Ka-Band Land Mobile Satellite Channel Model Incorporating Weather Effects

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***Abstract*—A Ka-band land mobile satellite (LMS) channel model which is able to take into account weather impairments is proposed. The statistics of the received signal and the BER performance of the system under the proposed channel model are obtained and compared with the results generated using Loo's weather-affected LMS channel model. The proposed Ka-band LMS channel model is shown to be more reasonable as it gives realistic results.**

***Index Terms*—Ka-band, LMS channel model, rain, weather effects.**

I. Introduction

THE CONGESTION of radio spectrum in the lower L/S band (1–2 GHz) and the maturing of Ka-band (20/30 GHz) technologies are creating a lot of interest in the Ka-band [1]. However, propagation in the Ka-band (20/30 GHz) is more susceptible to weather impairments and shadowing than the lower frequency bands [1], [2]. Average rain and shadowing may disrupt the communication completely especially in equatorial climates where high rainfall rates are experienced. Currently available LMS channel models in the literature are not applicable to the Ka-band LMS systems as they focus on lower frequency bands where weather impairments can be ignored. Most of the research work related to the Ka-band propagation measurements and LMS channel modeling has been reported in [2]–[5]. The channel models in [2], [3] only consider mobile environment effects like shadowing/blockage and multipath fading. The weather effects are taken into consideration in the channel model developed by Loo [5], but these effects are not correctly reflected. In this model, the weather effects tend to cancel out the fading induced by the mobile environment, and hence predict an improved performance in the presence of weather effects. This motivated us to propose a new Ka-band LMS channel model which correctly incorporates tropospheric effects. In this letter, a weather affected LMS channel model is proposed based on Lutz's model [6], which is a special case of the multistate channel model applicable for a nonuniform propagation environment [3], [4].

II. Propagation Impairments at Ka-Band

The Ka-band mobile satellite transmission mainly includes the following propagation impairments: effects related to the troposphere (or weather) and the effects due to the environment in the vicinity of the receiver. The former denoted as w includes rain attenuation, gaseous absorption, cloud attenuation, scintillation etc. The later denoted as β is the same as in other frequency bands (L/S), and basically consists of shadowing/blockage and multipath fading effects. These two effects represented by w and β are assumed to be statistically independent because the underlying mechanisms are independent. The received signal amplitude can be interpreted as $r = \beta w$, assuming that the transmit signal amplitude is normalized to unity.

The Ka-band propagation studies show that when weather impairments are not considered, the basic concept for L/S band LMS channel modeling is also applicable to the Ka-band [2]–[5], except for more severe shadowing and faster multipath fluctuations encountered in the Ka-band. In this letter, based on the data collected by Rice [2], Lutz's model is adopted [6] in the case of no weather impairments. According to Lutz's model, the LMS channel is a two-state (good and bad states, namely nonshadowing and shadowing states) Markov model. In the nonshadowing state, the received signal amplitude follows a Rician distribution.

$$p_{\mathrm{good}}(r) = 2kr\exp(-k(r^2+1))I_0(2kr) \tag{1}$$

where k is a Rice factor. In the shadowing state, no direct signal path exists and the multipath fading has a Rayleigh characteristic with its envelope s_0 following a lognormal distribution. The probability density functions (pdfs) of the multipath fading and its envelope are

$$p_{\mathrm{bad}}(r|s_0) = \frac{2r}{s_0}\exp\left(-\frac{r^2}{s_0}\right) \tag{2}$$

and

$$f_{lg}(s_0) = \frac{10}{\sqrt{2\pi}\,\sigma\ln 10}\,\frac{1}{s_0}\exp\left[-\frac{(10\log s_0-\mu)^2}{2\sigma^2}\right] \tag{3}$$

respectively. Evidently in the bad state, the channel is actually a Suzuki distribution, and its pdf is

$$p_{\mathrm{bad}}(r) = \int_0^\infty p_{\mathrm{bad}}(r|s_0)f_{lg}(s_0)\,ds_0. \tag{4}$$

The two states (good and bad) are time-sharing and can be modeled as a Gilbert model. Assuming that A is the average duration of the bad state, the pdf of the received signal amplitude can be represented by

$$p_\beta(r) = (1-A)p_{\mathrm{good}}(r) + Ap_{\mathrm{bad}}(r). \tag{5}$$

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According to the Loo's Ka-band propagation measurement in Canada at an elevation angle of 14°, w follows a Gaussian distribution when combining all tropospheric factors

$$p_w(r) = \frac{1}{\sqrt{2\pi}\,\sigma_w} \exp[-(r - m_w)^2/2\sigma_w^2]. \qquad (6)$$

Among all the weather impairments, rain attenuation is the most serious especially in tropical heavy rain zones. The long term statistics of the rain attenuation can be modeled by a lognormal process [7]

$$P_L(L) = \frac{1}{\sqrt{2\pi}\,\sigma_d L} \exp\left[-\frac{(\ln L - m_d)^2}{2\sigma_d^2}\right], \qquad L \geq 0 \quad (7)$$

where L is in decibels, m_d and σ_d are also in decibels. The study of Emillio [8] regarding the relation of rain attenuation between fixed systems and mobile systems shows that the probability distribution of the envelope of a mobile receiver can be obtained from that of the fixed system, by multiplying a factor which approximately varies between 0.5 and 2.0 and is independent of rain attenuation.

III. Weather Affected LMS Channel Model

Based on the assumption that the impairments due to the mobile environment and tropospheric condition are independent, Loo proposed that the pdf of the signal amplitude, $r = \beta w$, under the dual impairments be given by [5] as

$$p_T(r) = p_\beta(r) p_w(r) \qquad (8)$$

where $p_\beta(r)$ and $p_w(r)$ are the pdfs of the mobile fading (5) and weather impairments (6), respectively. When two processes are independent, it is not correct mathematically to express the pdf of their multiplication as (8).

Here a new Ka-band LMS channel model is proposed taking into account weather impairments. The pdf of the received signal conditioned on fixed weather impairments can be described by a conventional LMS model (5). Therefore, the pdf of the received signal, $r = \beta w$, through weather affected Ka-band LMS channel is obtained by averaging it over the weather impairments, which can be expressed as

$$p(r) = \int_0^\infty p(r|w) p_w(w)\, dw \qquad (9)$$

where $p_w(w)$ is the pdf of the weather impairments (6), $p(r|w)$ is the pdf of the fading due to mobile environment conditioned on the specific weather impairments w. When β and w are independent, we get

$$p(r|w) = \frac{1}{w} p_\beta\left(\frac{r}{w}\right). \qquad (10)$$

When all weather impairments are considered, the pdf of the received signal in the good state can be obtained by substituting (1), (10), and (6) into (9). Similarly, the pdf in the bad state is obtained by substituting (4), (10), and (6) into (9).

When only rain attenuation is considered, in the good state, the received signal can be represented as

$$r = R \exp[-h(L + c)] \qquad (11)$$

where R is Rician fading due to multipath; $h = \ln 10/20$ and L (in decibels) is the rain attenuation; and c is a constant scaling factor of rain attenuation from the fixed system to the mobile system. Then we get $w = \exp[-h(L + c)]$. According to the pdf of L in (7), $p_w(w)$ can be rewritten as

$$p_w(w) = \frac{-\exp\left\{-\frac{\left[\ln\left(-\frac{(hc + \ln w)}{h}\right) - u\right]^2}{2\sigma^2}\right\}}{w(hc + \ln w)\sqrt{2\pi}\,\sigma}, \quad 1 > w > 0. \qquad (12)$$

Then the conditional pdf of $p_\beta(r)$ can be rewritten as

$$p_\beta(r|w) = \frac{2rk}{w} \exp(-k((r/w)^2 + 1)) I_0\left(2k\,\frac{r}{w}\right). \qquad (13)$$

The pdf of the received signal can be obtained by substituting (12) and (13) into (9).

Similarly, in the bad state, the received signal can be represented as

$$r = RS \exp(-h(L + c)) \qquad (14)$$

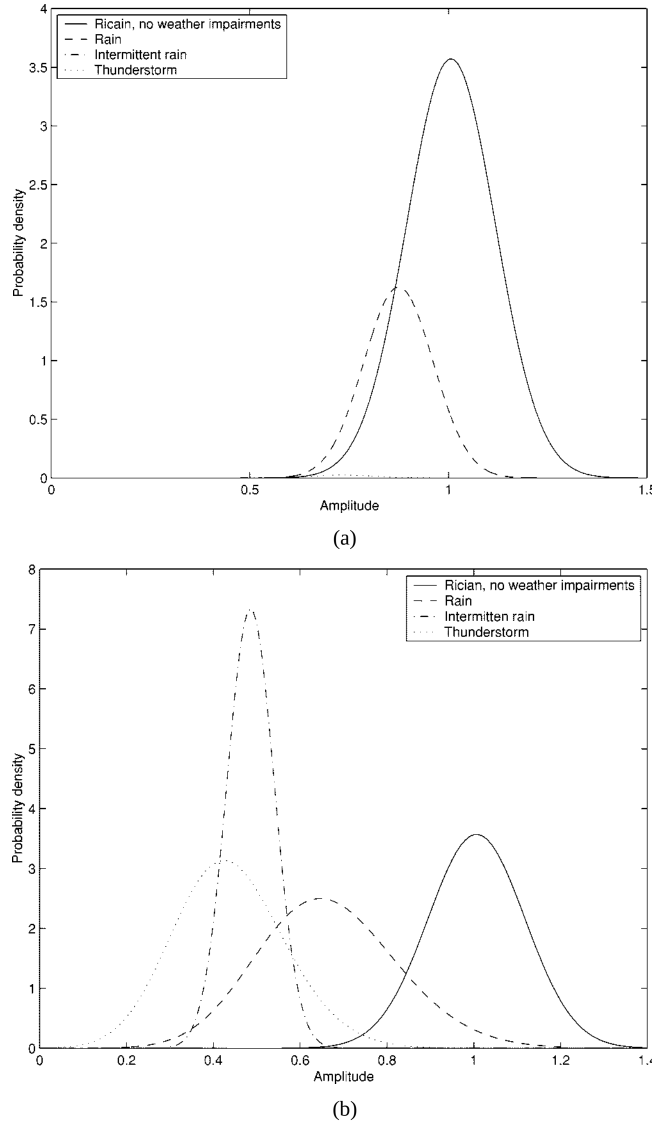

Fig. 1. The pdfs of the received signal in nonshadowing state under different weather conditions.

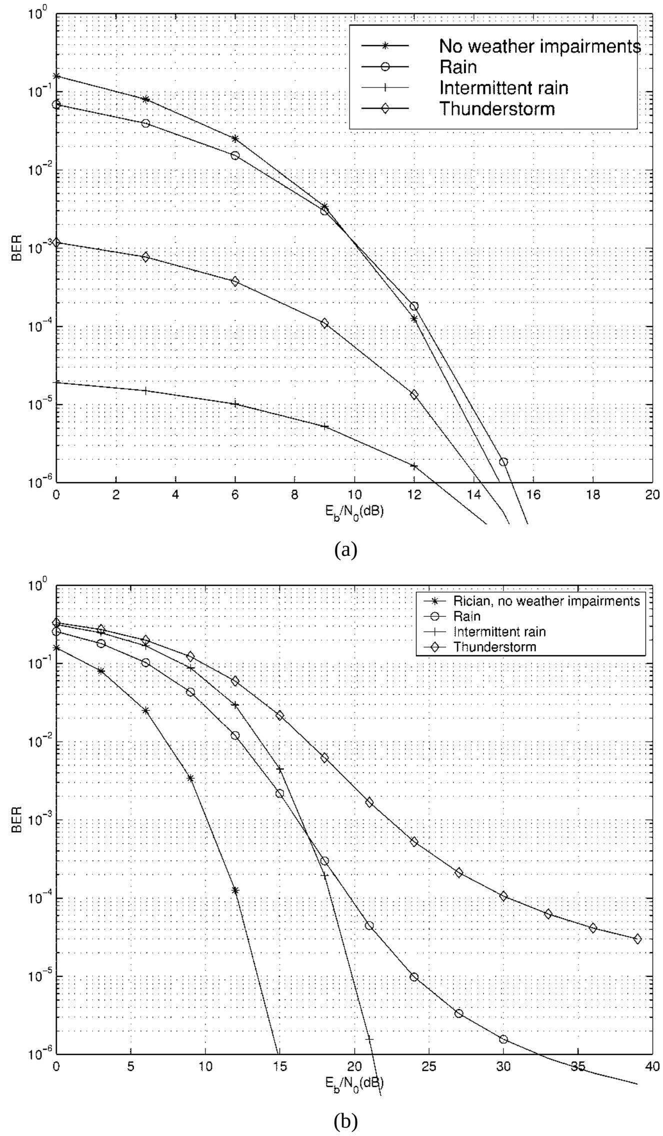

Fig. 2. The BER performance of a BPSK receiver in nonshadowing state under different weather conditions.

where S denotes lognormally distributed shadowing. The pdf of the received signal can be obtained by using a similar method as in the good state. However, even an expression in integral form is very complicated, hence a simplified representation is needed. The spectral width of rain attenuation is in the range 0.06–0.1 $\min^{-1}$ [7]; while the average shadowing duration is about 10 ms when the speed of a mobile terminal is 50 km/h. This means that the duration of rain attenuation is much longer than the shadowing. Therefore, we can assume that the slow variation of the received signal still follows a lognormal distribution and rain attenuation causes the mean of received signal to decrease. Hence the pdf of the received signal can be represented by (4), except that the logarithmic mean of the lognormal process in (3) is $\mu_w + \mu$ instead of μ. Here μ_w denotes the average contribution of rain attenuation to the received signal, and can be expressed as

$$\mu_w = E[L + c] = \exp(m_d + \sigma_d^2/2) + c \tag{15}$$

where m_d and σ_d are the logarithmic mean and standard deviation of the rain attenuation.

IV. Numerical Results and Conclusions

To verify the feasibility of the proposed channel model, pdf and BER curves in nonshadowing state under three weather conditions, rain, intermittent rain and thunderstorm, are presented. The parameters of weather impairments and the fading due to mobile environment collected by Rice *et al.* [2] and Loo *et al.* [5], respectively, are adopted. The pdf of the received signal with Loo's and our model are shown in Fig. 1. From Fig. 1(a), we can see that in the case of an intermittent rain or thunderstorm, the pdfs of the received signal amplitude at any value are nearly zero, which evidently does not agree with the common knowledge of the channel. Moreover, the different areas below the curves indicate that these pdfs obtained by Loo's model are actually not pdfs, although they are described as such. While with the proposed channel model, Fig. 1(b) indicates that weather impairments result in the degradation of the received signal, i.e., considering weather impairments, the received signal takes smaller value with higher probability. Evidently the proposed model makes more sense by reflecting correctly the practical scenario of weather impairments.

Fig. 2 shows the BER performance of a BPSK receiver using the proposed and Loo's model. The comparison of Fig. 2(a) and (b) shows that with Loo's model, weather impairments do not degrade the BER performance of the communication systems, but result in an improved communication performance, which is incorrect. While the proposed model is able to clearly predict the degradation of BER performance caused by weather impairments as shown in Fig. 2(b). The theoretical analysis and numerical results show that the proposed Ka-band LMS channel model is more appropriate.

References

[1] J. V. Evans, "Prospects U.S. global satellite system operating at Ka-band," in *IEEE Aerospace Conf.*, vol. 4, 1998, pp. 525–537.

[2] M. Rice, J. Slack, and B. Humpherys, "K-band land–mobile satellite channel characterization," *Int. J. Satellite Commun.*, vol. 14, pp. 283–296, 1996.

[3] E. Kubista, F. Perez Fontan, M. Angeles Vazquez Castro, S. Bunomo, B. R. Arbesser-Rasburg, and J. P. V. Poiares Baptista, "Ka-band propagation measurements and statistics for land mobile satellite applications," *IEEE Trans. Veh. Technol.*, vol. 49, pp. 973–983, May 2000.

[4] Y. Xie and Y. Fang, "A general statistical channel model for mobile satellite systems," *IEEE Trans. Veh. Technol.*, vol. 49, pp. 744–752, May 2000.

[5] C. Loo and J. S. Butterworth, "Land mobile satellite channel measurement and modeling," *Proc. IEEE*, vol. 86, pp. 1442–1463, July 1998.

[6] E. Lutz, D. Cygan, M. Dippold, F. Dolainsky, and W. Papke, "The land mobile satellite communication channel—Recording, statistics, and channel model," *IEEE Trans. Veh. Technol.*, vol. 40, pp. 375–384, May 1991.

[7] A. Burgueno, E. Vilar, and M. Puigcerver, "Spectral analysis of 49 years of rainfall rate and relation to fade dynamics," *IEEE Trans. Commun.*, vol. 38, pp. 1359–1366, Sept. 1990.

[8] E. Matricciani, "Transformation of rain attenuation statistics from fixed to mobile satellite communication system," *IEEE Trans. Veh. Technol.*, vol. 44, pp. 565–569, Aug. 1995.