Time Series Predictor of Ku-Band Rain Attenuation over an Earth-Space Path at a Tropical Location

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Abstract

A channel model is proposed to predict the time series of Ku-band rain attenuation during rain events at a tropical location. The model is based on considering the Gaussian distribution of the conditional occurrence of rain attenuation with a particular value of the attenuation occurring before. The mean and standard deviation for the distribution are modelled with the experimental data. The attenuation at a particular time instant is predicted from the measured values at earlier instants. The channel model has tested well giving predicted attenuations which agree with the measured values above 2 dB with a mean error within 10%.

1. Introduction

The rain attenuation causes significant degradation of signal level of satellite signals at frequencies above 10 GHz that make it necessary to assess the fade margin of the signal during a rain event. The fade counter measure technique such as adaptive control of signal power, coding and data rate, can be effectively implemented if a reliable channel model is obtained. The channel models for rain fading were earlier obtained based on the statistical characterization of rain fading in terms of conditional probability density function (PDF) [1-3]. However, the predictive capability of these channel models to obtain the attenuation values during rain events was not demonstrated. The real time prediction of rain attenuation can be very useful to implement the fade counter measure techniques to maintain the quality of service.

In this paper, a technique for predicting the rain attenuation of a Ku-band satellite signal during rain events at Kolkata, India has been presented. The rain attenuation is predicted at an instant of time from the previously sampled values obtained experimentally during the rain event. The predictor requires, as inputs, the statistical features of the signal variation at the location obtained over a long term period, one year in the present case.

2. Experimental Data

The rain attenuation of Ku-band signal over an earth-space path has been measured by receiving a signal at frequency 11.172 GHz transmitted with horizontal polarization from satellite NSS-6 (geostationary at 95^0 E) at an elevation of 63^0 at Kolkata, India (22°34' N, 88°29' E), a tropical location, since June 2004 [4]. The sampling interval of the data acquisition used in the present study is 1 sec. Also, an optical raingauge is operated at the satellite receiving site to measure the rain rate simultaneously with monitoring the satellite signal. In the present study, the experimental data on rain attenuation obtained in the year 2006 have been utilized to statistically characterize the channel model, and the testing of the channel model is performed with the experimental measurements made in 2007.

3. Characterization of Fading Channel Model

The fading of the channel due to attenuation has been assigned to three segments namely, constant, down and up segment as proposed by Fiebig [1]. The signal segment type $\Delta(kT_s)$ is determined from the difference between the two consecutive samples of rain attenuation (a) and with the following criteria.

$$\Delta(kT_s) \begin{array}{lll} = C \text{ (constant)} & \text{if} & |\, a(kT_s) - a((k\text{-}1)T_s) \,| < \ \ 1 \text{ dB} \\ = D \text{ (down)} & \text{if} & a(kT_s) - a((k\text{-}1)T_s) \ <= -1 \text{ dB} \\ = U \text{ (up)} & \text{if} & a(kT_s) - a((k\text{-}1)T_s) \,| >= \ 1 \text{ dB} \end{array} \quad (1)$$

Where k = 1,2,3, …, T_s is the time interval between two consecutive samples. The probability density functions (PDF) of the conditional likelihood of attenuation occurrence $P(y/x)$ are derived from the experimental data for each segment type (C, D, U). P(y/x) is defined as the likelihood that the attenuation is y dB conditioned that it has been x dB T_s sec before. PDFs in the form of Gaussian distribution for each months of the year 2006 are used to predict the attenuation for rain events occurring in 2007. The mean (μ) and standard deviation (σ) of the PDF at different values of attenuation (x) are obtained for different months. As an example, the mean and the standard deviation of PDF for the month of August 2006 are shown in Fig. 1(a) and Fig. 1(b).

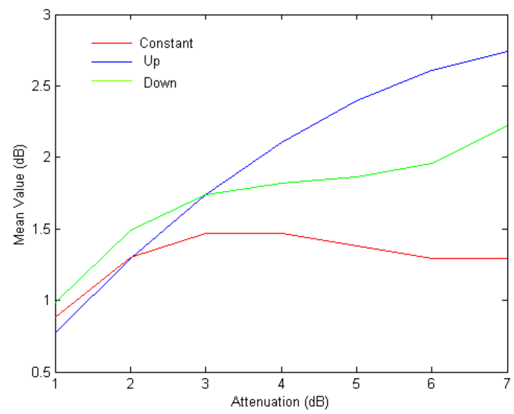

Fig. 1(a) Variation of the mean value (μ) of PDF with the attenuation (x) for different types signal segments for August 2006.

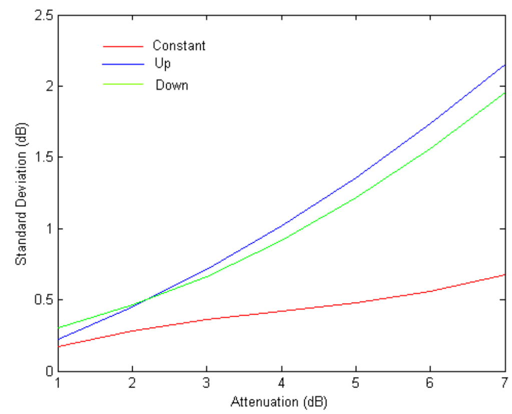

Fig. 1(b) Variation of the standard deviation (σ) of PDF with the attenuation (x) for different Types of signal segments for August 2006.

The mean (μ) and standard deviation (σ) of PDF are modeled as the function of the attenuation value x in terms of third order polynomial expressions namely,

$$\mu(x) = a_0 + a_1x + a_2x^2 + a_3x^3 \quad (2)$$

$$\sigma(x) = b_0 + b_1x + b_2x^2 + b_3x^3 \quad (3)$$

The values of the polynomial coefficients for $\mu(x)$ and $\sigma(x)$ for the monsoon months, when most of the rain occurs at Kolkata, are given in Table 1 and Table 2.

Table 1 Values of coefficients of the polynomial expressions for the model of the mean (μ)

Month	Seg	a_0	a_1	a_2	a_3
May	C	0.29	0.66	- 0.14	0.0095
	D	0.4	0.59	- .011	0.0072
	U	0.085	0.71	- 0.13	0.0085
Jun	C	0.19	0.59	- 0.14	0.011
	D	0.23	0.58	- 0.049	0.0012
	U	0.05	0.57	- 0.049	0.00036
Jul	C	0.13	0.95	- 0.2	0.014
	D	0.31	0.81	- 0.15	0.011
	U	- 0.05	1	- 0.15	0.0087
Aug	C	0.13	0.95	-0.21	0.014
	D	0.11	1.1	-0.24	.018
	U	-0.13	1.2	-0.22	0.015

Table 2 Values of coefficients of the expressions for the model of the standard deviation (σ)

Month	Seg	b_0	b_1	b_2	b_3
May	C	0.22	- .001	0.023	-0.002
	D	0.1	0.19	0.013	-0.024
	U	0.028	0.19	0.012	-0.017
Jun	C	0.11	0.17	0.016	- .0028
	D	0.27	- .017	0.13	- 0.014
	U	0.17	0.047	0.13	- 0.015
Jul	C	0.087	0.05	0.027	- .0005
	D	0.16	0.017	0.066	- .0038
	U	0.076	.00014	0.087	- .0063
Aug	C	0.16	0.19	-0.034	0.0029
	D	0.096	0.26	-0.033	0.0048
	U	-0.006	0.24	-0.0014	0.0017

4. Rain Attenuation Predictor

Once the fading channel model is characterized with the mean and standard deviation of PDF of conditional occurrences of rain attenuation values, this can be used to predict the time series of rain attenuation, using the measurements at few initial instants, during a rain event. The channel predictor gives the output $y(nT_s)$, where n = 1,2,3,…., and T_s is the sampling interval. The predictor is initiated by the starting measurement during the rain event as follows: (i) the first two samples of the measured attenuation is used to identify the type of signal segment (C/D/U), and (ii) the second sample data is taken as the attenuation value $x(2T_s)$ to obtain the value of attenuation $y(3T_s)$ after T_s sec.

The procedure with the following sequential steps is adopted to obtain the predicted output $y(\mathrm{n}T_s)$.

i) The type of signal segment $\Delta(\mathrm{n}T_s)$ is determined from two previous samples using relation (1).
ii) The values of μ and σ for the attenuation value x obtained at the instant $(n\text{-}1)T_s$ are computed from relation (2) and (3) and using Table 1 and 2.
iii) With computed values of μ and σ, the Gaussian random variable is generated which is the predicted value of attenuation.
iv) The predicted value is then compared to the actually measured value of attenuation to obtain the correction term which is the difference between the predicted and measured value. This correction term is added to the next predicted value to make it closer to the measured value.
v) The above steps, i) to iv), are repeated during the rain event till the channel model predicts the complete attenuation time series.

5. Validation with Experimental Measurements

The validation of the channel model to predict the rain attenuation was carried out with the experimental data obtained during the year 2007. It is expected that the statistical behaviour of the attenuation in 2006 should not be significantly different from that in 2007, and the models of μ and σ will be applicable to the data of 2007.

Fig. 2 and Fig. 3 give the results of comparison of predicted attenuation values with the measured values for a rain event occurring on 12 August 2007. Fig. 2(a) gives predictions prior to one sampling interval which is 1 sec in the present case. The magnitudes of percentage errors against the attenuation values are plotted in Fig. 2(b) showing that the error decreases with the increase in attenuation and the mean error is within 10% for attenuation values exceeding 2 dB. In this particular rain event, large scale attenuation variations have superimposed on them the fast fluctuations due to scintillation which often occurs during rain events at the present location. Fig. 3(a) depicts the attenuation prediction with the samples taken 10 sec apart that do not exhibit fast fluctuations. In this case, the prediction is better than the previous case as fast fluctuations were less predictable, and this is evident from Fig. 3(b) which reveals a smaller error margin, on the whole, associated with the prediction.

6. Conclusion

A channel model has been proposed to predict the time series of rain attenuation at Ku-band over an earth-space path at a tropical location. The predictive capability of the channel model has been achieved by deriving the models, based on long term data, of mean (μ) and standard deviation (σ) of the Gaussian distribution of the conditional occurrences of the attenuation value (y) with a certain value of attenuation (x) occurring *a prioi*. The statistical models are obtained with the data of the year 2006. The predictor has tested well with the experimental data obtained during the year 2007, indicating that this type of predictor can be suitable for real time attenuation prediction during rain events which can have useful application in the context of fade counter measure techniques.

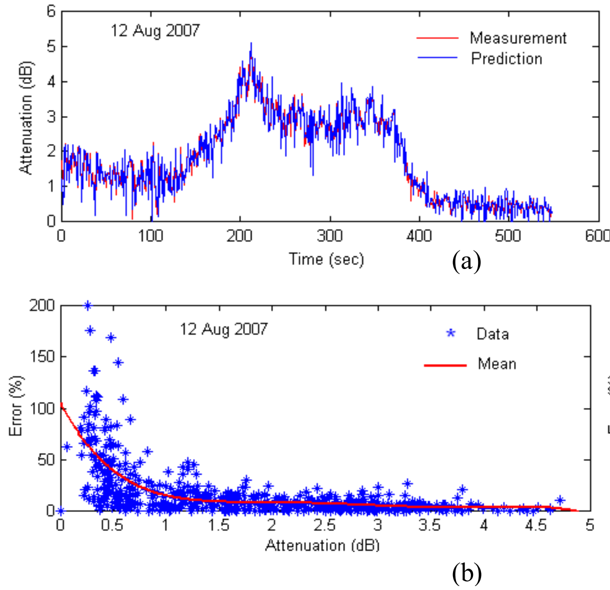

Fig. 2 (a) Comparison between the predicted and the measured attenuation during a rain event for a sampling interval of 1 sec.
(b) The percentage of error in the predicted value against the attenuation.

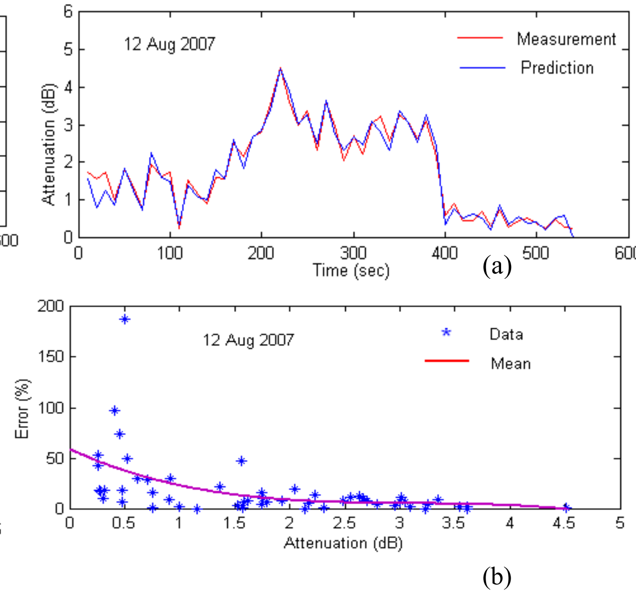

Fig. 3 (a) Comparison between the predicted and the measured attenuation during a rain event for a sampling interval of 10 sec.
(b) The percentage of error in the predicted value against the attenuation.

7. Acknowledgment

This work has been supported by a grant from Indian Space Research Organisation (ISRO) for the project "Radio remote sensing of the tropical atmosphere" being carried out at S K Mitra Centre for Research in Space Environment, University of Calcutta.

8. References

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