論文 98-23-4-34

A Rice-lognormal Channel Model for Nongeostationary Land Mobile Satellite System

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※The authors wish to acknowledge the financial support of the Korea Research Foundation made in the Program Year 1997.

ABSTRACT

This paper introduces a channel model that is a combination of Rice and log-normal statistics, with independent shadowing affecting each direct and diffuse component, respectively. This model extends the channel model of a combined Rice and Log-normal, proposed by Corazza, to include the independent shadowing. The validity of model is confirmed by comparisons with the data collected in the literature, the analytical model, and the computer model in terms of probability distribution of the envelope of each model. The model turns out to be one of many well-known narrowband models in limiting cases, e.g. Rayleigh, Rice, log-normal, Suzuki, Loo, and Corazza. Finally, the examples of bit error probability evaluations for several values of the elevation angle in the channel are provided.

I. Introduction

As a consequence of the growing interest in land mobile satellite (LMS) systems, much effort is being devoted to the problem of modeling nonselective multipath fading and shadowing in the LMS communication channel.

Loo[1] proposed a model, suitable for rural environments, which assumes that the received signal is affected by nonselective Rice fading with lognormal shadowing on the direct component only, while the diffuse scattered component has constant average power level. Corazza et al.[2] introduced a probability distribution model which is a combination of Rice and lognormal statistics, with shadowing affecting both direct and diffuse components.

But shadowing mainly occurs due to gross changes in the topology of the physical channel and each propagation path. It is appropriate to model each shadowing on the direct component and the diffuse component as the independent shadowing with the same statistics.

In this paper we propose a channel model which is a combination of Rice and log-normal statistics, with independent shadowing affecting each direct and diffuse component, respectively. We present the channel modeling and its validation by providing the model parameters in a rural tree shadowed environment. Finally, we evaluate the performance of a system adopting LEO constellation over a wide range of el-

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論文番號:97273-0807
接受日字:1997年 8月 7日

evation angles.

The paper is organized as follows. In Section II, we present the fading channel model. In Section III, we validate the channel model against measured data and computer model, and then present numerical results. In Section IV, we evaluate the probability of error for nongeostationary systems. In Section V we draw conclusions.

Ⅱ. Fading Channel Model

The mathematical derivations required to describe the fading channel model are given in this section.

All fading channels are based on the manipulation of a white Gaussian random process when the expression for the Gaussian random process $a(t)$[3] is given by

$$a(t) = Re\{[a_c(t) + ja_s(t)]\exp[j2\pi f_c t]\} \quad (1)$$

where

$$a_c(t) = Re \sum_{k=-N/2}^{N/2} V_k \exp[j(2\pi k f_0 t + \lambda_k)] \quad (2)$$

$$a_s(t) = Im \sum_{k=-N/2}^{N/2} V_k \exp[j(2\pi k f_0 t + \lambda_k)] \quad (3)$$

A. Rayleigh Fading Channel

The Rayleigh fading channel model is given by

$$a(t) = Re^{j\theta} \quad (4)$$

where the envelope is Rayleigh and the phase is uniform.

$$R = \sqrt{a_c^2(t) + a_s^2(t)} \quad (5)$$

$$\theta = \tan^{-1}(a_s(t)/a_c(t)) \quad (6)$$

B. Rician Fading Channel

When a fading process has a line-of-sight component, A_c, the Rician process is given by the following expression:

$$a_c(t) = Re\{[A_c + a_c(t) + ja_s(t)]\exp[j2\pi f_c t]\} = Ce^{j\varnothing} \quad (7)$$

where the envelope and the phase are given by

$$C = \sqrt{[A_c + a_c(t)]^2 + a_s^2(t)} \quad (8)$$

$$\varnothing = \tan^{-1}(a_s/(A + a_c)) \quad (9)$$

C. Log-normal Fading Channel [3]

The log-normal model is given by

$$\begin{aligned} A(t) &= Se^{j\phi} = y_c(t) + jy_s(t) \\ &= \exp[\mu + \sqrt{d_0}\, x_c(t) + j\sqrt{d_0}\, x_s(t)] \end{aligned} \quad (10)$$

where $x_c(t)$ and $x_s(t)$ are narrow-band Gaussian random processes.

D. The Land Mobile Satellite Fading Channel Model proposed by Loo (Rayleigh/Lognormal) [3]

It assumes that the LOS component under shadowing is log-normally distributed and that the multipath effect is Rayleigh distributed. The two processes are additive.

The channel is given by

$$a(t) = Re\{[y_c(t) + a_c(t) + j(y_s(t) + a_s(t))]\exp[j2\pi f_c t]\} \quad (11)$$

The land mobile satellite fading channel is given by

$$re^{j\phi} = Re^{j\theta} + Se^{j\varphi} \quad (12)$$

where the envelope and the phase are given by

$$r(t) = \sqrt{[y_c(t) + a_c(t)]^2 + [y_s(t) + a_s(t)]^2} \quad (13)$$

$$\phi(t) = \tan^{-1}((y_s(t) + a_s(t))/(y_c(t) + a_c(t))) \quad (14)$$

E. The Land Mobile Satellite Fading Channel Model proposed by Corazza et al. (Rician/Lognormal)

Corazza et al. [2] proposed a probability distribution model which is a combination of Rice and lognormal statistics, including the shadowing which affects both the direct and the diffuse components.

In this subsection, we describe the channel model introduced by Corazza et al. in terms of random phasors in the following form:

$$re^{j\phi} = Ce^{j\alpha}Se^{j\varphi} = CSe^{j(\alpha+\varphi)} = (A_c + Re^{j\theta})Se^{j\varphi} \qquad (15)$$

where the envelope and the phase are given by

$$r(t) = CS = ([A_c + a_c(t)]^2 + a_s^2(t))^{1/2} \cdot (y_c^2(t) + y_s^2(t))^{1/2} \qquad (16)$$

$$\phi(t) = \tan^{-1}\left[\frac{(A_c + a_c(t))\,y_s(t) + a_s(t)\,y_c(t)}{(A_c + a_c(t))\,y_c(t) - a_s(t)\,y_s(t)}\right] \qquad (17)$$

F. The Channel Model with Independent Shadowing affecting each direct and diffuse component. (Rician/Lognormal)

In this subsection, we assume that the two log-normal shadowing processes affecting direct and diffuse components are independent and have the same statistics. That is, the statistics of log-normal process are characterized by environment such as rural, suburban and urban, and the independent log-normal processes affect the direct and the diffuse components with the same statistics, respectively.

This channel is given by

$$re^{j\phi} = A_cS_1e^{j\varphi} + RS_2e^{j(\theta+\varphi)} \qquad (18)$$

G. Analytical fading channel models

Expressions for the analytical fading channel are now given in terms of their envelope probability distribution, $p(r)$.

1) *The Channel proposed by Loo(Rayleigh/Lognormal) [3]:*

$$\text{Rayleigh}: p(r) = (r/b_0)\exp[-r^2/(2b_0)] \qquad (19)$$

$$\text{Lognormal}: p(z) = \frac{1}{z\sqrt{2\pi d_0}}\exp\left[-\frac{(\ln z-\mu)^2}{2d_0}\right] \qquad (20)$$

$$p_r(r_0) = \frac{1}{b_0\sqrt{2\pi d_0}}\int_0^{r_0}\int_0^{\infty}\frac{r}{z}\exp\left[-\frac{(\ln z-\mu)^2}{2d_0} - \frac{r^2+z^2}{2b_0}\right] I_0(rz/b_0)\,dz\,dr \qquad (21)$$

where b_0 represents the average scattered power due to multipath, μ and $\sqrt{d_0}$ are the mean and standard deviation.

2) *The Channel model proposed by Corazza et al.[2]:*

$$\text{Rician}: p(r) = 2(K+1)\frac{r}{s^2}\exp\left[-(K+1)\frac{r^2}{s^2} - K\right] I_0\left(2\frac{r}{s}\sqrt{K(K+1)}\right) \qquad (22)$$

$$\text{Lognormal}: p(s) = \frac{1}{h\sigma s\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{\ln s-\mu}{h\sigma}\right)^2\right] \qquad (23)$$

$$p_r(r_0) = \int_0^{r_0}\int_0^{\infty}\frac{p(s)}{s}\,p_R\left(\frac{r}{s}\right)ds\,dr \qquad (24)$$

where K is so called Rice factor and $h = (\ln 10)/20$, μ and $h\sigma$ are the mean and the standard deviation, respectively.

3) *The Channel model with Independent Shadowing affecting each direct and diffuse component.:*

Consider the sum of random phasors,

$$re^{j\phi} = A_cS_1e^{j\varphi} + RS_2e^{j(\theta+\varphi)} \qquad (25)$$

where S_1 and S_2 are independent Lognormal distribution, respectively and R has a Rayleigh distribution.

If S_1 and S_2 are temporarily kept constant, then the conditional probability density function of r is simply that of a Rician vector:

$$p(r\,|\,s_1, s_2) = \frac{r}{b_0 s_2^2}\exp\left[-\frac{(r^2/s_2^2) + (A_c s_1/s_2)^2}{2b_0}\right] I_0\left(\frac{rA_cs_1}{b_0 s_2^2}\right) \qquad (26)$$

where b_0 represents the average scattered power due to multipath, and $I_0(\cdot)$ is the modified Bessel function of zeroth order.

Applying the theorem of total probability, one can obtain

$$p(r)=\int_0^{\infty}\int_0^{\infty} p(r|s_1, s_2)\,p(s_1)\,p(s_2)\,ds_1 ds_2 \quad (27)$$

From this, $p(r)$ is given by

$$p(r)=\int_0^{\infty}\int_0^{\infty} \frac{r}{b_0 s_2^2}\exp\left[-\frac{r^2+A_c^2 s_1^2}{2b_0 s_2^2}\right] I_0\left(\frac{A_c r s_1}{s_2^2 b_0}\right) p(s_1)\,p(s_2)\,ds_1 ds_2 \quad (28)$$

It has been assumed that each $p(s_1)$ and $p(s_2)$ is independent lognormal, given by

$$p(s_1)=(\sqrt{2\pi d_{01}}\,s_1)^{-1}\exp[-(\ln s_1-\mu_1)^2/2d_{01}] \quad (29)$$

$$p(s_2)=(\sqrt{2\pi d_{02}}\,s_2)^{-1}\exp[-(\ln s_2-\mu_2)^2/2d_{02}] \quad (30)$$

where $\sqrt{d_{01}}$, $\sqrt{d_{02}}$ and μ_1, μ_2 are the standard deviation and mean, respectively.

When $A_c=0$, (26)-(30) provide the Suzuki p.d.f. In the limit for $d_{01}\to 0$, $d_{02}\to 0$, each $p(s_1)$ and $p(s_2)$ tends to Dirac pulse located at the mean value of the distribution, i.e., it tends to $\delta(s_1-e^{\mu_1})$, $\delta(s_2-e^{\mu_2})$. $p(r)\to p(r|e^{\mu_1}, e^{\mu_2})$ and the channel is Rice.

Therefore,

$$p(r)=\int_0^{\infty}\int_0^{\infty} \frac{r}{b_0 s_2^2}\exp\left[-\frac{r^2+A_c^2 s_1^2}{2b_0 s_2^2}\right] I_0\left(\frac{A_c r s_1}{s_2^2 b_0}\right) \frac{1}{2\pi s_1 s_2\sqrt{d_{01}d_{02}}} \exp\left[-\left(\frac{(\ln s_1-\mu_1)^2}{2d_{01}}+\frac{(\ln s_2-\mu_2)^2}{2d_{02}}\right)\right] \quad (31)$$

Equation (31) allows further observation: when $d_{02}\to 0$, $p(s_2)\to\delta(s_2-e^{\mu_2})$, $p(r|e^{\mu_2})$ tends to Loo's model, i.e., the channel is Rayleigh/Lognormal. When $b_0\to 0$, $p(r)$ tends to lognormal channel. When $d_{01}\to 0$, $d_{02}\to 0$ and $A_c\to\infty$, then fading is absent. When $d_{01}=d_{02}$ and $\mu_1=\mu_2$, $p(r)$ tends to Corazza's model, i.e., the channel is Rician/Lognormal. Therefore, depending on the combination of A_c, μ_1, μ_2 and b_0, the proposed channel model can be reduced to any one of the usual nonselective fading models.

Finally, the cumulative distribution function (c.d.f.) of the envelope is

$$p(r_0)=\Pr\{r<r_0\}=\int_0^{r_0} p(r)\,dr \quad (32)$$

Ⅲ. Model Validation and Results

A. Model Validation

The proposed channel model was validated with respect to data available in the literature. Fig. 1 collects the cumulative distribution function data provided in [1] and [2] for the cases referred to as infrequent light shadowing and frequent heavy shadowing. In the same Fig. 1 we provide the fitting curves obtained by means of (32) with parameters μ_1, μ_2, $\sqrt{d_{01}}$, $\sqrt{d_{02}}$ and K which are optimized by trial and error. For comparison, the calculated c.d.f. of (32) is compared with the c.d.f. in [1] and [2].

The empirical formulas should be derived to fit measured data over a wide range of elevation angles. As an example, we used some data collected by ESA at L band in a rural tree shadowed environment[4]. The resulting empirical formulas allow interpolation for any α in the range of $20^\circ<\alpha<80^\circ$:

$$K(\alpha)=K_0+K_1\alpha+K_2\alpha^2$$
$$\mu(\alpha)=\mu_0+\mu_1+\mu_2\alpha^2+\mu_3\alpha^3 \quad (33)$$
$$\sqrt{d_0(\alpha)}=\sqrt{d_{0_0}}+\sqrt{d_{0_1}}\,\alpha+\sqrt{d_{0_2}}\,\alpha^2+\sqrt{d_{0_3}}\,\alpha^3$$

Table 1. The Coefficients for Empirical Formulas

$\sqrt{d_{01}}$, $\sqrt{d_{02}}$	μ_1, μ_2	K
$\sqrt{d_{0_1}}=8.19\times10^{-1}$	$\mu_1=-2.74$	$K_0=2.73$
$\sqrt{d_{0_2}}=-1.26\times10^{-2}$	$\mu_2=1.36\times10^{-1}$	$K_1=-1.07\times10^{-1}$
$\sqrt{d_{0_3}}=-2.27\times10^{-5}$	$\mu_3=-2.28\times10^{-3}$	$K_2=2.77\times10^{-3}$
$\sqrt{d_{0_4}}=7.46\times10^{-7}$	$\mu_4=1.27\times10^{-5}$	

The coefficients for the example are reported in Table I.

B. An Application of Computer Models for Fading Channel

This subsection describes the parameters for channel models. All computer models for the fading channels are based on the manipulation of a white Gaussian random process. These models compare with analytical models in terms of their probability distribution of the envelope of the fading signal. The channel model parameters used in the simulation are given in Table II. The parameters were optimized by trial and error.

In Table III, we provide optimized parameters of two independent lognormal processes of (29) and (30).

Table 2. Channel Model Parameters

Shadowing			Fading
Loo's[1]	$\sqrt{d_o}$	μ	b_0
Light	0.115	0.115	0.1580
Heavy	0.806	-0.910	0.0631
Corazza	$h\sigma$	μ	K
Light	0.1151	0.13	4.0
Heavy	0.2878	-1.08	6.0

Table 3. The Parameters of Channel Model with Independent Shadowing

Our model	$\sqrt{d_{01}}$, $\sqrt{d_{02}}$	μ_1, μ_2	K
Light	0.12	0.195	4.0
Heavy	0.34	-1.150	0.6

C. Numerical Results

Numerical results are given in this subsection in terms of the p.d.f.s of the analytical and computer models for fading channel which were defined in the previous sections. Equation (21), (24) and (32) were used to calculate the p.d.f. and the sample size of 200,000 has been used to obtain these probability distributions by simulation. Many calculations with different values for channel model parameters were carried out with the objective of fitting results from the application of our model to those derived in [1] and [2].

Fig. 1 shows a comparison of the c.d.f. for the received envelope calculated using (32) and that computed from Loo's[1] and Corazza's[2] for infrequent light shadowing (sparse tree cover) and frequent heavy shadowing (dense tree cover). For the case of infrequent light shadowing, the model shows the best fit throughout the fading range. For the case of frequent heavy shadowing, the results of the model show reasonably good agreement around the median region and some deviation near the tails of the distribution. Generally, the results of our model match very well with both Loo's c.d.f. and Corazza's c.d.f.

Fig. 2 shows a comparison of the computer model and the analytical model for the fading channel proposed in this paper. The results of two models show reasonably good agreement.

Fig. 3 shows a comparison between measured c.d.f. data in the rural tree shadowed environment as a function of the elevation angle in [4] and the proposed c.d.f. with parameters given by (33) and simulation. The results show reasonably good agreement.

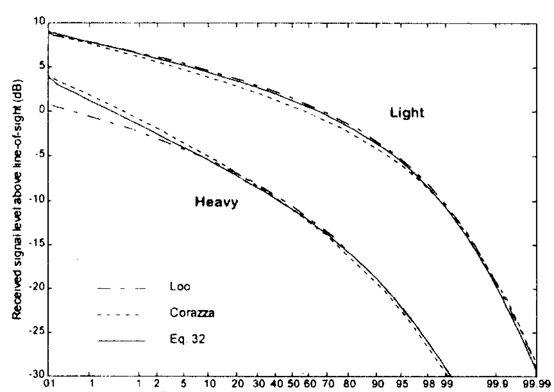


Fig. 1 Comparison between Analytical c.d.f. data in Light and Heavy shadowing

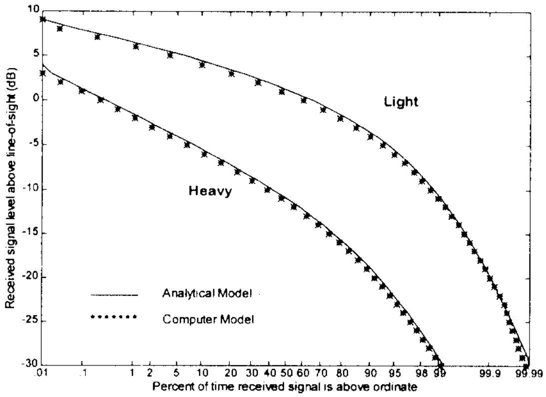


Fig. 2 Comparison between Analytical c.d.f. data given by (32) and Simulation data in Light and Heavy shadowing

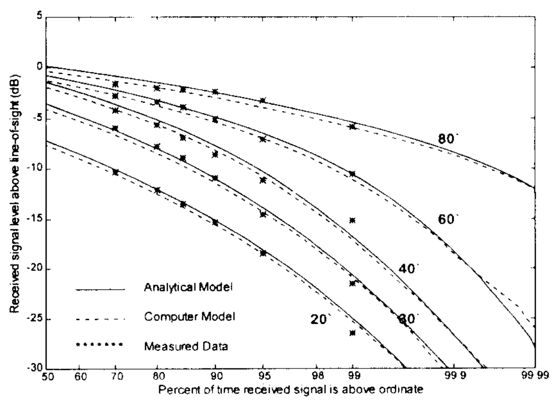


Fig. 3 Comparison among the measured, the analytical, and the simulated c.d.f.s with parameters given by (33)

Ⅳ. Probability of Error in the Nongeostationary LMS Channel

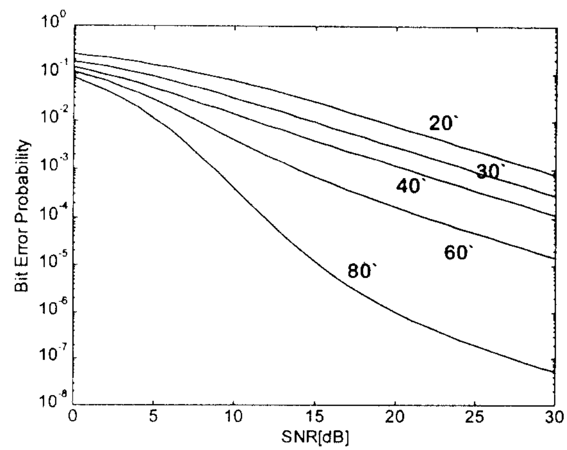
The symbol error probability for transmission in channels affected by nonselective fading can be written as

$$p_e = \int_0^{\infty} p(e \mid r)\, p_r(r)\, dr \tag{34}$$

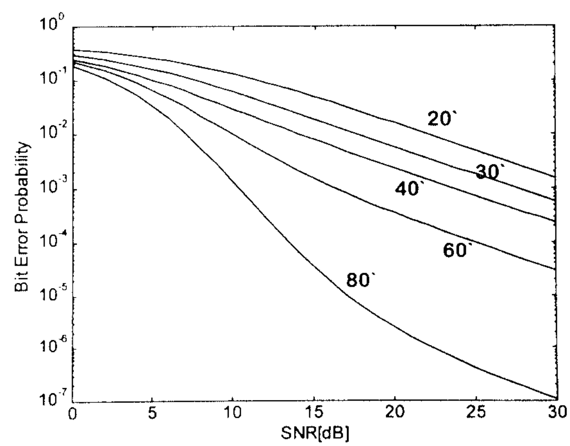
where $p(e|r)$ is the symbol error probability conditioned on a certain value of r and $p(r)$ is given by (31).

The error probability provided by (34) depends on the model parameters μ_2, $\sqrt{d_0}$ and K, which are the function of elevation angle for a given site.

Making use of the proposed model, the bit error probability for coherent BPSK and DBPSK modulations has been evaluated at different elevation angles (see Fig. 4).



(a) CBPSK



(b) DBPSK

Fig. 4 Bit error probability for the elevation angle

Ⅴ. Conclusion

This paper described a channel model for land mobile satellite communications that is a combination of Rice and lognormal statistics, with independent shadowing affecting both direct and diffuse components, respectively. In this paper, we have shown that the assumption of independent shadowing affecting the direct and the diffuse components is reasonable based on the results generated from the analysis and the computer simulation. In addition, we evaluated the bit error probability in few conditions of modulation as a function of the SNR for several values of the elevation angle. The computer models will be useful in the computer-aided modeling of communications system under the fading conditions and also useful in simulating propagation effects in the laboratory.

In this paper, we only considered the independent shadowing affecting the direct and the diffuse components. An extension to the correlated shadowing model as a function of the elevation angles is left as an interesting future study.

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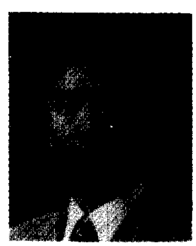

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