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Effect of clouds on Ku-band satellite link in tropical island countries – preliminary report

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Abstract

Dependence of radio wave attenuation by cloud water content has been investigated by analyzing simultaneous records of the strength of Ku-band satellite downlink and 'insolation'. Preliminary analysis suggests that with increasing cloud coverage in the satellite downlink path, the cloud induced attenuation also increases. The cloud attenuation showed a logarithmic dependence on reduction in insolation. In Fiji, a tropical island country, the maximum attenuation of Ku-band signals by cloud was ~ 11%.
Keywords*: Cloud attenuation, satellite communication, tropical island*

1. Introduction

For radio communication and remote sensing, there is a shift from C-band to higher frequency bands. Such higher frequencies are needed due to the requirement of larger bandwidths of radio systems. Above the 10 GHz frequency limit, signal fading due to physical phenomena related to the propagation of radio waves through the atmosphere becomes appreciable requiring the fade margin of the system to be increased. Rain is the parameter which causes most attenuation to communication links. Investigation of radio link attenuation by rain has been of interest to many researchers from diverse geographic sites (Maekawa *et al*., 2006; Ramachandran and Kumar, 2007 and references therein). Findings by these researchers have led to a proposal to modify the International Telecommunication Union - Recommendation (ITU–R) rain attenuation model for the tropics. Apart from rain rate, other effects less significant for impairment in radio communication, but much more frequent are due to atmospheric gases (oxygen and water vapor), and non-precipitating water (cloud) especially cumulus cloud cells responsible for the formation of thunderstorms. The International Telecommunication Union has proposed a model for estimating attenuation due to clouds and fog (ITU-R P.840 – 5, 2012). The performance of radio systems deteriorates due to cloud attenuation and cloud noise temperature (Ho *et al*., 2005). Panagopoulos *et al*. (2004) have reported a comparative study of the attenuation by cloud on Ku (12/14 GHz), Ka (20/30 GHz) and V (40/50 GHz) bands with the V band suffering the most. Attenuation due to the presence of convective clouds in the transmission path has also been reported by other researchers (Ippolito, 1986; Maekawa *et al*., 2006; Sarkar and Kumar, 2007). Maekawa *et al.* (2011) stated that large discrepancies in rain attenuation, higher than 15 dB, may happen due to localized structures of convective clouds. The adverse impact of hydrometeors on communication links have been successfully used for remote sensing of rain. The idea behind this technique is to relate the rain-induced signal attenuation to the path-averaged rain rate along the considered link. Available sensors for rainfall measurements are principally weather radar, rain gauges, disdrometers and remote sensing satellites. It has been reported that path integrated rain accumulation has been estimated using measurements from point-to-point microwave links (Barthes and Mallet, 2013; Kaufman and Rieckemann, 2011; Wang *et al*., 2012). Also, it has been pointed out that the major difficulty in this application to retrieve rain characteristics are fluctuations of the received signal due to atmospheric scintillations, changes in the composition of the atmosphere (water vapor concentrations, cloud water content) and variations in satellite features. Hence, for proper exploitation of the high frequency bands – for communication or remote sensing, measurements of various contributing factors to microwave attenuation in the atmosphere should be carried out over as many locations as possible (Adhikari *et al.*, 2011). In tropical island countries like Fiji, observations suggest that clouds may be present 50% of the time as a yearly average, and/or continuously for periods of weeks on end. In this communication we present the preliminary results of a systematic analysis of the signal strength of the Ku-band commercial satellite downlink and its correlation to the cloud cover.

The parameters affecting the intensity of the incoming solar radiation, or insolation at a site, are the latitude, zenith angle of the sun, the water vapor content of the atmosphere and aerosols. Aerosols are characterized by Aerosol Optical Depth (AOD), a dimensionless quantity which represents the total attenuation caused by aerosols. It has been conclusively determined (Gueymard, 2005; Gueymard and Myers, 2009) that, when the sun's disk is not obscured, the direct normal incidence (DNI) is affected by AOD, and by the precipitable water in the cloud. Ruiz-Arias *et al*. (2013) reported that the maximum effect of AOD on the direct normal incidence is less than 15%. Thus, it is reasonable to assume that on a cloudy day, the reduction in the radio wave signal at a site is mainly due to the presence of the water particles in the cloud. Due to the lack of cloud water content data at the site, recorded insolation was assumed to be a measure of the precipitable water in the cloud. It is to be noted that insolation record is available only for the daytime hours.

2. Measurement Systems

A solarimeter connected to a data logger was used to record the insolation. Simultaneous records of insolation and satellite downlink signal strength were taken continuously from August - October 2007.

The effect of clouds on Ku-band was studied using the PBS - Television satellite downlink signal, which is transmitted from Sydney, Australia and received in Fiji through Intelsat 701 @ 180^0 E. The downlink frequency is 12.648 GHz. The site for measurement of the signal was the University of the South Pacific, Suva, Fiji Lat: 18.08^0 S, Long: 178.3^0 E and is about 1.5 km from the sea. The receiver antenna is an off-centre 1.2 m parabolic dish. The output of the LNB was connected to a spectrum analyzer, which was interfaced to a computer (details of recording system ref: Ramachandran and Kumar, 2003; 2004). The average signal strength on a clear day was taken as the reference signal. Ideally, the signal strength should remain a constant for a given transponder and a receiver system. However the recorded strength of the signal showed a small diurnal variation with minute scintillations (SNR ~ 17 dB) and this variation was observed on all the days.

3. Results and Analysis

The insolation measurements were taken every 10 minutes, and then averaged over an hour. This hourly data set was used to get the daily plots of the diurnal variation of insolation. In Suva, peak insolation was recorded around midday on all the days. Based on the records of insolation, the days were classified as clear and cloudy days. On visibly clear days, the diurnal variation of the insolation was like a bell shape reaching its peak around 1200 hrs. with very little variation between 1100 ~ 1300 hrs. The peak value varied between 802 and 998 W/m^2. Records of rainy days (rain present during any part of the daytime) were first excluded from the analysis. Days were then selected whose diurnal variation followed an approximate bell shape. The days were then placed into 4 different groups with different range of peak insolation. Group 1: (200 – 400) W/m^2 (5 days); Group 2: (400 – 600) W/m^2 (17 days); Group 3: (600 – 800) W/m^2 (15 days); Group 4: > 800 W/m^2 (11 days). Group 4 days were then termed as "clear days". It is to be noted that the range of the peak insolation within a group is large which may cause a large scatter of the insolation records. The diurnal mean of insolation for the different groups were computed. Figure 1 shows the diurnal variation (0600 – 1800 hrs.) of the mean insolation for these individual groups (groups 1 – 4) of days. To highlight the scatter of the insolation records, scatter bars are included in Figure 1 for the Group 2 days, where the ends of the scatter bars indicate the maximum and minimum values of the insolation recorded at that hour.

The satellite downlink strength (PBS data) was recorded for the entire period of study. For the purpose of this study, the records for the 4 different groups of days were considered separately. For each day of the different groups, the PBS data were averaged for each hour and the diurnal variations in signal strengths (dBm) were computed. From the hourly averages of the readings for each separate group, data were retrieved and the variations were plotted for the day-time hours (0600 – 1800 hrs) and are shown in Figure 2.

In Figure 2, except for the anomalous variation seen on Group 1 days around 1400 hours, all the cloudy days exhibited progressively larger reduction in signal strength with increase in cloud cover (decrease of insolation). The anomalous variation was due to a sudden surge on the PBS signal received on one day, 31 August 2007.

The ITU R P.840-5 specifies the estimation of attenuation due to cloud as

$$A = \frac{L K_l}{\sin\theta} \text{ dB} \tag{1}$$

where θ is the elevation angle, K_l ((dB/km)/(g/m^3)) is the frequency dependent specific attenuation coefficient and L (kg/m^2) the total columnar content of liquid water at the site. The recommendation also provides a plot for the variation of K_l with frequency and also a formula to calculate K_l. Thus, to quantify the attenuation at a given site, with known elevation angle then requires knowledge of L – the precipitable water in the cloud. The recommendation further provides global contours for the exceedances of columnar liquid water. Liquid water content in the cloud will contribute directly to the absorption and scattering of satellite downlink waves. Around noon (1200 local time), the insolation reaches maxima (Figure 1) and the suns radiation measured by the solarimeter approximates DNI. For nearly DNI, assuming the AOD contribution to signal reduction is less (Gueymard, 2005; Gueymard and Myers, 2009) compared to the contribution by water vapor content in

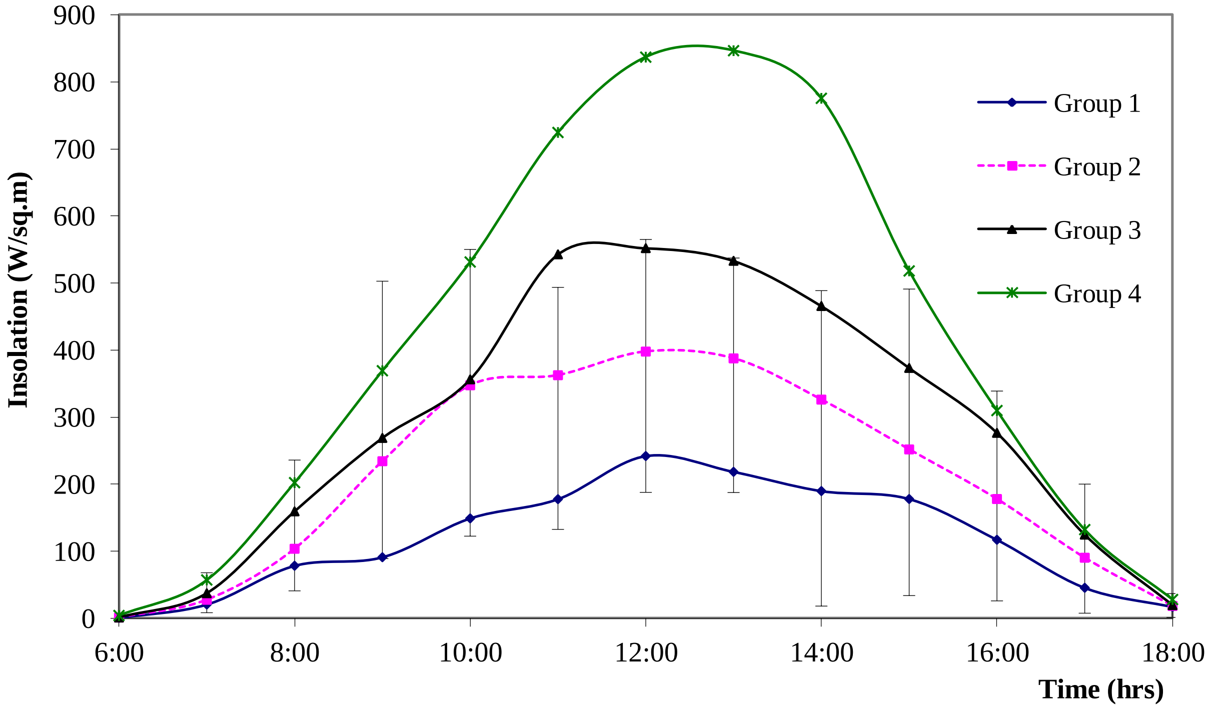

Figure 1. Diurnal variation of the insolation for the 4 groups of days.

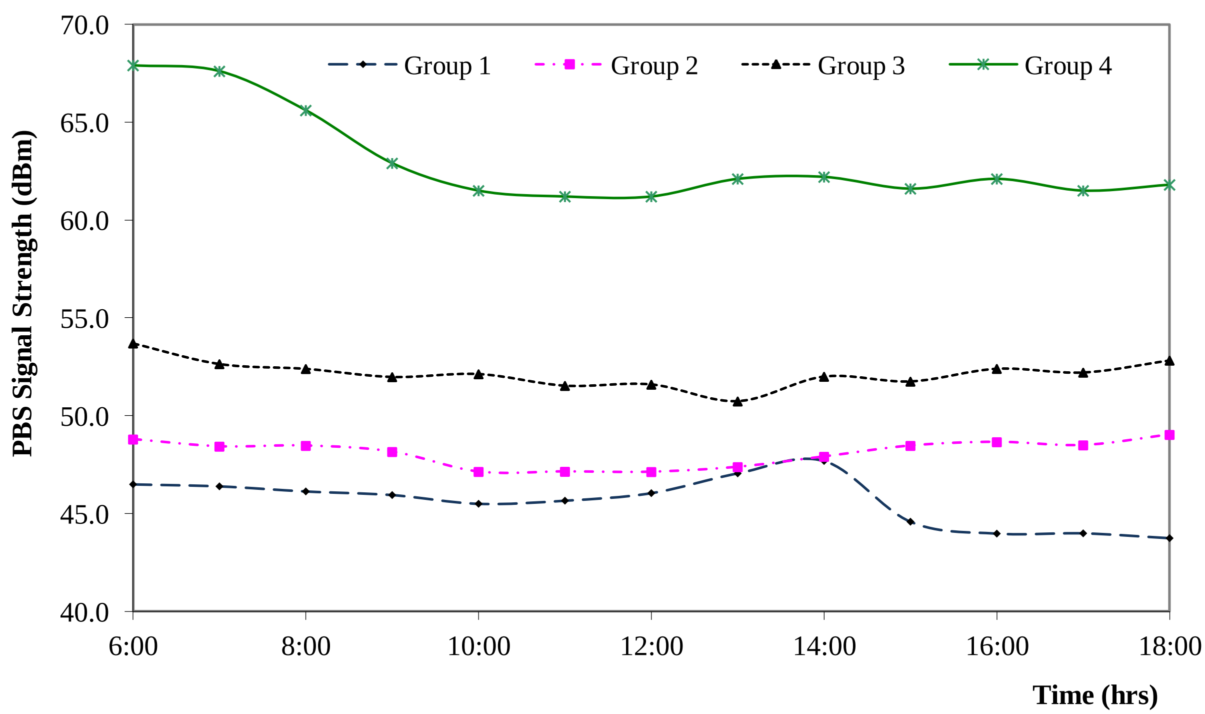

Figure 2. Diurnal variation of the PBS signal strength for the 4 groups of days.

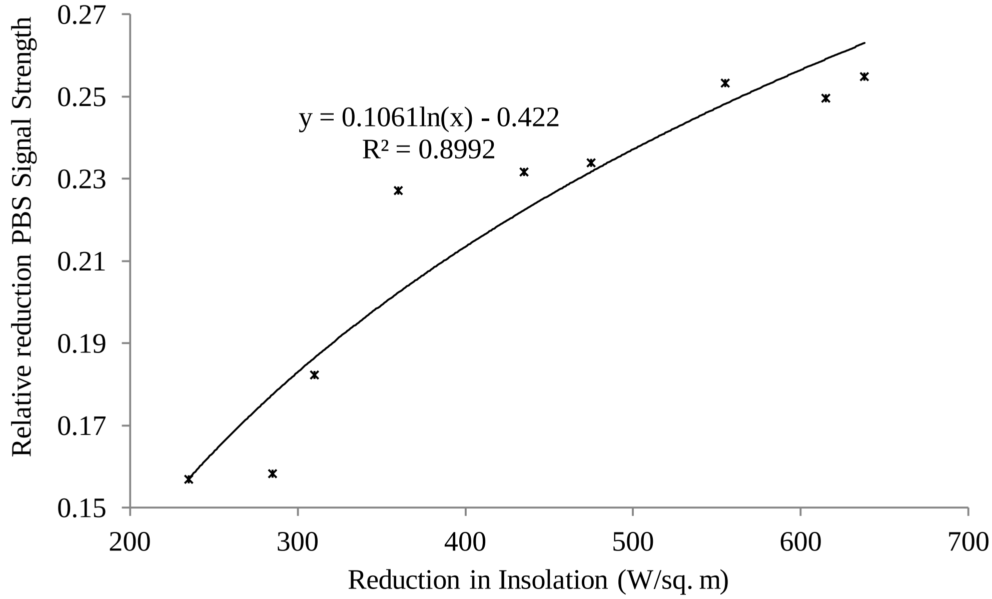

Figure 3. Variation of relative reduction in PBS strength and reduction in insolation.

the cloud, attenuation in PBS signal strength can be assumed to be entirely due to the water content in the cloud. Hence analyzing the variation in PBS signal strength and solar radiation around this time will give a good correlation of the attenuation of the Ku-band waves to the liquid water content in the cloud. In order to maintain the solarimeter readings close to DNI, readings from Figures 1 and 2 were chosen from 1100 to 1300 hrs. (Sun is nearly overhead). A total of 9 readings were extracted for the PBS and insolation records at 1100, 1200 and 1300 hrs. The reduction of insolation (reduction DNI ≡ increase of precipitable water in the cloud) and the relative reduction in PBS signal (increase in attenuation) were calculated and were plotted as shown in Figure 3. [{Insolation (Group 4 – Groups 1, 2, 3} on *x* axis; {PBS (Group 4 – Groups 1,2,3)/ PBS Group 4 } on *y* axis].

The graph clearly indicates the increase in attenuation of the downlink strength with increase of cloud cover. A least square fitting technique approximates the dependence of Ku-band signal strength and cloud cover as logarithmic. Note that the points in the plot cluster into three groups. This is because the original readings for insolation and PBS signal strength were divided into three groups.

4. Conclusion

Preliminary results show that the attenuation of the Ku-band signals has a logarithmic dependence with reduction in insolation by clouds. According to ITU recommendation, attenuation of Ku-band signal is directly proportional to the total columnar content of liquid water. Observations suggest that the reduction in insolation through a cloud does not have one on one relation to the liquid water content in the cloud. Investigation of the Ku-band attenuation and insolation for a longer period is expected to yield groups of days with smaller ranges (avoiding clustering), which may provide refinement to the observed logarithmic dependence.

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