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Performance Analysis of Rain Fades on Microwave Earth-to-Satellite Links in Bangladesh

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ABSTRACT

Rain is a dominant source of attenuation at higher frequencies in tropical and subtropical regions and consequently degrades the system performance in tropical and subtropical regions. The knowledge of rain fade and it's performance is essential in order to optimize system capacity and meet quality and reliability. The rain intensity data for Bangladesh is not available since it has not been measured so far. In this paper, one-minute integration time rain intensity is derived from measured annual rainfall statistics from long term rainfall data collected from 34 meteorological stations for last thirteen years which can be used to design microwave systems in any parts of Bangladesh. The converted rain intensity data and ITU-R recommended rain intensity are used to estimate the deviation of rain fades at C, Ku and Ka-bands for comparison. The deviations are found to be small at lower frequency bands and are significantly higher at higher frequency bands.

Keywords - *Rain Rate, rain fade, microwave link design*

I. INTRODUCTION

The very fast growth in communication systems has brought saturation to the most desirable frequency band (1 to 10 GHz). This fact has led to the utilization of higher frequencies extending the radio frequency spectrum into the millimeter wavelength region. Rain is a dominant source of attenuation at higher frequencies. Attenuation due to rain at frequencies above 10 GHz, mainly leads to outages that compromise the availability and quality of service, making this one of the most critical factors in designing microwave link in tropical and subtropical regions. The design of new telecommunication systems requires the knowledge of rain fade in order to optimize system capacity and meet quality and reliability criteria [1].

For a reliable communication system, unavailability time during a year has to be kept at 0.01 percent. This corresponds to availability time of 99.99 percent during a year. Therefore rainfall with one-minute integration time is very important parameter to predict attenuation at 0.01% of time availability [2, 3, 4]. In this paper, one-minute integration time rain intensity data are derived from last thirteen years annual rainfall statistics measured at 34 meteorological stations in Bangladesh. The converted rain intensity data are used to estimate rain fades at C, Ku and Ka-bands.

II. RAIN STATISTICS OF BANGLADESH

Bangladesh is located at 88^0 to 93^0 longitude (East) and 20^0 to 27^0 Latitude (North). Because of its location just south of the foothills of the Himalayas, where monsoon winds turn west and northwest, Bangladesh receives the heavy average precipitation. For the prediction of rain attenuation in Bangladesh daily rainfall data (mm) of 34 rain stations are collected from Meteorological Department of Bangladesh for last 13 years. In many stations few daily rainfall data were missing. So availability calculation was required. The availability of data of corresponding rain stations are shown in Table – 2. Those daily rainfall data were converted into average annual accumulation, M (mm/year).

III. CONVERSION OF RAIN STATISTICS TO RAIN INTENSITIES

Common rain attenuation prediction methods require 1- min rain rate data, which is scarce in the tropical and subtropical region. However, yearly rainfall data are available at many meteorological stations. **A** method for converting the available rainfall data to the equivalent 1 min rain rate cumulative distribution (CD) would be very useful for radio wave engineers. For this reason 1 min rain rate CD can be estimated by the use of the refined Moupfouma model and long-term mean annual rainfall data.

Several studies have shown that the Moupfouma model with refined parameters can best describe the 1 min rain rate distribution in tropical regions. Moupfouma found that the 1 min rain rate CD could be expressed as [3]

$$p(R \geq r) = 10^{-4}\left(\frac{R_{0.01}+1}{r+1}\right)^{b} \exp(u[R_{0.01}-r]) \qquad (1)$$

where r [mmih] represents the rain rate exceeded for a fraction of the time, and b is approximated by the following expression:

$$b = \left(\frac{r-R_{0.01}}{R_{0.01}}\right) \ln\left(1+\frac{r}{R_{0.01}}\right) \qquad (2)$$

The parameter U in eqn. 1 governs the slope of rain rate CD, and depends on the local climatic conditions and geographical features. For tropical localities

$$u = \frac{4\ln 10}{R_{0.01}} \exp\left(-\lambda\left[\frac{r}{R_{0.01}}\right]^{\gamma}\right) \qquad (3)$$

where λ and γ are positive constants. Based on the measured 1min rain rate CD at several locations in Malaysia, Singapore and Indonesia [3], it was found that in tropical regions the best values for the parameters λ and γ are given in Table 1:

Table 1: Parameters

	λ	γ
M < 3000 mm	0.707	0.060
M > 3000 mm	0.398	-0.125

Thus, the Moupfouma model requires three parameters λ, γ and $R_{0.01}$. M is the mean annual rainfall. The first two parameters are easily determined from Table 1. To estimate $R_{0.01}$, it is suggested that it be derived from the value of M at the location of interest. 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. All these five models use the power law relationship [3, 4]

$$R_{0.01} = \alpha M^{\beta} \qquad (4)$$

where α and β are regression coefficients. Chebil has made a comparison between the five models based on measured values of M in Malaysia, Indonesia, Singapore, Brazil and Vietnam. He showed that his model is the best estimate of the measured data [2,3]. In Chebil model the regression coefficients α and β are defined as [2]

$$\alpha = 12.2903 \text{ and } \beta = 0.2973 \qquad (5)$$

Using Chebil model, long-term mean annual rainfall data has been converted to 1 min rain rate data and are presented in Table – 2.

Table 2: Measured mean annual rainfall and rain intensity at thirty four stations in Bangladesh

Station Name	Average of 13 years availability of data	Average Annual accumulation M (mm/year)	$R_{0.01}$ (mm/hr)
Dhaka	100	2118.00	119.77
Mymensingh	100	2316.30	123.00
Tangail	100	1882.23	115.64
Faridpur	100	1830.15	114.68
Madaripur	100	2013.92	117.99
Chittagong	99.83	2924.92	131.83
Sandwip	89.736	3604.76	140.28
Sitakunda	99.705	3054.00	133.54
Rangamati	100	2713.46	128.92
Comilla	100	2195.30	121.05
Chandpur	99.85	1981.76	117.42
M.Court	99.178	3062.15	133.64
Feni	99.325	2935.46	131.97
Hatiya	69.209	2552.46	126.60
Cox's Bazar	100	3890.15	143.50
Kutubdia	100	2986.53	132.65
Teknaf	100	4360.69	148.45
Sylhet	99.978	3916.38	143.78
Srimangal	100	2442.53	124.95
Rajshahi	100	1572.92	109.63
Ishurdi	100	1562.92	109.42
Bogra	100	1818.69	114.46
Rangpur	100	2398.23	124.28
Dinajpur	100	2140.30	120.14
Sayedpur	100	2389.61	124.14
Khulna	100	1905.07	116.05
Mongla	100	2053.38	118.67
Satkhira	100	1846.38	114.98
Jessore	100	1767.07	113.49
Chuadanga	100	1602.00	110.23
Barisal	100	2136.53	120.08
Patuakhali	100	2695.92	128.68
Khepupara	100	3027.07	133.18
Bhola	100	2368.00	123.81
ITU-R Map		-	95

The highest rain intensity is observed at Teknaf at 148.45 mm/hr and lowest at Ishurdi is 109.42 mm/hr. The rain intensity recommended by ITU-R map is found 95 mm/hr for Bangladesh [5] which is far lower than converted rain intensity from measured long term annual rainfall.

IV. METHODS OF RAIN ATTENUATION PREDICTION

The following technique is used for estimating the long-term statistics of rain attenuation for the design of earth to satellite systems [6]:

$R_{0.01}$: point rainfall rate for the location for 0.01% of an average year (mm/h)

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).

The geometry is illustrated in Figure 1 where
A = frozen precipitation
B = rain height
C = liquid precipitation
D = Earth-space path

Step1: Determine the rain height, h_R, as given in Recommendation ITU-R P.839.

Step2: For $\theta \geq 5°$ compute the slant-path length, L_s, below the rain height from:

$$L_S = \frac{(h_R - h_S)}{\sin \theta} \quad \text{km} \qquad (6)$$

For $\theta < 5°$, the following formula is used:

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

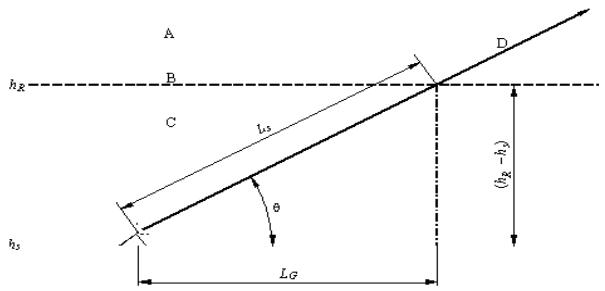

Fig 1: Schematic presentation of an earth-space path given the parameters to be input to the attenuation prediction process.

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.

Step3: Calculate the horizontal projection, L_G, of the slant-path length from:

$$L_G = L_s \cos \theta \quad \text{km} \qquad (7)$$

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 Table 2.

Step5: Obtain the specific attenuation, γ_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:

$$\gamma_R = k\,(R_{0.01})^{\alpha} \quad \text{dB/km} \qquad (8)$$

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

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\frac{L_G\,\gamma_R}{f}} - 0.38\left(1 - e^{-2L_G}\right)} \qquad (9)$$

Step7: Calculate the vertical adjustment factor, $v_{0.01}$, for 0.01% of the time:

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

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

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

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

Else, $\chi = 0$ degrees

$$\nu_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}\left(31\left(1 - e^{-(\theta/(1+\chi))}\right)\frac{\sqrt{L_R\,\gamma_R}}{f^2} - 0.45\right)} \qquad (10)$$

Step 8: The effective path length is:

$$L_E = L_R\, \nu_{0.01} \quad \text{km} \qquad (11)$$

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

$$A_{0.01} = \gamma_R\, L_E \quad \text{dB} \qquad (12)$$

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:

$$A_{\%P} = A_{0.01}\left[\frac{P}{0.01}\right]^{[0.065 + 0.033\ln(P) - 0.045\ln(A_{0.01\%}) - \beta(1-P)\sin\theta]} \qquad (13)$$

V. RESULTS AND DISCUSSION

Following the approach presented in section III and IV, we estimate the long-term statistics of due to rain for 34 rain stations in Bangladesh. Considering Singapore Satellite ST1 located at 88 degree East longitude and earth station at Dhaka at 90^o longitude (East) and 24^o Latitude (North), the elevation angle is 61.8^0. Using above methodology from step 1 to step 10, rain fades have been estimated for all thirty four rain stations as well as those recommended by ITU-R and presented in Table – 4 and are depicted in Fig. 2 and Fig. 3 in terms of attenuation (dB) versus percentage of time and in Fig.4 and Fig. 5 in terms of deviation versus system reliability. In all cases the signals are assumed as horizontally polarized and the regression coefficients are given in Table – 3.

Table 3: Regression Coefficients for Estimating Specification Attenuation

Horizontal	C-band (4GHz)	Ku-band (12GHz)	Ka-band (20GHz)
α	1.3912	1.1584	1.0280
k	0.0001611	0.0241	0.0934

Table 4: Estimated rain fades for all three frequency bands at horizontal polarization.

Frequency	$A_{0.01}$ (dB) at Measured Maximum $R_{0.01}$	$A_{0.01}$ (dB) at Measured Minimum $R_{0.01}$	$A_{0.01}$ (dB) at Predicted ITU-R $R_{0.01}$
4 GHz	1.65	1.08	0.90
12 GHz	77.59	54.49	46.41
20 GHz	156.39	114.29	99.21

For all the three bands, rain attenuation are estimated based on ITU-R recommended rain rate as well as converted rain rate from long term measured data. It is obvious that ITU-R predicted rain attenuation are lower than those predicted using measured rain rate in all cases. The differences are 0.75 dB at C-band, 31.18 dB at Ku-band and 57.18 dB at Ka-band when $R_{0.01}$ is maximum and 0.18 dB at C-band, 8.08 dB at Ku-band and 15.08 dB at Ka-band when $R_{0.01}$ is minimum. Hence to design reliable microwave link is very critical at Ku and Ka- bands and needs careful and accurate estimation of rain attenuation in Bangladesh.

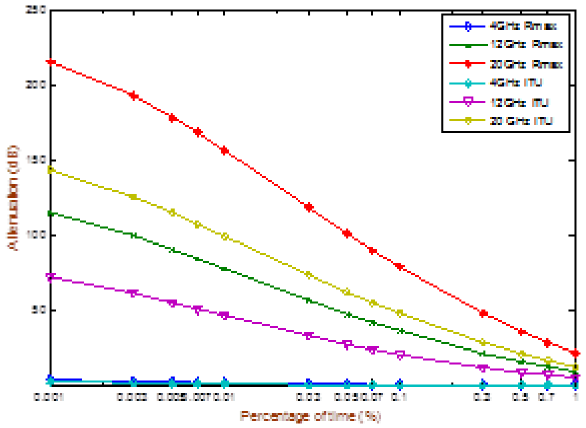

Fig 2: Comparison of predicted rain attenuation at C/Ku/Ka-Band with H-polarization using measured maximum $R_{0.01}$ and ITU-R proposed $R_{0.01}$.

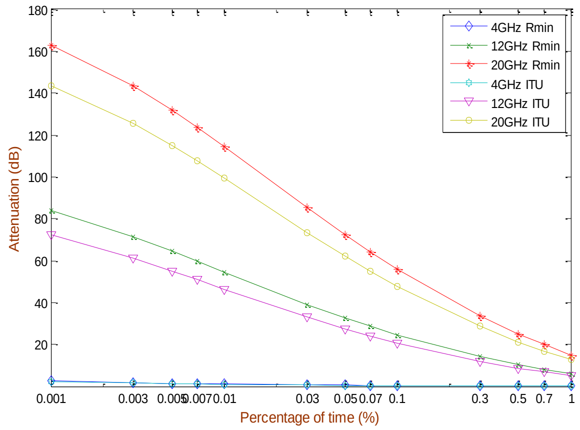

Fig 3: Comparison of predicted rain attenuation at C/Ku/Ka-Band with H-polarization using measured minimum $R_{0.01}$ and ITU-R proposed $R_{0.01}$.

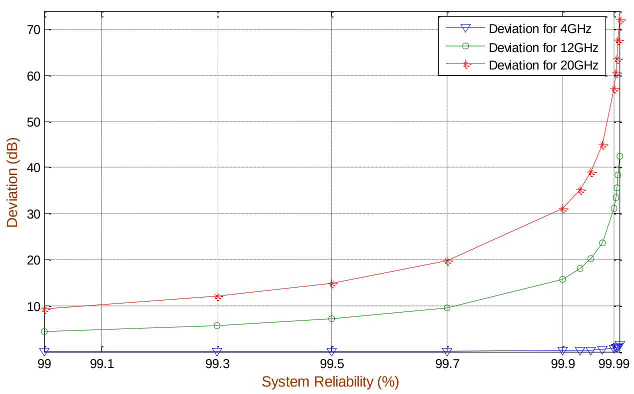

Fig 4: Deviation between Measured Maximum $R_{0.01}$ and ITU-R predicted $R_{0.01}$ at C/Ku/Ka-Band with H-polarization.

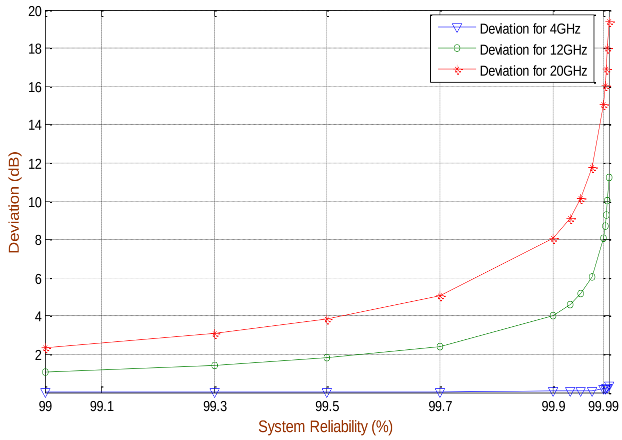

Fig 5: Deviation between Measured Minimum $R_{0.01}$ and ITU-R predicted $R_{0.01}$ at C/Ku/Ka-Band with H-polarization

From Fig. 2 to Fig. 5, it is observed that the effect of rain attenuation in Ku and Ka bands are significant. It is also observed that with the increase of system reliability, deviation between measured attenuation and ITU-R predicted attenuation increases. So it is clear that ITU-R recommendation underestimates the rain rate measured in Bangladesh and consequently the rain fade estimation introduces significant errors especially at Ku and Ka-bands. But the measured rain rate data is converted from measured long term annual rainfall data, it is too preliminary to comment correctly. Hence to design reliable microwave link is very critical at Ku and Ka- bands and needs careful and accurate estimation of rain attenuation in Bangladesh.

From various studies [1-2,4,7] it has been observed that for some countries ITU-R underestimates the value of rainfall rate, $R_{0.01}$ (mm/hr) and sometimes overestimates. For example in Malaysia the value of ITU-R predicted $R_{0.01}$ is 145 mm/hr at any locations where measured $R_{0.01}$ varies from 80-150 mm/hr [1]. So for areas with lower rainfall such as Chuping, Temerloh, Kuala Lumpur and Senai $R_{0.01}$ is lower than the ITU-R value. It is observed that for areas with higher rainfall rate such as Taiping, Jerangau and Tapah, $R_{0.01}$ is 145mm/h where the ITU-R value is quite acceptable [2]. Also ITU-R rain zoning overestimated rain rate values in Nigeria [4]. Here deviation between Measured $A_{0.01}$ and ITU-R predicted $A_{0.01}$ at Ku-Band (12.675 GHz) is approximately 19.6 dB. In Brazil for different locations ITU – R underestimated rain rate values and the deviation is approximately 4-5 dB at Ku – Band (11.452 GHz) [7].

VI. CONCLUSIONS

Rain is a dominant source of attenuation at higher frequencies in tropical and subtropical regions. Therefore accurate estimation of rain fade is very essential in order to design reliable microwave links in such regions. This paper presents the cumulative rainfall data collected for thirteen years in different parts of Bangladesh. Using appropriate conversion model, the long-term annual rainfall data has been converted to rain intensity data. The rain intensity proposed by International Telecommunication Union (ITU-R) as well as converted data are used to investigate the rain fade for microwave propagation in Bangladesh. These prediction shows that use of Ku and Ka-bands is very challenging and critical in this region. However the measured rain rate data is converted from measured long term annual rainfall data. From deviation curves it is observed that with the increase of system reliability, deviation between predicted attenuation at measured maximum and minimum $R_{0.01}$ and ITU-R predicted attenuation increases. Therefore it is recommended to measure rain intensity and rain drop size distribution urgently for the design of reliable microwave link in Bangladesh.

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