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Time series prediction of rain attenuation from rain rate measurement using synthetic storm technique for a tropical location

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ABSTRACT

A comparison of measured attenuation series with the attenuation series obtained from rain rate measurement by using synthetic storm technique is made for Ku band signal at a tropical location. Validity of the model is tested for the long-term statistics in terms of the cumulative distribution of attenuation occurrence and fade duration. Applicability of the model is also shown to be valid event-wise. It has been demonstrated that the long term statistics of predicted rain attenuation are insensitive to storm translation speed. No significant differences are found when cumulative distributions of predicted attenuation values are compared for different data sampling intervals. It has been observed that there exists a good correlation between the predicted and measured values of attenuation for at least 80% of the events.

1. Introduction

Frequencies above 10 GHz are of primary interest in satellite communication systems, since they provide larger transmission bandwidth and higher data rate. However, the use of these frequency bands is limited by different propagation effect mainly due to rain attenuation. If time series prediction of rain attenuation is possible, fade countermeasure techniques such as adaptive control of signal power, coding and data rate can be effectively implemented. The method of time series prediction for rain attenuation has been presented in [1]. Experimental data for rain attenuation to develop channel model are not always available and often they exist only for specific sites, frequencies and elevation. But a large set of rain rate data is available worldwide. As rain attenuation is strongly correlated with rain rate intensity, time series predictor of rain rate can be easily converted into rain attenuation predictor by using so-called synthetic storm technique (SST). SST has been proposed in [2] to convert instantaneous rain rate into attenuation under some assumption. So far, validity of the SST model is presented in terms of yearly cumulative distribution [2–5]. In [6,7] validation results are presented on an event by event basis, but only event duration and peak attenuation are compared for V band signals for temperate region.

In this paper, measured rain rate series during a rain event is converted into attenuation series for the Ku band signal for a tropical region. Time series prediction of attenuation is done during rain events using the method described in [1]. However, in the present case, SST converted attenuation values are considered as inputs instead of actual attenuation measurements. Validity of the synthetic storm technique is not only tested event-wise but also with long term statistics. Resemblance between measured and predicted event is also shown by calculating cross correlation coefficient. Storm translation speed suitable for our region is also selected from experimental results.

2. Experimental data

Propagation measurements over an earth-space path have been carried out at Kolkata, India (22°34′ N, 88°29′ E), a tropical location by receiving a Ku band signal at frequency 11.172 GHz transmitted with horizontal polarization from satellite NSS-6 (geostationary at 95° E) at an elevation of 63°, since June 2004 [8]. The received signal is down converted to an L-band frequency by the low noise block converter (LNBC) and fed to the spectrum analyzer that is used as the receiver for monitoring the satellite signal level. The signal level measurements are recorded with a data logger and stored in a PC. Further, the rain fall rates at the satellite receiver site have been measured simultaneously by an optical rain gauge (ORG). The dynamic ranges for rain rate and attenuation measurements are 500 mm/h and 20 dB respectively. The minimum detectable change in rainfall rate is 0.2 mm/h and rain attenuation is 0.1 dB. The recorded rain rate and attenuation data are passed through a raised square cosine filter with cutoff frequency 0.025 Hz to eliminate the scintillation effects and other fast fluctuations. In the present study,

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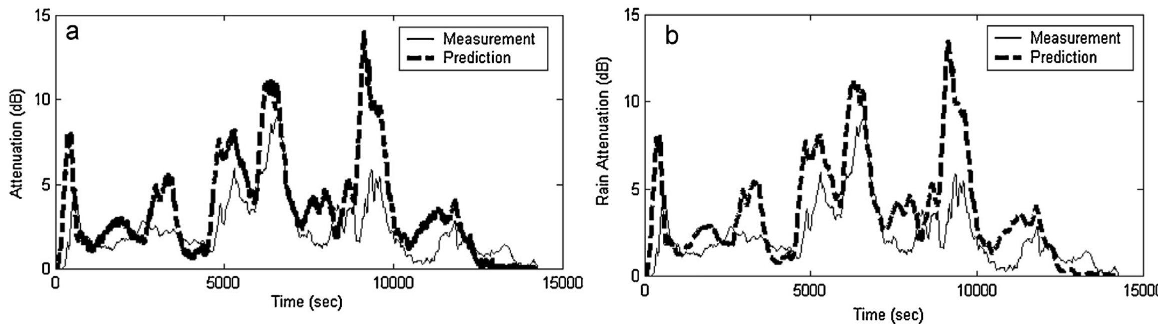

Fig. 1. (a) Comparison between the measured attenuation values with the predicted values obtained from SST for the rain event of 17th June, 2007. The storm speed is taken as $v = 8$ m/s and (b) comparison between the measured attenuation values with the predicted values obtained by time series predictor for the rain event of 17th June, 2007. Measurement needed by the predictor is taken as the attenuation values obtained by SST.

the four year measurement period (2005–2008) has been considered during which total 694 rain events are observed. In this paper, when cumulative distribution is calculated, the entire time span of measurement is considered.

3. Model testing with experimental data

The synthetic storm technique (SST) converts a rain rate time series recorded at a given location into a signal attenuation time series. This conversion requires the knowledge about the length of the signal path through the rain cell, the velocity (v) of the rain cell and the rain rate (R) at the location under investigation. The physical and mathematical fundamentals of the method are described in [2]. The vertical structure of the precipitation medium is modelled with two layers [2], layer A with raindrops at 20 °C and layer B with melting hydrometeors at 0 °C. The input parameters needed by the SST model for our region are considered as follows.

The altitude above sea level of the earth station is $H_S = 0.025$ km. According to [9] the height of the precipitation (rain and melting layer) above sea level used in the simulation is calculated as $H_B = 5$ km. Also, the depth of the melting layer (h) is considered to be 0.4 km regardless of the latitude. According to [2] the height above sea level, H_A, of the upper limit of layer A is given by:

$$H_A = H_B - h = 4.6\,\text{km}$$

The radio path lengths are given by

$$L_A = \frac{H_A - H_S}{\sin(\theta)} = 5.5836\,\text{km}$$

$$L_B = \frac{H_B - H_S}{\sin(\theta)} = 5.135\,\text{km}$$

The parameters k and α necessary to relate rainfall rate to the specific rain attenuation (dB/km) are calculated from [10]. We have used different storm speeds $v = 1$–12 m/s to show the sensitivity of this parameter to the SST model. The measured rain rate values for the rain event on 17 June 2007 are converted to attenuation values using SST and compared with the actual measurements in Fig. 1(a). Good matching has been observed between measurement and prediction. These SST predicted values are now used as measurements for the method described in [1] to predict the time series of rain attenuation for the rain event on 17 June 2007. The time series predicted values are compared with the actual attenuation measurements in Fig. 1(b). Fig. 2 gives the comparison between the cumulative distributions of the prediction errors (%) occurred in Fig. 1(a) and (b). For the first case, shown in Fig. 1(a), the error occurred only due to SST prediction. Whereas in the second case, shown in Fig. 1(b), the error is due to both SST prediction and time series prediction, resulting in a small increase in the total error. However, the overall error is still small indicating that the SST predicted values can be considered as the input to the time series predictor in the absence of actual attenuation measurements.

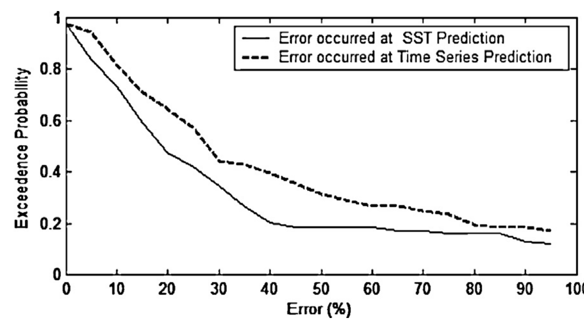

Fig. 2. Comparison between the cumulative distributions of prediction errors (%) due to SST prediction as shown in Fig. 1(a), and time series prediction with SST values as input as shown in Fig. 1(b).

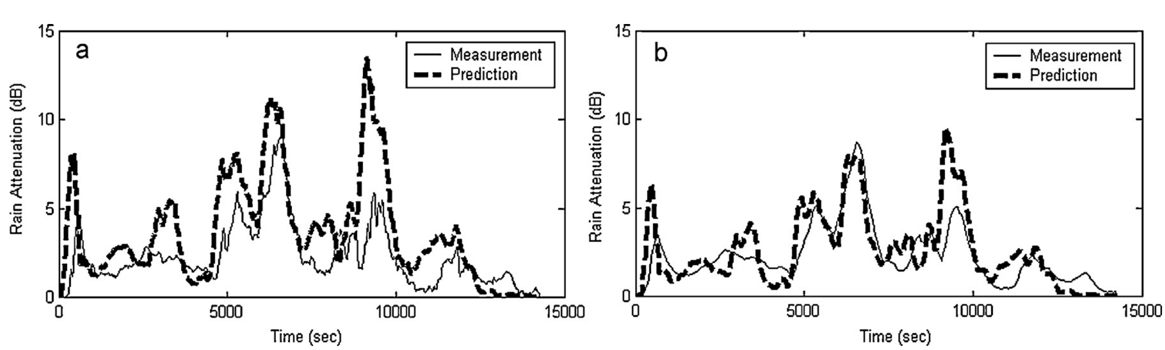

Fig. 3. Comparison between the measured attenuation values with the predicted values obtained from SST for the rain event of 17th June, 2007 with (a) 10 s sampling interval and (b) 60 s sampling interval.