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Diversity gain for rain attenuation over Earth-space path at a tropical location

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Abstract

The present study proposes a technique by which the diversity gain can be estimated for a site utilizing the propagation data obtained at a single station. The technique is crucial in estimating diversity parameters in the absence of multi-station data. The rain decay parameter, as defined in the Simple Attenuation Model (SAM), is used to derive the rain rate and consequently rain attenuation at different distances from the single receiving site. The tropical location has been found to experience a wide variability of rain features during different periods of the year causing strong seasonal variations in the diversity gain. A comparison of the diversity gain obtained from the present propagation data and the ITU-R model indicates the necessity of modifying the model parameters of the ITU-R model. The modified model incorporates the seasonal variation and exhibits better prediction capability than the ITU-R model as related to the tropical location.

Keywords: Rain attenuation; Diversity gain; Tropical region; Rain decay parameter

1. Introduction

The outage of Earth-space satellite communication link at frequencies above 10 GHz due to path attenuation (Bhattacharya et al., 2007; Sujimol et al., 2015) becomes a serious issue in tropical regions where moderate to high rain is very common during the pre-monsoon (April–May) and the monsoon (June–September) seasons. The outage of satellite links due to rain attenuation can last for significant duration at tropical regions. Several techniques are available to overcome the outage performance due to attenuation in an Earth-space path, such as, power control technique and fade mitigation technique (Ippolito, 2008). The fade mitigation techniques can be effectively implemented if short-term prediction can be made on the basis of either rain rate or rain attenuation measurements (Das and Maitra, 2013). Diversity techniques involving site, frequency and time are also used to mitigate the propagation effects due to rain attenuation. Site diversity (SD) technique counteracts attenuation of signal and ensures higher link availability by receiving the signal at a different but nearby site. Studies on SD are mostly carried out over temperate regions (Acosta et al., 2013; Drufuca and Macchiarella, 1983; Pawlina, 2002; Hall and Alnutt, 1975). However, similar study over tropical location is scarce (Timothy et al., 2001). Usually, two or more geographically separated ground receivers are used to obtain diversity gain to overcome the effects of attenuation during intense rain periods (Leong et al., 2012; Shukla et al.,

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2010). But in the case of unavailability of multi-station observations the present study proposes a new technique to estimate diversity gain within the rain cell structure using a single station data. In the present study a single receiver at the site of intense rainfall has been considered to estimate the diversity gain during different seasons at a tropical location, Kolkata, India. The rain decay parameter obtained from Simple Attenuation Model (SAM) has been used to calculate the rain rate and consequently rain attenuation at some distant sites from the satellite signal receiving site. From the exceedance probability of rain attenuation at the signal receiving site and at different distances from that site within the rain cell structure, the diversity gain has been calculated and compared with the existing models (ITU-R and Hodge).

2. Experimental data

The Ku-band signal from the NSS-6 satellite (Geostationary at 95° latitude with an elevation of 62.5°) has been continuously monitored at Kolkata (22°34′ N, 88°29′ E) over the last one decade (Maitra and Chakravarty, 2005; Maitra et al., 2007; Bhattacharya and Maitra, 2011; Adhikari and Maitra, 2011; Sarkar et al., 2014). The signal is received at 11.142 GHz and then down converted to an L-band signal by using a low noise block converter (LNBC). The down converted signal is then fed to a spectrum analyzer. The signal measurements are recorded with a data logger and stored in a computer. The details of the experimental system are described in earlier papers (Chakravarty and Maitra, 2010; Adhikari et al., 2011, 2012; Maitra et al., 2012; Maitra and Chakravarty, 2009). The received signal level data are calibrated to obtain Ku-band signal degradations. The signal degradations during rain are low-pass filtered to obtain the rain attenuation at Ku-band frequency. The rainfall rate at the same satellite receiver site is measured with an Optical Rain Gauge (ORG). The sampling interval of the satellite data and the rain rate data is 1 s. The present study includes the pre-monsoon (April–May), monsoon (June–September) and post-monsoon (October) data of the year 2009–2010 of Ku-band satellite propagation with concurring rain rate record of ORG. The downtime of the equipment is approximately 15% of the afore-mentioned study period.

3. Methodology

Tropical region experiences a large fraction of convective events where heavy rain usually occurs within a limited horizontal extent. The rain cells can extend few kilometers in horizontal direction and tend to become smaller as the intensity of the rain increases. Moderate to heavy rain events at tropical region can lead to quite significant amount of signal degradation at Ku-band frequencies. To characterize the performance of diversity systems, the commonly used performance parameters are diversity gain and improvement factor (Roy et al., 2011; Stutzman and Dishman, 1984). Diversity gain defines the signal gain achieved with more than one receiver instead of a single receiver for a given percentage of time. It 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. Let $A_S\ (p)$ be the fade margin required for single site operation and $A_J\ (p)$ be that for two site operation to maintain particular system availability at p% of time, then the diversity gain can be expressed as:

$$G_d(p) = A_S(p) - A_J(p) \tag{1a}$$

Improvement factor ($I_d\ (A)$) estimates the decrease in exceedance probability of fixed signal degradation obtained with more than one receiver compared to a single receiver. It can be defined as:

$$I_d(A) = \frac{p_S(A)}{P_J(A)} \tag{1b}$$

where $P_S\ (A)$ is the probability of exceedance of attenuation value A for a single site and $P_J\ (A)$ is that for the joint site (Ippolito, 2008; Kourogiorgas et al., 2012).

In order to estimate the diversity parameters for the present location, firstly different rain events of the year 2009 and 2010 have been identified. The rain decay parameter (Γ) at the experimental site has been obtained for a specific point rainfall rate (R_0) and rain attenuation (A), from the SAM model as mentioned below (Maitra et al., 2007):

$$A = \gamma\left[\frac{1-\exp[-\alpha\Gamma\ln(R_0/10)L_S\cos\theta]}{\alpha\Gamma\ln(R_0/10)\cos\theta}\right] \quad \text{for } R_0 \geqslant 10\,\text{mm/hr} \tag{2}$$

where L_S is the slant path length given by:

$$L_S = \left[\frac{H_E - H_0}{\sin\theta}\right] \tag{3}$$

The effective rain height, H_E, the Earth station altitude, H_0, and the elevation angle, θ, are taken as 5 km, 0.024 km and 62.5°, respectively (Maitra et al., 2007). The specific attenuation (γ) can be evaluated from:

$$\gamma = KR_0^{\alpha} \tag{4}$$

The parameters k and α are frequency dependent parameters (Adhikari et al., 2011; Ippolito, 2008; ITU-R P838-3, 2005) and the values of which are taken as 0.02455 and 1.1216, respectively. The values of decay parameter (Γ) corresponding to different rain rates (R_0) have been obtained for all the rain events pertaining to the years 2009 and 2010. The spatial rainfall, R_l, along the slant path distance, from the receiver can be evaluated using the mathematical relation as given below (Arnold et al., 1981; Bhattacharya and Maitra, 2011; Chakravarty and Maitra, 2010):

$$R_l = R_0\exp[-\Gamma\ln(R_0/10)l\cos\theta] \tag{5}$$

where l is the distance along the slant Earth-space path. In the present study, the distances that have been considered to evaluate the diversity gains are varied from 500 m to 5 km from the receiver. The specific attenuation, γ_l, at a