Rain Attenuation Prediction for Satellite Communications Link at Ku and Ka Bands Over Bangladesh

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***Abstract*—The growing demand of microwave communication systems has overcrowded the frequency band below 10 GHz, thus system designers and RF engineers are forced to shift to higher bands of frequencies. However, signal power degradation at higher frequencies such as Ku and Ka bands is prominent and it is mainly due to rain. This leads to frequent service interruption and hence it is essential to predict the attenuation in an efficient manner. In this work, we have analyzed and predicted the attenuation in Ka and Ku bands from the 60 years of collected rainfall data of eight major zones of Bangladesh. Predicted attenuation is compared with International Telecommunications Union (ITU) recommended attenuation based on rain intensity. This work provides attenuation variation characteristics in the aforesaid bands and rain attenuation prediction in key parts of Bangladesh**

Keywords— Rain attenuation, Service Interruption, Annual rainfall variation, Ku and Ka bands, Communications link, ITU etc.

I. INTRODUCTION

Due to the growing demand, bandwidth in satellite channels and the lower bands being densely populated, satellite channels need to shift to the higher bands like Ku and Ka. In these high frequencies the electromagnetic waves propagating through the troposphere region of the atmosphere suffers from different impairments like attenuation, scintillation, depolarization etc. Rain is a dominant source of attenuation at frequencies above 10 GHz in tropical and subtropical regions [1]. In the design of most telecommunication systems, the dynamic characteristics of fading due to atmospheric propagation are of concern to optimize system capacity and meet the quality and reliability criteria [2]. Raindrops absorb and scatter radio waves, leading to signal attenuation and reduction of the system availability and reliability [3]. Rain attenuation can cause the largest attenuation and is usually the limiting factor at Ku and Ka-band satellite link design [4]. As it is inappropriate to provide adequate fixed link margin a-priori, proper prediction knowledge is required to compensate attenuation in an efficient manner. For a reliable communication system, unavailability time during a year has to be kept at 0.01 percent [5-6]. Knowledge of the 1-minute rain rate distribution is important for the prediction of rain attenuation at any location [7]. There is a need to calculate the attenuation due to rain from the knowledge of rain rates for satellite link [8]. Attenuation by rain can be predicted accurately if the rain is precisely described all the way along the path which degrades signal power [9]. The long term cumulative annual rainfall data are available for most of the parts of Bangladesh. The available annual rainfall data between 1948 and 2011are collected from eight major parts of Bangladesh. Using an appropriate conversion model which is described in section III, the long-term annual rainfall data have been converted to rain intensity. The rain intensity proposed by International Telecommunication Union (ITU-R) as well as converted data have been used to predict the rain attenuation for earth-to-satellite at C, Ku and Ka-Bands. The annual rainfall variation and rain attenuation statistics are obtained from annual rainfall rate. Rain attenuation profile all over Bangladesh has not yet been analyzed in depth. We have attempted to analyze those collected rain data to predict rain attenuation for major zones of Bangladesh, considering available long term rain data and compared those results with ITU recommended rain intensity.

II. INPUT DATA

Daily rain data (in millimeter, mm) have been collected from Bangladesh Meteorological Department (BMD) between 1948 and 2011. We have chosen eight sites/zones for rain attenuation

Fig.1: Bangladesh map showing rain attenuation predicted zones.

prediction in Bangladesh. Eight different zones are categorized as central (C), mid-western (MW), north-western (NW), south-western (SW), northern (N), north-eastern (NE), southern (S) and south-eastern (SE). These zones are shown in Fig.1. In our work, we have used Intelsat satellite 906 that is stationed at 64.15°E on Indian Ocean Region (IOR). This satellite has footprint over Bangladesh and provides telecommunications and broadcasting services for our country. The eight different sites with their major parameters are given in Table 1.

Table 1: Site information

Location	Position		Look Angles		Height above sea level (m)
	Lat. (N)	Long. (E)	Elev.	Az.	
Mohakhali	23.78^0	90.41^0	49.51^0	230.82°	8.45
Faridpur	23.60^0	89.85^0	50.2^0	230.1^0	8.10
Sylhet	24.89^0	91.87^0	47.6^0	231.2^0	33.53
Rajshahi	24.36^0	88.60^0	50.5^0	227.7^0	19.50
Rangpur	25.75^0	89.25^0	49.3^0	227.1^0	32.61
Betbunia	22.63^0	92.13^0	48.90^0	234.50^0	33.20
Khulna	22.81	89.24^0	51.2^0	230.3^0	2.10
Barisal	22.70°	90.36^0	50.3^0	231.9^0	2.10

III. Rain Intensities and Annual Rainfall

Common rain attenuation prediction methods require 1- minute (min) rain rate data which are scarce in the tropical and subtropical region [7]. However, yearly rainfall data are available at many meteorological stations. A method for converting those available rainfall data to the equivalent 1-min rain rate cumulative distribution (CD) would be very useful to radio engineers for link budget calculation. For this reason, 1-min rain rate CD can be estimated by the use of the Moupfouma model and long-term mean annual rainfall data. This model is good for tropical and temperate climate [3]. The Moupfouma model requires three parameters; λ and γ are co-efficient factors and depend on the local climatic conditions and geographic features and $R_{0.01}$ is the rain intensity exceeded during 0.01 percent of time in an average year (mm/hr). Based on the measured 1-min rain rate CD at several locations in Malaysia, Singapore and Indonesia, it was found that the best values for the parameters λ and γ in tropical regions are as given in Table 2.

Table 2: Parameters λ and γ

Annual Rain Intensity	λ	γ
M<3000	0.707	0.060
M>3000	0.398	-0.125

Several techniques have been described for the estimation of $R_{0.01}$ from the long-term mean annual rainfall *M*. These include the Morita model, Hosoya *et al.* model, Ajayi *et al.* model, Tropical India regression model and Chebil model [5]. To estimate $R_{0.01}$, it is suggested that it could be derived from the value of M at the location of interest. All these five models use the power law relationship

$$R_{0.01} = \alpha M^{\beta} \qquad (1)$$

where α and β are regression coefficients. In Chebil model the regression coefficients α and β are defined as α = 12.2903 and β = 0.2973. Using Chebil model, long-term mean annual rainfall data have been converted to 1-min rain rate data and presented in Table 3.

It is found that the highest rain intensity have been observed at south eastern region of Bangladesh equivalent to 136 mm/hr and lowest at North western zone equivalent to 111 mm/hr. The rain intensity recommended by ITU-R map is found 95 mm/hr for Bangladesh [6] which is far lower than converted rain intensity. Zone wise measured mean annual rainfall data and corresponding converted rain intensity are given in Table 3.

Table 3: Measured mean rainfall and converted rain intensity

Name of Zone	Measured Mean Annual Rainfall, M (mm)	Converted Rainfall rate , $R_{0.01}$ (mm/hr)
Central	2.1127183e+003	120
Mid Western	1.8590672e+003	115
North Eastern	2.6877339e+003	129
North Western	1.6334967e+003	111
Northern	2.0488421e+003	119
South Eastern	3.2161013e+003	136
South Western	1.7374404e+003	113
Southern	2.4117472e+003	124
ITU Map [6]		95

Heavy rainfall is the characteristic of Bangladesh with the exception of the relatively dry western region of Rajshahi where the mean annual rainfall is about 1633mm; most parts of the country receive around 2000 mm of rainfall per year. Maximum mean annual rainfall is observed at Chittagong in south eastern zone which is 3200mm. Annual rainfall variations in different zones of Bangladesh are shown from Fig. 2 to Fig. 5.

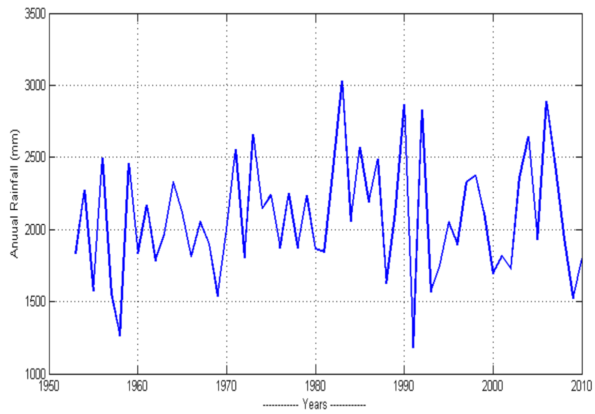

Fig. 2: Annual rainfall variation measured in central zone (Dhaka) during the Year 1952-2010.

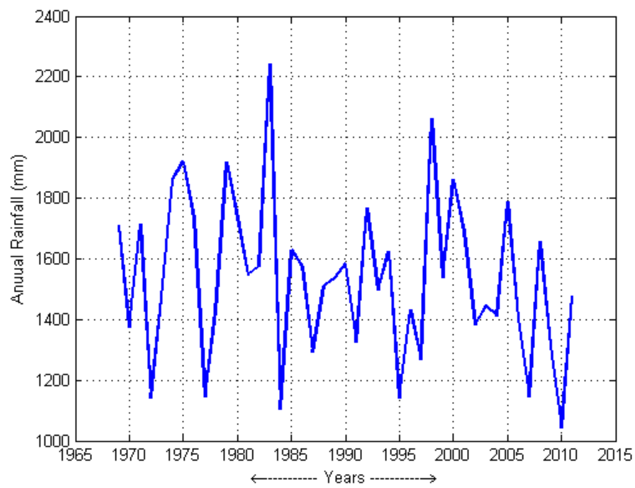

Fig. 3: Annual rainfall variation measured in North-Western zone (Rajshahi) during the Year 1967-2011.

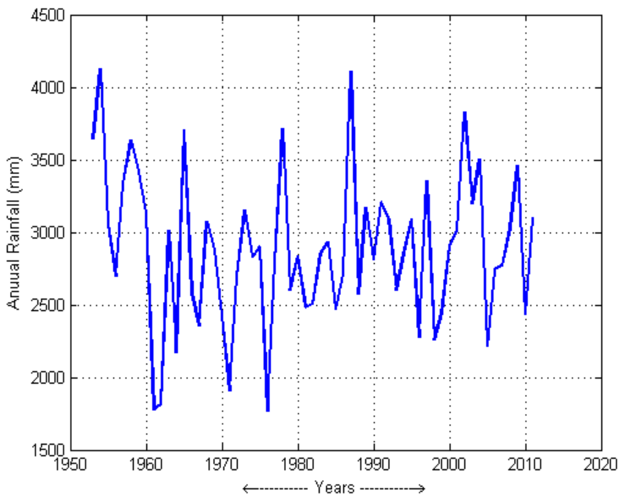

Fig .4: Annual rainfall variation measured in South-Eastern zone (Chittagong) during the Year 1948-2011.

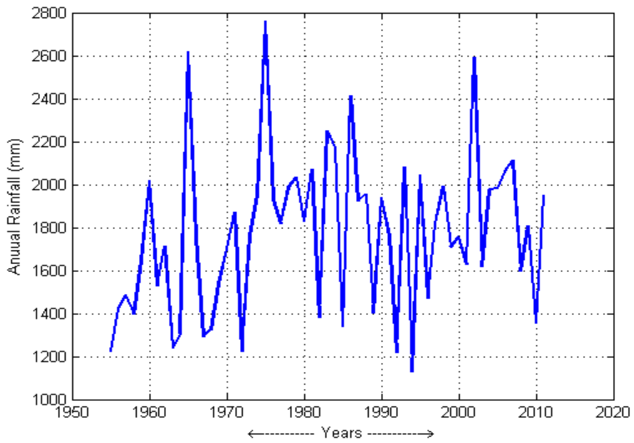

Fig. 5: Annual rainfall variation measured in South-Western zone (Khulna) during the Year 1955-2011.

IV. LONG-TERM RAIN ATTENUATION STATISTICS

The following procedure provides estimates of the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 55 GHz. The following parameters are required:

- $R_{0.01}$: point rainfall rate for the location for 0.01% of an average year (mm/hr)
- h_s: height above mean sea level of the earth station (km)
- θ: elevation angle (degrees)
- φ: latitude of the earth station (degrees)
- f: frequency (GHz)
- R_e: effective radius of the Earth (8500 km)

If local data for the earth station height above mean sea level is not available, an estimate can be obtained from the maps of topographic altitude given in Recommendation ITU-R P.1511. The geometry is illustrated in Fig. 6.

Step 1: In step-1 we determined the rain height, h_R, as given in Recommendation ITU-R P.839.

Step 2: For $\theta \geq 5°$, we computed the slant path length, L_s, below the rain height from:

$$L_s = \frac{(h_R - h_s)}{\sin \theta} \qquad \text{km} \qquad (2)$$

For θ < 5, the following formula is used:

$$L_s = \frac{2(h_R - h_s)}{\left(\sin^2\theta + \frac{2(h_R - h_s)}{R_e}\right)^{1/2} + \sin\theta} \qquad \text{km} \qquad (3)$$

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.

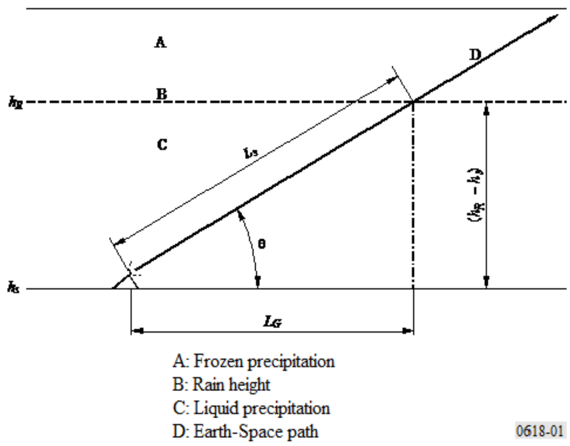

Figure 6: Schematic presentation of an earth space path giving the parameters to be input into the attenuation prediction process.

Step 3:We calculated the horizontal projection, L_G, of the slant path length from:

$$L_G = L_s \cos \theta \qquad \text{km} \qquad (4)$$

Step 4: We obtained the rainfall rate, $R_{0.01}$ for 0.01% exceedance of an average year (with an integration time of 1 min). This result is given table 3. 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: Then, we obtained the specific attenuation γ_R, using the frequency-dependent coefficients given in Recommendation ITU-R P.838-3 and the rainfall rate, $R_{0.01}$, determined from Step 4, by using:

$$\gamma_R = k(R_{0.01})^{\alpha} \qquad \text{dB/km} \qquad (5)$$

Frequency dependent regression co-efficient (co-eff.) k and α are obtained according to ITU-R P.838-3 for estimating specific attenuation at linear (vertical) and circular polarization. Those values are given in Table 4 and 5.

Table 4: Co-efficient values for k and α at 6, 12, 14 , 20 and 30 GHz frequency

Co-eff.	C-Band (6 GHz)	Ku Band (12 GHz)	Ku Band (14 GHz)	Ka Band (20 GHz)	Ka Band (30 GHz)
k	0.0004878	0.02455	0.04126	0.09611	0.2291
α	1.5728	1.1216	1.0646	0.9847	0.9129

To overcome complexity, only one satellite earth station located at Dhaka (Mohakhali) is considered to get regression co-efficient values at circular polarization. This station has an elevation angle 49.51 degrees.

Table 5: k and α values for C-Band (Circular Polarization)

Co-eff.	C-Band (4 GHz)	C-Band (6 GHz)
k	0.0001766	0.0005967
α	1.3547	1.5830a

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

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\frac{L_G\ \gamma_R}{f}} - 0.38\left(1 - e^{-2L_G}\right)} \qquad (6)$$

Step 7: We calculated the vertical adjustment factor, $v_{0.01}$, for 0.01% of the time:

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

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

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

If $|\varphi| < 36°$, $\chi = 36 - |\varphi|$ degrees

Else, $\chi = 0$ degrees

$$\nu_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}\left(31\left(1 - e^{-(\theta/(1+\chi))}\right)\frac{\sqrt{L_R\ \gamma_R}}{f^2} - 0.45\right)}$$

Step 8: The effective path length is:

$$L_E = L_R\ \nu_{0.01} \qquad \text{km} \qquad (7)$$

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

$$A_{0.01} = \gamma_R\ L_E \qquad \text{dB} \qquad (8)$$

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 $p \geq 1\%$ or $|\varphi| \geq 36°$: $\beta = 0$

If $p < 1\%$ and $|\varphi| < 36°$ and $\theta \geq 25°$:

$\beta = -0.005(|\varphi| - 36)$

Otherwise: $\beta = -0.005(|\varphi| - 36) + 1.8 - 4.25\sin\theta$

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{-(0.655 + 0.033\ln(p) - 0.045\ln(A_{0.01}) - \beta(1-p)\sin\theta)} \qquad \text{dB} \qquad (9)$$

This method provides an estimate of the long-term statistics of attenuation due to rain. When comparing measured statistics with the prediction, allowance should be given for the rather large year-to-year variability in rainfall rate statistics (ITU-R P.678).

Rain data were collected between 1948 and 2011 from eight different zones. Total 35 stations were used to obtain probability distribution of annual rainfall all around Bangladesh. Annual rainfall within 50 mm range is stacked and considered as each segment. It is observed that maximum and minimum rainfall in Bangladesh is 1017 mm and 6095 mm respectively from 60 years rain data. The probability of distribution of annual rainfall is shown Fig. 7.

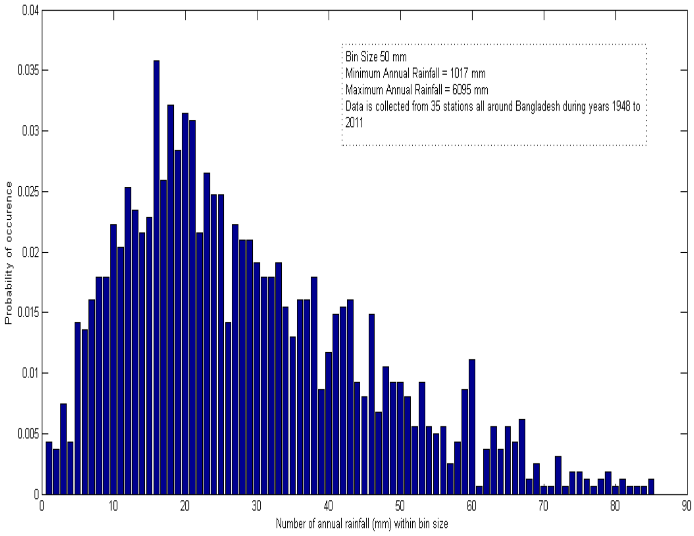

Fig. 7: Probability distribution of annual rainfall (in mm) for all regions of Bangladesh.

Rain attenuation comparison at C, Ku and Ka band frequencies for different zones of Bangladesh with ITU is shown in Table 6 for vertically polarized signal.

Table 6: Attenuation comparison at 0.01% of time exceeded for an average year (linear)

Freq. in GHz	Different zones and ITU attenuation (dB) at A0.01% (Linear Polarization)								
	C	MW	NE	NW	N	SE	SW	S	ITU
4	0.41	0.39	0.47	0.38	0.41	0.47	0.38	0.42	0.33
6	0.55	0.51	0.63	0.49	0.55	0.65	0.49	0.57	0.40
12	16.53	16.01	17.68	15.63	16.48	17.95	16.63	16.75	14.31
14	22.29	21.62	23.67	21.08	22.16	24.06	21.25	22.61	19.36
20	40.29	39.16	42.48	38.23	40.08	43.36	38.59	40.99	35.09
30	74.36	72.42	77.88	70.80	73.89	79.75	71.61	75.71	65.00

From Table 6, it is observed that attenuation at C band for 4 GHz and 6 GHz frequency is 0.4 and 0.5 dB respectively when the signal is vertically polarized. In this case, difference between 4 GHz and 6 GHz is 0.1 dB only. But from Table 7, attenuation at 4 GHz and 6 GHz frequency is 0.4 dB and 3 dB respectively when the signal is circular polarization. At 4 GHz frequency, rain attenuation for linear polarization and circular polarization is almost same. But, at 6 GHz frequency attenuation for circular polarization is around 2.5 dB is more than attenuation for vertically polarized signal. Attenuation Table 6 and Table 7 are prepared based on 0.01% of time exceeded for an average year. For Ku and Ka band frequency, signal is considered vertically polarized. At 12, 14, 20 and 30 GHz frequency, rain attenuation is around 16 dB, 22 dB, 39 dB and 73 dB respectively. For all of these three bands C, Ku and Ka band, Rain attenuation prediction is obtained based on ITU-R recommended and converted rain intensity from long term rain data available in Bangladesh. The difference of predicted rain attenuation based on rain rate measured in Bangladesh and ITU at C-Band 4 GHz and 6 GHz frequency is only 0.1 dB. On the other hand, for Ku and Ka bands at 12 GHz, 14 GHz, 20 GHz and 30 GHz frequencies, deviations with ITU data is about 2 dB, 3 dB, 5 dB and 10 dB correspondingly.

Table 7: Attenuation comparison at 0.01% of time exceeded for an average year (Circular)

Freq. in GHz	Different zones and ITU attenuation (in dB) at A0.01% (Circular Polarization)								
	C	MW	NE	NW	N	SE	SW	S	ITU
4	0.47	0.45	0.54	0.42	0.47	0.54	0.43	0.48	0.37
6	3.16	3.16	3.40	2.94	3.16	3.50	2.96	3.20	2.67

Fig. 8 to Fig.13 shows the attenuation for different zones of Bangladesh and ITU at different percentage of time and various frequency bands based on rain intensity.

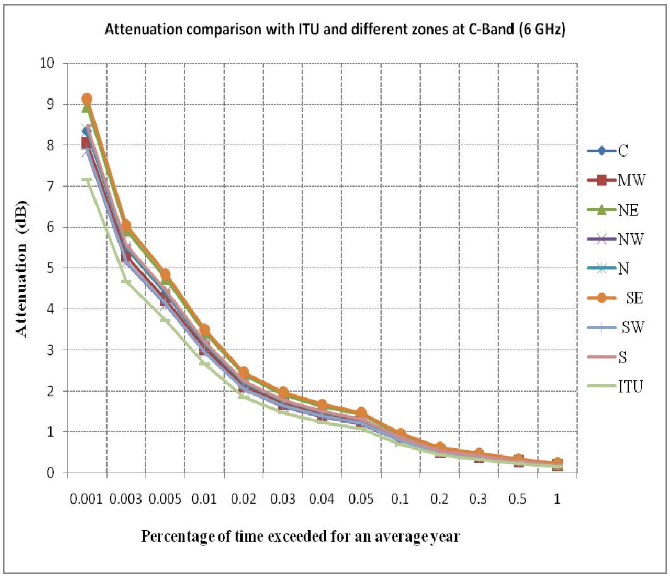

Fig. 8: Variation of predicted attenuation (For C-Band, 6 GHz, circular polarization) at different percentage of time exceeded for an average year.

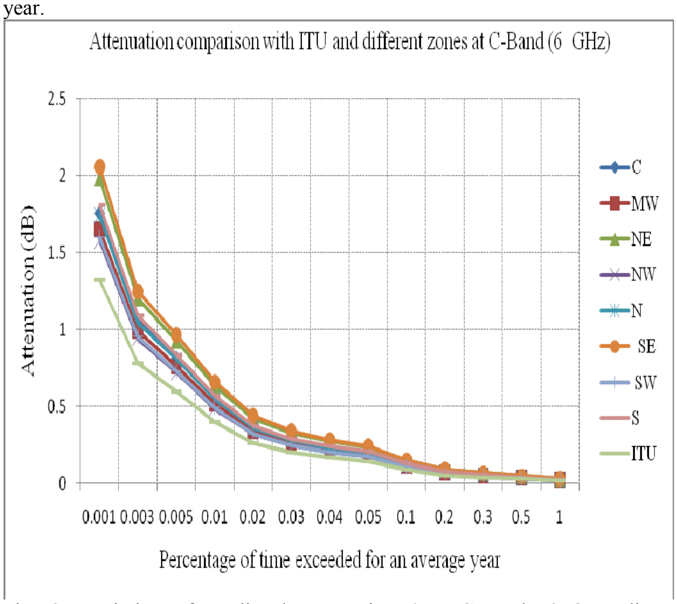

Fig. 9: Variation of predicted attenuation (For C-Band, 6 GHz, linear polarization) at different percentage of time exceeded for an average year.

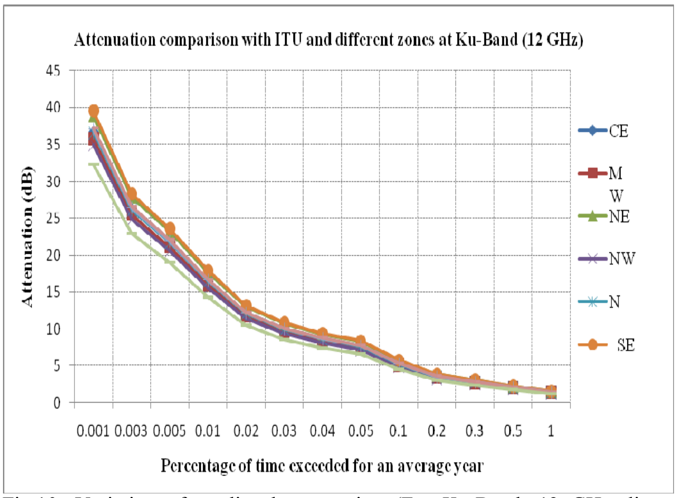

Fig.10: Variation of predicted attenuation (For Ku-Band, 12 GHz, linear polarization) at different percentage of time exceeded for an average year.

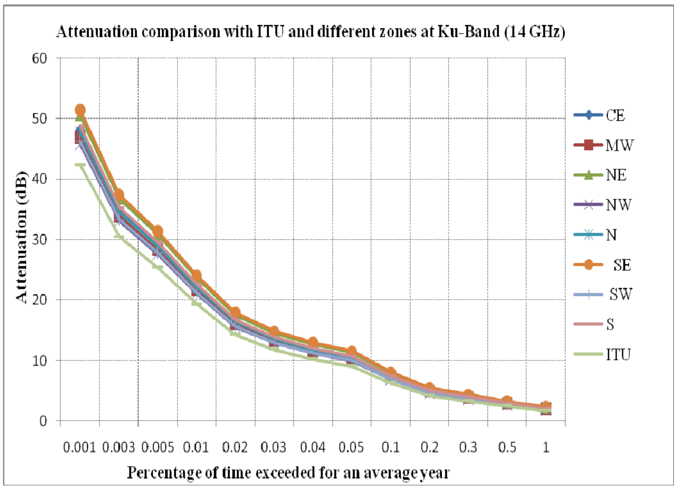

Fig. 11: Variation of predicted attenuation (For Ku-Band, 14 GHz, linear polarization) at different percentage of time exceeded for an average year.

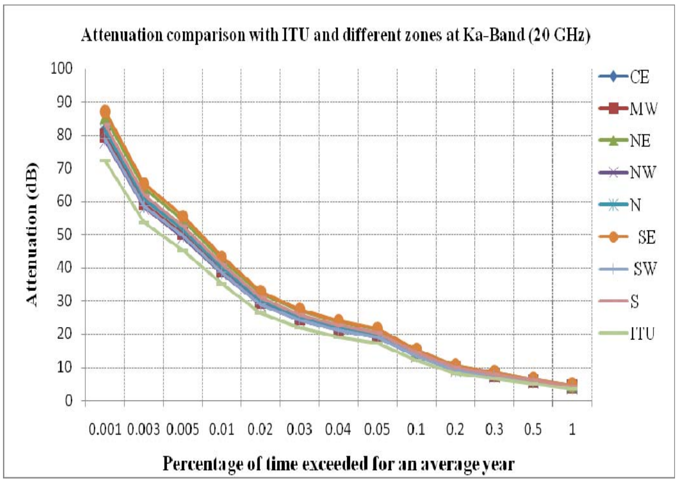

Fig.12: Variation of predicted attenuation (For Ka-Band, 20 GHz, linear polarization) at different percentage of time exceeded for an average year.

From Fig. 8 to Fig.13, it can be observed that predicted rain attenuation for central, mid-western, north-western, northern, southern and south-western zone are almost same and these zones are less attenuated zones. On the other hand, north eastern and south-eastern have higher rain attenuation. Based on the observation, Bangladesh can be divided into two major rain attenuation zones. The differences of attenuation between lower rain attenuated zone and higher rain attenuation zone are approximately 1.5, 2.5, 3 and 5 dB for 12, 14, 20 and 30 GHz frequency respectively.

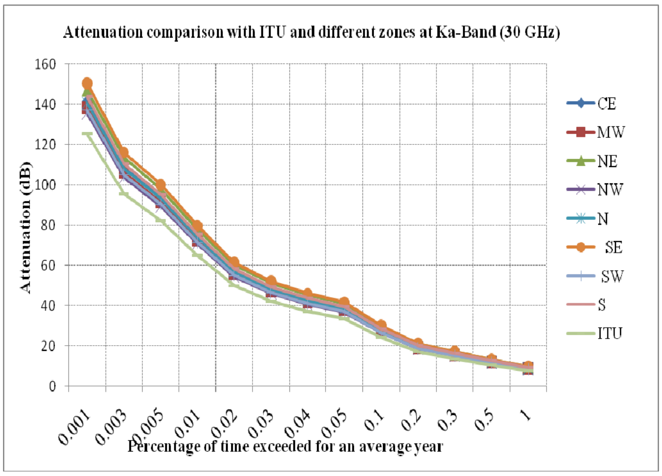

Figure 13: Variation of predicted attenuation (For Ka-Band, 30 GHz, linear polarization) at different percentage of time exceeded for an average year.

V. CONCLUSION

Rain is the principal source of attenuation at frequency more than 10 GHz. Because of densely congested lower bands frequency up to 10 GHz, scientists and engineers are moving to higher bands such Ku and Ka. It is evident that signal power degradation at Ku and Ka band due to rain can frequently unlock receivers and therefore interrupt services. For link reliability in the range of 99.99%, it is very important to estimate rain attenuation accurately for microwave communication link in any region where the rain is convective in nature like Bangladesh. For our study, rain attenuation profile is obtained for major parts of Bangladesh. It is observed that rain attenuation at C-Band below 6 GHz is not significant as compared to Ku and Ka band. Rain attenuation at the higher bands like 14 GHz, 20 GHz and 30 GHz frequency is significant; it is a great challenge to keep link alive with high reliability. This experiment will be helpful for link budget calculation in satellite communication systems in different parts of Bangladesh. This work is also useful for power estimation towards earth-space and space-earth direction. Bangladesh government is going to launch first commercial satellite in geostationary orbit within a few years. Therefore, it will be valuable for designing advanced Ku and Ka-bands transponders as well.

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REFERENCES

[1] M. R. Islam, M.A. Rahman, S. K. Eklas Hossain and M. S. Azad "Rain fade analysis on earth-space microwave link in a subtropical region", 5th International Conference on Electrical and Computer Engineering (ICECE 2008), pp-793-798, Dhaka, Bangladesh, 2008.

[2] F. Moupfouma and L. Martin 'Modeling of the rainfall rate cumulative distribution for the design of satellite and terrestrial communication systems', Int. J. Sat. Communication, vol. 13, pp. 105- 115, 1995.

[3] J. S. *Ojo* , M. O. Ajewole and S. K. Sarkar "Rain rate and rain attenuation prediction for satellite communication in Ku and Ka bands over Nigeria" Progress in Electromagnetic Research B, vol. 5, pp. 207–223, 2000.

[4] J. S. Mandeep and J. E. Allnutt "Rain Attenuation Predictions at Ku-Band in South East Asia Countries". Progress in Electromagnetic Research, vol.76, pp.65-74, 2007.

[5] J. Chebil, , and T.A. Rahman "Rain rate statistical conversion for the prediction of rain attenuation in Malaysia", Electron. Letter, vol. 35, no. 12, pp. 1019-1021, 1999.

[6] ITU-R, P.837-4, "Characteristics of precipitation for propagation modeling", ITU, Geneva, Switzerland, 2003.

[7] J. Chebil and T.A. Rahman, "Development of 1 min rain rate contour maps for microwave applications in Malaysian Peninsula" Electronics Letters, vol. 35 , no. 20, pp. 1772-1773, 1999.

[8] ITU-R, P.618-8, "Propagation data and prediction methods required for the design of earth-space telecommunication systems", ITU, Geneva, Switzerland, 2003.

[9] U. Kesavan, A. R. Tharek, A. Y Abdul Rahman and S. K. Abdul Rahman "Comparative studies of the rain attenuation predictions for tropical regions", Progress in Electromagnetic Research , vol. 18, pp-17-30, 2011.