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# Study of Propagation Channel Modeling and Comparison of Rain Cell Models over a Tropical Location using Ground based Observations

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## Abstract

This paper presents some important results of propagation channel modeling at a tropical location, Kolkata. Propagation impairments, namely, rain attenuation, cloud attenuation and water vapor attenuation has been investigated using ground based measurements. Though rain attenuation shows high values at high frequencies and low elevation angles, however the effect of cloud attenuation at earth-space path is also significant. It has been observed that rain has significant impact on bit error probability. Site diversity is a useful fade mitigation technique which is based on the concept of horizontal extent of rain cells. Performance of Different rain cell models have been compared in connection to calculate diversity gain over this location. The ITU-R model shows the best performance.

## 1 Introduction

The implementation of satellite communication and upcoming 5G communication systems in a specific region requires an adequate knowledge of the propagation characteristics pertaining to that region. Study of propagation channel characteristics at Ka and higher frequency bands is still limited over a tropical location due to lack of data to characterize the propagation parameters. A degradation of signal propagated over an earth-space path occurs due to various meteorological phenomena such as rain, cloud and water vapor. Some detailed studies of rain, cloud and water vapor attenuation have already been studied over a tropical location Kolkata using ground based measurements [1-6]. At the location of Kolkata, India rain attenuation of 8.95 dB has been observed with satellite signals for 0.01 % of time at Ku-band. Cloud attenuation observed from radiometric measurements at 30 GHz shows 3 dB before rain commencement. The role of water vapor in determining atmospheric attenuation has been observed at 3 different frequencies using radiometric measurements. In addition to atmospheric losses, there is free space loss, which is dependent on link distance and the transmitted frequency [7]. Atmospheric propagation impairments also affect the signal after it is demodulated at the receiver. There are very few studies reported on the relationship between rain rate and bit error probability (BEP) [7]. As rain attenuation is the major propagation impairment, it is necessary to mitigate the effect of rain. In this connection, the site diversity is a very useful technique which uses the concept of rain cells [1, 8]. In this paper, the effect of various propagation impairments on earth-space communication has been investigated. In this connection, the performance of various rain cell models for site diversity over this location has been studied.

## 2 Data and Methodology

Observations from ground based instruments located at the Institute of Radio Physics and Electronics, University of Calcutta have been used in the present investigation. A Disdrometer has been operated which measures rain drop size distributions of different drop diameters that are sorted into 20 individual size intervals (starting from 0.359 mm to 5.5 mm) with 30 s sampling intervals. It calculates rain rate and radar reflectivity from drop size distribution. An RPG HATPRO multi-frequency radiometer has been used to obtain cloud and water vapor attenuation over Kolkata. Radiometer measures brightness temperature, liquid water path (LWP), integrated water vapor (IWV) [9]. GPM IMERG precipitation comprises various precipitation-relevant satellite passive microwave (PMW) sensors data and has been computed using Goddard Profiling Algorithm (GPROF2017). Then the data have been gridded and inter calibrated to the GPM Combined Ku band Radar-Radiometer Algorithm (CORRA) product, and combined into half-hourly 0.1°x0.1° fields. For the rain attenuation exceedance and worst month statistics, disdrometer data of the period 2010-2013 have been used. For cloud attenuation exceedance, radiometer data of the period 2010-2011 have been used.

## 3 Results

In the result section, propagation impairments due to rain, cloud and water vapor have been observed in connection with some atmospheric parameters. The effect of rain rate on BER has also been shown over this location based on some ground based rain rate measurements. In the last part, performance of some rain cell site diversity models have been investigated to calculate diversity gain over this location.

### 3.1 Rain Attenuation

Figure 1 shows the comparison of GPM and disdrometer rain rate and rain attenuation. Disdrometer data have been averaged for 30 minutes. The disdrometer and GPM IMERG show good matching of rain rates. However rain rates show small values due to average effect. Figure 2a shows the rain rate of disdrometer for an event on 25 May 2009. Specific rain attenuation has been calculated from drop size distribution using Mie scattering theory. Total rain attenuation has been calculated using ITU-R model [10] Figure 2b shows calculated rain attenuation from drop size distribution at 30 GHz, 60° elevation angle. For 100 mm/h rain rate, it shows 60 dB attenuation value at

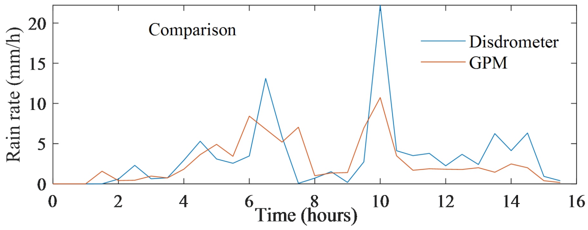


**Figure 1.** (a) Comparison between Disdrometer and GPM of rainfall on 25 May 2009.

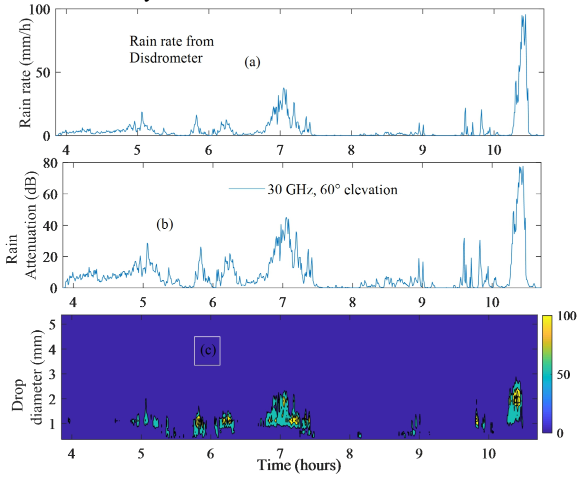


**Figure 2.** (a) rainfall, (b) Rain attenuation and (c) DSD on 25 May 2009.

30 GHz frequency and 60° elevation angle. Figure 2c shows the DSD for the same event. To investigate the variation of rain attenuation with elevation angle and frequency simultaneously, rain attenuation at two

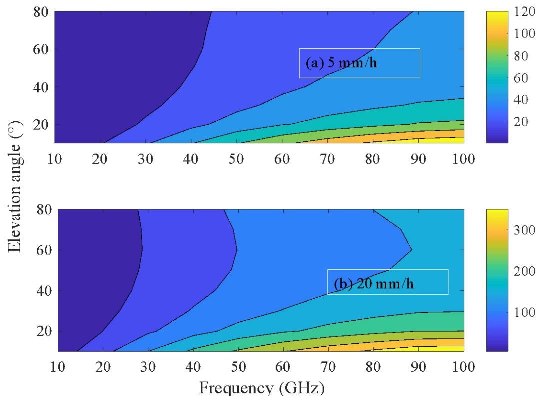


**Figure 3.** Contour plot of rain attenuation with frequency and elevation angle for (a) 5 mm/h and (b) 20 mm/h rain rate.

rain rates, namely, 5 mm/h and 20 mm/h have been calculated for the elevation angles 10° to 80° and for the frequencies 10 GHz to 100 GHz. It can be seen from Figure 3 that though the rain rate is 20 mm/h, the attenuation can be quite significant at high frequencies and low elevation angles. These phenomena should be taken into consideration for the design of upcoming Ka and higher frequency bands mobile satellite communication over the tropical region. The exceedance and worst month concept is significant to design radio communication systems on the basis of the link availability [3, 8]. Exceedance probability of rain attenuation and worst month statistics have been shown in Fig. 4a and 4b respectively. Exceedance probability is higher in monsoon than pre-monsoon period. The month of August represents the worst month.

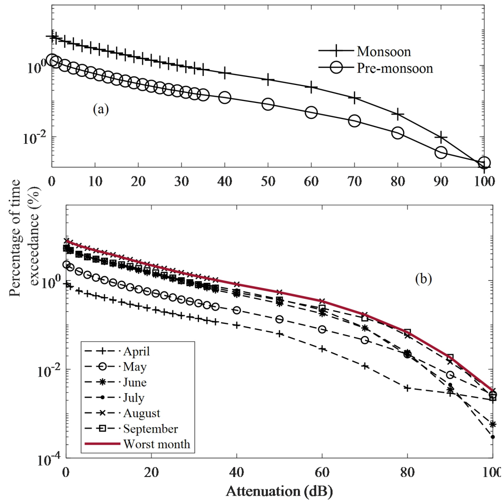


**Figure 4.** Exceedance probability and (b) worst month statistics of rain attenuation.

## 3.2 Cloud and Water Vapor Attenuation

The information of atmospheric attenuation at higher frequency is important for upcoming 5G propagation channel modeling during rain and clear air conditions. Effect of rain on signal deterioration has been discussed in the previous section. Cloud is the next important propagation impairment after rain at higher frequency bands. Cloud attenuation has been calculated using radiometric measurements with the help of ITU-R model [11] which is based on Rayleigh approximation. LWP has been used to calculate the cloud attenuation. The radiometer gives ‘0’ and ‘1’ rain flags at the time of rainy and non-rainy conditions respectively. Though the value of water vapor attenuation is very small compared to rain and cloud attenuation, it should be taken into account for the fade margin calculation of satellite communication links. Relative humidity (RH) plays an important role for water vapor attenuation [11]. Figure 5a shows diurnal variation of cloud attenuation for 30 GHz elevation angle 60° on a clear day 2 June 2010. Figure 4c shows the liquid water content of the same day. Highest values of cloud attenuation are 1.5 dB at 30 GHz. Diurnal variation of water vapor attenuation and RH has been observed for the same day in Figure 4b and 4d respectively. Water vapor attenuation and RH show maximum value of 0.156 dB and 27 % respectively for the clear day. The cloud attenuation exceedances for monsoon and pre-monsoon seasons have been observed in Fig. 5e. At 30 GHz, the cloud attenuation exceedance is significant from the perspective of satellite link outage.

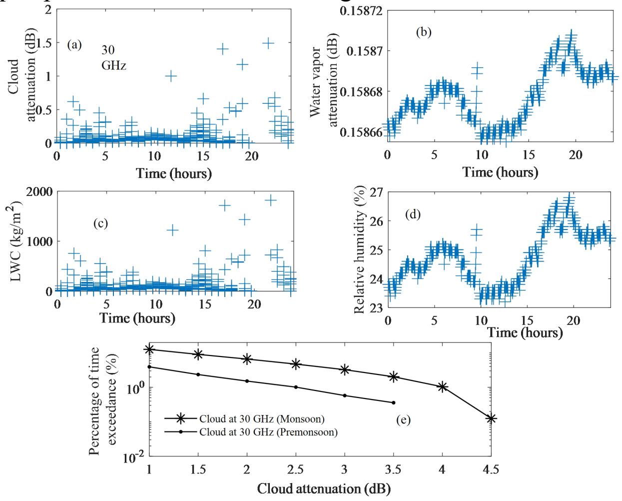


**Figure 5.** Diurnal variation of (a) cloud attenuation at 30 GHz with elevation angle 60°, (b) water vapour attenuation at 30 GHz, (c) LWC, (d) relative humidity on 2 June 2010 and (e) exceedance probability of cloud attenuation at 30 GHz.

## 3.3 Bit error probability at rainy condition

Effect of rainfall on BER has been investigated in this section. The carrier to noise ratio (E/N) is directly related to the atmospheric losses. The detailed formulations have been given in [7]. The atmospheric losses due to rain have been calculated using disdrometer rain rate data at 30 GHz for the monsoon period of 2010-2013. The E/N ratio is related to symbol error probability (SEP) for Quadrature phase shift keying (QPSK) modulation using the formula,

$$SEP = 2Q(\sqrt{\tfrac{E}{N}}) - Q^2(\sqrt{\tfrac{E}{N}}) \qquad (1)$$

Where, $Q(x) = 0.5erfc(\frac{x}{\sqrt{2}})$ (2)

The SEP is related to the bit error probability (BEP) using the following formula:

$$BEP = SEP/(log_2^M) \qquad (3)$$

where M= number of bits. Figure 6 shows the exceedance probability of BEP for different modulation schemes, namely, QPSK, 8PSK and 16PSK for the monsoon period of 2010-2013. Rain has a significant impact on the BEP [7]. It is evident from the formulation [7] that the carrier to noise ratio decrease as the rain attenuation increases and consequently, the BEP increase. Higher exceedance probability of BEP has been observed at 16-PSK. In this context, some error correction techniques, namely Low Density Parity Check (LDPC) and Bose–Chaudhuri–Hochquenghem (BCH), can be used to avoid high error rates, and, consequently, to improve channel efficiency. Fade mitigation techniques, coding, and modulation scheme and EIRP adjustment can be used to mitigate the effect of rain. It is evident that site diversity is a very useful technique to counter the effect of rain in tropical region experiencing heavy rain attenuation. In the next section, performance of various rain cell models to calculate diversity gain have been discussed. Rain rate data from disdrometer have been used for this purpose.

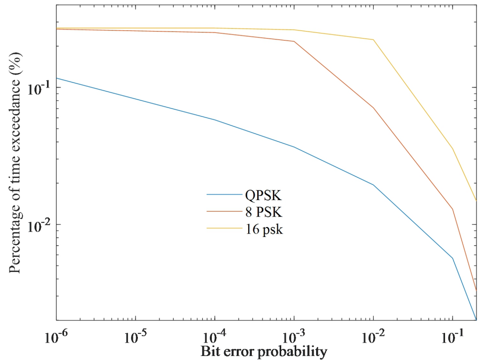


**Figure 6.** Percentage of time exceedance of BEP for the monsoon period.

## 3.4 Rain cell site diversity

The most serious problem in the earth to satellite communication link design at Ka and higher frequency bands comes from rain attenuation. The information of rain attenuation can be obtained either by direct measurements or by statistical description through some well established models. For the latter case, the information about rain rate and frequency are important. Several techniques can be used to mitigate the effect of rain attenuation. Site diversity technique ensures high link availability by receiving the signal at a different site. This technique uses the concept of cellular structure of rain cells for a limited horizontal and vertical extent. Some models are well established like Lin model [12], Moupfouma model [13] and ITU-R model [14]. They are mainly based on the concept of rain cell. These models consider effective rain rate at some distance from the actual site. Due to the horizontal structure of rain, rain rate is always considered to decrease as the distance from the original location increases. In this section, a comparison of diversity gain has been made based on the above rain cell models. Rain attenuation at the present site has been calculated using the rain rate from disdrometer at 20 GHz and 30° elevation angle for the monsoon period of 2010. Rain attenuation at 5 km distance from the disdrometer site has been calculated using Lin, Moupfouma and ITU-R models based on effective rain rate concept [12-14]. Diversity gain is used to characterize any diversity system [1, 8] and is measured as the difference between the path attenuation associated with the single terminal and more than one terminal for a given percentage of time. Figure 7 shows the single site exceedance at disdrometer site and joint site exceedance for Lin, Moufouma and ITU-R model at 5 km away from the disdrometer site. Diversity gain has been calculated at 0.01 % of time for the different models at 20 GHz and has been shown in Table 1. The result indicates the best performance of the ITU-R model compared to other models over this location at 0.01 % of time.

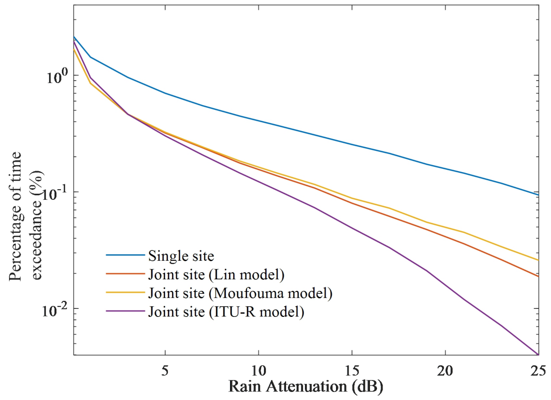


**Figure 7.** Percentage exceedance probability of rain attenuation at the single site and joint site for Lin, Moupfouma and ITU-R model for monsoon 2010.

**Table I: Diversity gain at 20 GHz for 0.01 % of time**

| | Lin | Moufouma | ITU-R | Monoaxial | Our model |
|---|---|---|---|---|---|
| Diversity Gain (dB) | 4.8 8 | 3.15 | 10.94 | 12.25 | 20 |

## 4 Conclusions

In this paper, atmospheric propagation impairments, namely, rain, cloud and water vapor attenuation, impact of rain attenuation on bit error probability and different rain cell models have been studied using ground based observations for upcoming satellite communication at Ka and higher frequency bands. Rain attenuation has been calculated from rain rate data of Disdrometer for different frequencies and elevation angles. Rain attenuation statistics have been observed at 30 GHz. The month of August shows the worst month over this location. Cloud and water vapor attenuation shows 1.5 dB and 0.16 dB respectively for an event at 30 GHz.) Cloud and water vapor attenuation can be significant for high values of liquid water and relative humidity respectively. At 30 GHz, the cloud attenuation exceedance is significant in the monsoon period. Variations of different atmospheric parameters such as, DSD, LWC and RH during the time of rain, cloud and water vapor attenuation have been observed respectively. As evident from calculations, at higher propagation losses, BEP is also high. Higher exceedance probability of BEP has been observed at 16-PSK compared to low order modulation scheme. Performance of some rain cell models in connection with calculating diversity gain has been compared over this location. Rain rates from disdrometer observations have been used to obtain effective rain rates at 5 km distance. The ITU-R rain cell model shows the best performance compared to other available models over this location. This study will be of much importance in terms of assessing propagation impairments and bit error probability, and planning for the appropriate fade mitigation technique for upcoming high frequency and low elevation mobile satellite communication. In future performance of MIMO system in a fading channel has to be evaluated as spatial diversity between the antennas can be used to increase the average capacity and reduce the outage probability.

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