT Percival disdrometer for recorded rain events with same 10 sec interval [10].

SAM: SAM is the Simple Attenuation model for predicting attenuation due to rain. This model utilizes the point rainfall rate for calculating attenuation. Simple Attenuation Model has been improved from an earlier version and now includes the effect of wave polarization. The model is for the prediction of rain attenuation statistics on earth-space communication links operating in the Ku and Ka band frequencies. Simple calculations produce attenuation values as a function of average rain rate. These together with rain rate statistics (either measured or predicted) can be used to predict annual rain attenuation statistics in region.

The Virginia Polytechnic Institute and State University Blacksburg, VA, has been engaged for several years in the development of rain attenuation models and related measurement programs. Several iterations of a quasi-physical model of rain attenuation on a slant path have been provided. Earliest versions of a comprehensive rain attenuation prediction model was the - Piecewise
Uniform Rain Rate Model. The Piecewise Uniform Model was later extended with an expanded global data base to an exponential shaped rain rake profile, and was called the Simple Attenuation Model (SAM). The simple attenuation model (SAM), incorporates the individual characteristics of stratiform and convective type of rainfall and utilizes the point rainfall rate at the ground to calculate the attenuation time series

\[ A = A_1 \times L, \]
\[ L = (H_e - H_0) / \sin(\theta) \]
\[ a = 4.21 \times 10^{-5} \times f^{2.42} \]
\[ b = 1.41 \times f^{-0.0779} \]

\( H_e \) = Effective rain height.
\( H_0 \) = Isothermal height from sea level.
\( L \) = Slant path length.
\( \theta \) = Elevation angle (degrees).
\( A_1 \) = Specific attenuation.

Rain attenuation.

The SAM is a semi empirical model that describes the spatial rainfall along a slant path length. Simple Attenuation Model has been improved from an earlier version and now includes the effect of wave polarization. The model is for the prediction of rain attenuation statistics on earth-space communication links operating in the Ku and Ka band frequencies. Calculations produce attenuation values as a function of average rain rate. These together with rain rate statistics (either measured or predicted) can be used to predict annual rain attenuation statistics in K.L. University.

![Figure-2. Kuband attenuation plot of February 16, 2014.](image)

![Figure-3. Kuband attenuation plot on February 16, 2014 with curve fitting.](image)

![Figure-4. Attenuation error between practically measured value and measured using SAM model with out curve fitting.](image)

![Figure-4. Attenuation error between practically measured value and measured using SAM model with out curve fitting.](image)
Figures from 2 to 5 shows the attenuation measurement on February 16th, 2014 using practically recorded beacon data and with the mathematical model. SAM in Figure-2 shows the measured and calculated attenuation using SAM model. At anytime measured attenuation is deaviating from the attenuation measured using mathematical model, this is because of some cable losses, and practically equipment deviates from its ideal version and also the measured attenuation fluctuates very frequently. To optimize those variations, curve fitting was used and also cable losses are considered as 2dB.

Figures from 6 to 9 shows the attenuation measurement on October 3rd, 2014 using practically recorded beacon data and with the mathematical model. SAM. in Figure-6 shows the measured and calculated attenuation using SAM model. At anytime measured attenuation is deaviating from the attenuation measured using mathematical model, this is because of some cable losses, and practically equipment deviates from its ideal version.
version, and also the measured attenuation fluctuates very frequently. To optimize those variations, curve fitting was used, and also cable losses are considered as 2dB.

**PREDICTION MODELS**

ITU-R P.618-11: Mentioned earlier, it is the most widely accepted model by the international propagation community and is used for estimating long term statistics of rain attenuation at high frequencies in most of the regions. The International Telecommunication Union first adopted a prediction of attenuation caused by rain in 25th Plenary Assembly in Geneva in 1982. The model is continuously updated as rain attenuation modeling is better understood. This gives the rain attenuation calculations required for international planning and coordination meetings and regional and world administrative radio conferences.

Here the name of model is **ITU-R P.618-11**. This gives summarized procedure for the computation of a satellite Path Rain attenuation. The following parameters are required for calculating attenuation [11].

- **R0.01**: point rainfall rate for the location of 0.01% of an average year.
- **hs**: height above mean sea level of the earth (km)
- **0**: elevation angle (degrees)
- **Φ**: latitude of the earth station (degrees)
- **f**: frequency (GHz)
- **Re**: effective radius of the earth (8500 km).

**Step-1**: Determine the rain height, hR, as given in Recommendation ITU-R P.839.

**Step-2**: For $0 \geq 5^\circ$ compute the slant-path length, $L_s$, below the rain height from:

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

(1)

For $0 < 5^\circ$, the following formula is used:

$$L_s = \frac{2(h_R - h_s)}{\sin^2 \theta + \frac{2(h_R - h_s)}{R_v}}^{1/2} + \sin \theta \text{ km}$$

(2)

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:

$$L_G = L_s \cos \theta \text{ km}$$

(3)

**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. 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, $\gamma_R$, 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:

$$\gamma_R = k (R_{0.01}) \alpha \text{ dB/km}$$

(4)

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

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

**Step-7**: Calculate the vertical adjustment factor, $\nu_{0.01}$, for 0.01% of the time:

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

For $\zeta > 0$, $L_R = \frac{L_G\, r_{0.01}}{\cos \theta} \text{ km}$

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

If $|\varphi| < 36^\circ$, $\chi = 36 - |\varphi| \text{ degrees}$

else, $\chi = 0 \text{ degrees}$

$$\nu_{0.01} = \frac{1}{1 + \sqrt{\sin \theta \left(31 \left(1 - e^{-0.45(\varphi/1+\chi)})\right)\sqrt{L_G \gamma_R} - 0.45\right)}$$

**Step-8**: The effective path length is:

$$L_e = L_R \, \nu_{0.01} \text{ km}$$

(5)

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

$$A_{0.01} = \gamma_R \, L_e \text{ dB}$$

(6)

**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 $p \geq 1\% |\varphi| \geq 36^\circ$: $\beta = 0$

If $p < 1\%$ or and $|\varphi| < 36^\circ$ and $0 \geq 25^\circ$
\[ \beta = \begin{cases} 0.005(|\phi| - 36) & \text{otherwise:} \\ -0.005(|\phi| - 36) + 1.8 - 4.25 \sin \theta & \end{cases} \]

\[ A_p = A_{b001} \left( \frac{P}{0.01} \right)^{-0.655 + 0.033 \ln(p) - 0.045 \ln(A_{b001}) - \beta(1-p) \sin \theta} \text{dB} \]

**DAH**

DAH rain attenuation model was developed by Asoka Dissanayake, Jeremy Allnutt and Fatim Haidara. The prediction model is similar to the ITU-R model where the rain related input to the model is the rain intensity at the 0.01% probability level. Inhomogeneity in rain in the horizontal and vertical directions are accounted for in the prediction. The method is applicable across the frequency range 4-35 GHz and percentage probability range from 0.001% to 10% [1,2].

**Step-1:** Obtain the effective rain height \( H \)

\[ H = 5.0 - 0.075(|\phi| - 23) \quad \text{for} \ \phi \geq 23 \]

Where \( \phi \) : the latitude of the earth station (deg)

**Step-2:** Calculate the slant path length \( L \)

\[ L = \frac{(H-H_0)}{\sin \theta} \text{Km for} \ \theta \geq 5 \]

**Step-3:** Calculate the horizontal projection of the slant-path \( L_h \)

\[ L_h = L \cos \theta \]

**Step-4:** Determine the specific attenuation \( \Gamma \) (dB/km)

\[ \Gamma = k (R0.01)^\alpha \]

Where \( k \) and \( \alpha \) are the same as ITU-R model, \( R0.01 \) is the point rain rate that exceed for 0.01% of a year (mm/h).

In ITU-R model, the expressions of \( k \) and \( \alpha \) are given as follows:

\[ k = \left[ k_H + k_v + (k_H - k_v) \cos(\theta)^2 \cos(2\theta) \right]/2 \]

\[ \alpha = \left[ k_H \alpha_H + k_v \alpha_v + (k_H \alpha_H - k_v \alpha_v) \cos(2\theta) \cos(2\theta) \right]/(2k) \]

Where \( t \) is the polarization tilt angle relative to horizontal.

**Step-5:** Calculate the horizontal path adjustment factor \( rh0.01 \) for 0.01% of the time

\[ rh0.001 = 1/(1 + 0.78 \sqrt{(LgY/f) - 0.38[1 - \exp(-2Lr)]}) \]

Where \( f \) is frequency in GHz.

**Step-6:** Calculate the adjusted rainy path length \( Lr \) (km) through rain

\[ L_r = L_g(\rho0.001)/\cos(\theta) \text{for} \ \zeta > \theta \]

Else \( L_r = (H-H_0)/\sin(\theta) \)

**Step-7:** Calculate the vertical adjustment factor \( rv0.01 \) for 0.01% of the time

\[ rv0.001 = 1/(1 + 3(1 - \exp(-2L)/f^2)) \sqrt{(\sin(\theta))} \]

**Step-8:** Calculate the effective path length through rain \( Le \)

\[ Le = L_r \cdot rv0.01 \]

**Step-9:** Determine the attenuation exceeded for 0.01% of an average year

\[ A_{0.01} = \gamma Le \text{dB} \]

**Step-10:** Determine the attenuation to be exceeded for other percentages of an average year in the range 0.001%-10%

\[ A_p = A_{b001} \left( \frac{P}{0.01} \right)^{-0.655 + 0.033 \ln(p) - 0.045 \ln(A_{b001}) - \beta(1-p) \sin \theta} \text{dB} \]

Figure-10 shows the percentage availability of satellite link in one year period by calculating the attenuation verses percentage time rain attenuation exceedance using ITU-R and DAH model. Practically predicted attenuation for most of the instances it was closely matched with the DAH model except at lower exceedance cases.
instant of time ITU-R underestimates the attenuation from the predicted one.

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