Frequency Scaling of Rain Attenuation at Ka band over Tropical Hill Station, Shillong

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Abstract

Present day satellite communication system application offering 100GB/s throughput and using very small-scale aperture terminal (VSAT), mostly uses the frequency band above 10 GHz. These frequency band is very susceptible to fading or link outage due to rain induced climatic challenge. However, the experimental arrangement at these frequencies may not be available for attenuation estimation and only option to adapt some scaling technique to scale the available measurements to that frequency. This work compares the available method over tropical locations along with conventional ITU-R method of frequency scaling and investigates the attenuation at higher frequency on the basis of worst month data of rain rate and rain attenuation over the hilly tropical location, Shillong.

1 Introduction

Designing a highly reliable satellite communication link at higher frequency over tropical region needs special attention as tropical region experiences rain induced climatic challenge during most of the time of a year. Frequency scaling is an important technique when the experimental arrangement for attenuation estimation at higher frequencies are not available and only option to adapt some scaling technique to scale the available measurements to that frequency. It is also an important component in avoidance technique, such as frequency diversity [6], by switching to different frequencies during heavy rain attenuation scenario.

Frequency scaling is further challenging for tropical regions as the existing models were developed mostly based on temperate regions data and the characteristics of rain changes significantly in tropical region in comparison to temperate regions. Hence, the issue needs to be addressed by considering rain microphysical parameter like rain drop size distribution [3] at the time of obtaining higher frequency attenuation from lower one. Alternatively, higher frequency attenuation can be estimated by taking differential phase and attenuation measurement into consideration due to heterogeneity of the medium [5].

Limited work has been done over tropical regions in this aspect. Some literature [2] estimated the rain attenuation for a satellite communication link at 19.8 GHz using the measured data of 12.25 GHz and ITU-R Rec. P.618-12[10] over the tropical location Korea. It is found that ITU-R model is not good enough for the prediction of higher frequency attenuation from lower frequency attenuation. During severe rain events, empirical frequency scaling ratio as used in ITU-R recommendation for frequency scaling, varies significantly. Another experimental work has been done for the prediction of 40 GHz attenuation from the attenuation at 20 GHz frequency using an instantaneous scaling as a result of drop size distribution over temperate climate using an optical disdrometer [7]. Scaling of interrelationship of intensity, duration and frequency of rain event is also reported using different rain gauges data [8]. A very recent literature [1] successfully estimated higher frequency attenuation time series in a very simplistic approach by only using the empirical parameters of lower frequency case and rain rate time series without using lower frequency attenuation time series. Here, Simple Attenuation Model (SAM) [9] is used to convert the rain time series to attenuation here.

2 Methodology

2.1. Experimental Description

Ka band signal of GSAT-14 satellite has been tracked at Shillong (25.68°N, 91.91°E), India for the worst month of the year of 2017 at North Eastern Space Applications center (NESAC), Indian Space research Organization (ISRO). Worst month is defined as the months of a year where average rainfall exceeds the average rainfall normally available throughout the year. The vertically polarized beacon signal is measured with a Ka band receiver and sampled at a rate of 10 Hz at 20.2 GHz and 30.5 GHz. A collocated Laser Precipitation Monitor (LPM) is used to get the rain information for the same period with 1 second temporal resolution. The rain intensity of one-minute resolution is used in this study. Both the data are obtained from SAC, ISRO for the analysis purpose.

2.2. Data Pre-processing

Rain attenuation time series is plotted for the complete time span of June to August, 2017. By visual inspection unwanted spikes, signal reception errors and signal interruptions are identified. Signal smoothening has been done using curve fitting tool and MATLAB software. Then the signal is filtered using Butterworth filter of 10th order to remove the fast fluctuation, i.e. scintillation. Reference level is set as the signal received in no rain condition. Reference level is also filtered to remove the fast fluctuation due to satellite movement and dry signal attenuation. At last the filtered reference level is subtracted from filtered signal to get the actual attenuation value.

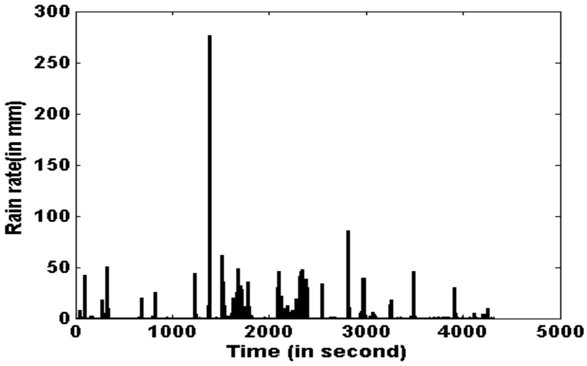

Figure 1. An example of the rain rate for the worst month of 2017

3 Frequency Scaling Models

3.1 ITU-R p.618.13

Attenuation at any higher frequency following ITU-R p. 618.13[10] as follows:

$$A_2 = A_1(\varphi_1, \varphi_2, A_1) \qquad (1)$$

Where,

$$\varphi(f) = \frac{f^2}{1 + 10^{-4} f^2}$$

$$H(\varphi_1, \varphi_2, A_1) = 1.12 \times 10^{-3} \left(\frac{\varphi_2}{\varphi_1}\right)^{0.5} (\varphi_1 A_1)^{0.55} \qquad (2)$$

A_1 and A_2 are attenuation at frequency f_1 and f_2 (GHz), respectively for the frequency range 7 to 55 GHz. If attenuation measurement a low frequency is available, attenuation at higher frequency can be obtained.

3.2 Attenuation using Frequency Scaling Technique of Acharya Model [1]

ITU-R model discussed above is based on empirical formula of attenuation which is not fixed practically, but varies specially in a challenging climatic condition. Therefore, instantaneous value is required for higher frequency attenuation prediction. According to ITU-R Rec. P. 838.3 [11], the specific attenuation S:

$$S = aR^b \qquad (3)$$

Where a and b are the frequency dependent power law coefficients and R is the rain rate at the location at any time. Total attenuation over the path:

$$A(f, t) = \int_0^{L_R} S\left(f, R(t, L)\right) dL \qquad (4)$$

Therefore, the rain rate profile needs to be known along the whole path from satellite to receiver to take care of severe rain condition. In absence of practical measurement SAM model [] is used for rain rate profile as:

$$R(t, h) = R_0(t)\ for\ R_0 <= 10mm/h \qquad (5)$$

$$R(t, h) = R_0(t) \exp\left[-\gamma \ln(\frac{R_0}{10})\, h\right]; for\ R_0 > 10mm/h \qquad (6)$$

Where R (t, h) is the rain rate at a distance h from receiver at any time t.

R_0 (t) is the point rain rate at the receiver at time t.

Putting the value from equation (5) and (6) Equation (3) is will be:

$$S(R_0, h) = (a\ Ro^b); for\ R_0 \le 10mm/h \qquad (7)$$

$$S(R_0, h) = a\ Ro^b \exp\left[-\gamma\ b \ln(\tfrac{R_0}{10})\, h\right]; for > 10mm/h \qquad (8)$$

Attenuation taking account of total path length

$$A = \int_0^L \alpha\ (s) ds = a\ Ro^b \int_0^L \exp\left[-\gamma\ b \ln\left(\frac{R_0}{10}\right) h\right] ds. \qquad (9)$$

The attenuation in terms of elevation angle

$$A = aRo^b \int_0^{H_R} exp\ [-\Upsilon\ b\ 1n(R0/10)H/tan\theta]dH/sin\theta \qquad (10)$$

Attenuation for complete rain height H_R,

$$A = \frac{(aRo^b)\left[1 - \exp\left\{-\gamma b\ cot\theta \ln\left(\frac{R_0}{10}\right) H_R\right\}\right]}{\gamma b cos\theta} \ln(\frac{R_0}{10})] \qquad (11)$$

Where: $\gamma' = \gamma \ln\left(\frac{R_0}{10}\right) cos\theta$

Final integrated attenuation

$$A = (a\ Ro^b)[1 - \exp\{-\gamma' b\ H_R\ cosec\theta\}]/\gamma' b \qquad (12)$$

4 Methodology

Two above mentioned frequency scaling methods are first compared with the experimental results. Then a new model is proposed by modifying the Acharya model and results are discussed as follows:

4.1 Rain Attenuation at 20.2 GHz and 30.5 GHz

Worst month rain rate statistics of 2017 over Shillong is shown in the Figure 1. Maximum rain rate obtained for the worst month (June to August) of the year 2017 is found to be around 276 mm/hr, which is quite high. Rain attenuation statistics for the worst month of the year of 2017 is shown in Figure 2 using 20.2 GHz beacon measurements and in Figure 3. using 30.5 GHz beacon measurements.

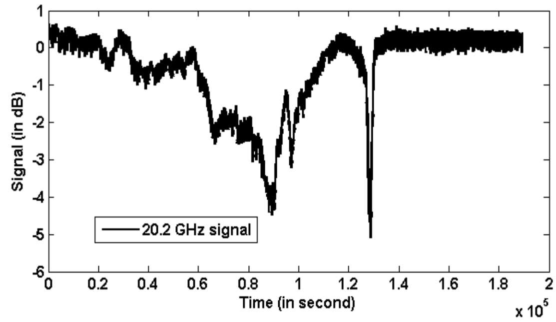

Figure 2. The signal received for the month of June to August 2017.

Maximum attenuation is found to be significantly high in the reception of 30.5 GHz signal in comparison with 20.2 GHz signal.

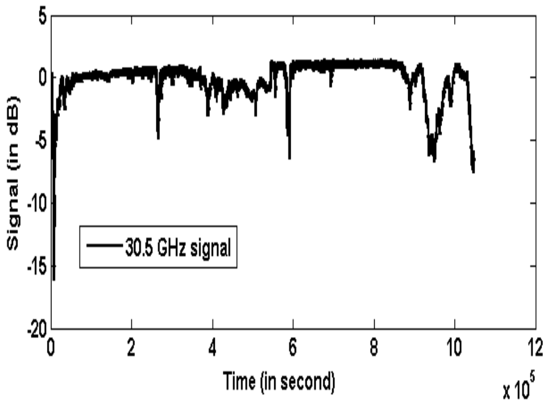

Figure 3. The signal received for the month of June to August 2017.

4.2 Performance comparison of the above two model from experimental measurement:

The attenuation statistics at 30.5 GHz is obtained using ITU-R model and the receiver signal data using beacon frequency 20.2 GHz is plotted with the attenuation statistics obtained using Acharya model [1] and the rain rate value as input and the experimentally measured data in figure 4. for the worst month of the year 2017 i.e. June, July and August of 2017.

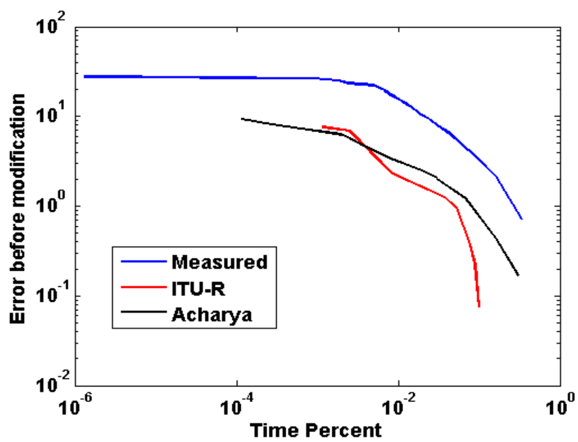

Figure 4. Performance comparison of two frequency scaling model of attenuation for worst month of 2017 over Shillong along with beacon measurement.

From the figure 4. it is indicated that both the ITU-R model and Acharya model [1] shows underestimation comparing with the actual result obtained from experimental measurement.

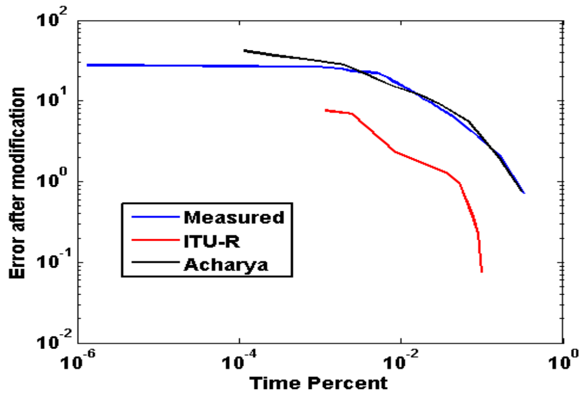

Figure 5. Performance comparison of Acharya frequency scaling model after modification along with ITU-R model and actual measurement during worst month of 2017 over Shillong.

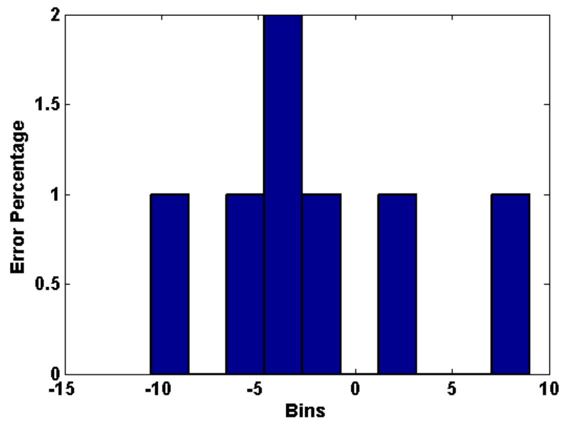

Figure 6. Error Comparison before and after modification of Acharya frequency scaling model.

Analyzing the rain statistics of the three worst months over Shillong it is found that the result obtained from Acharya model is well suited in troposphere as it uses rain rate profile without taking the piecewise concept of popular SAM [9] model over the tropical region where rain type is different from temperate region. However, the limitation of Acharya model is that it is lacking in actual synchronous rain rate measurement with signal beacon measurement for the validation of the model. The model may be corrected with average rain rate value which reflects the variability of rain climatic feature inside the tropical region.

4.3 Modification of Acharya model from Experimental Measurement over Tropical Region:

Therefore, by taking the simultaneous measurement of rainfall data over Shillong the modification of Acharya model is done as below:

$$A = \frac{(a\, Ro^{b})[1-\exp\{-\gamma' b\, H_R cosec\theta\}]}{\gamma' b} \times 2 \times Avg\_rain\_rate \quad \ldots\ldots 13$$

The performance of the modified Acharya model is reflected in figure 5. The error estimation before and after modification of Acharya model shown in figure 6. Where it is indicated that error percentage is reduced after modification, however error shows a significant percentage following the stochastic nature of rain induced attenuation.

5 Conclusion

A comprehensive comparison for the existing frequency scaling of attenuation is made to estimate the attenuation at the severe rain events using the worst month data of 2017 for the frequency above 10 GHz over hilly tropical region Shillong with a view to implement proper FMT in the case of radio signal link outage. Result indicates that the empirical formula of frequency scaling of ITU-R. P.618-13 is not constant during severe rain condition along the whole path from satellite to ground receiver, an instantaneous frequency scaling is appropriate on the basis of varying rain rate following SAM model. However, SAM model on the basis of piecewise assumption uses break point rain rate profile at 10 mm/hr. As there is no such threshold point exists between heavy and light rain over tropics. Acharya model takes the entire rain rate profile without piecewise concept. However experimental measurement shows quite a high value comparing with both ITU-R and Acharya model may be due to the reason that Acharya model lacking in simultaneous rain rate data to validate the model. Therefore, regional rain characteristics inside the tropical region must be considered while developing the model of attenuation. The Acharya model does not require the attenuation time series at lower frequency to get the higher frequency attenuation values making an advantage over ITU-R model, however lacking to quantify spatial effect at the time of frequency scaling of attenuation. More data over tropical region to validate the developed model will make the frequency scaling model stable for tropical region. The model will be very helpful to assess the attenuation at higher frequency band above 10 GHz where experimental measurement is not available.

6 Acknowledgements

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