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Review article

An overview of shadowed fading wireless channels in terms of a cascaded approach

P.M. Shankar *

Department of Electrical & Computer Engineering, Drexel University, Philadelphia, PA 19104, United States

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ABSTRACT

Wireless channels suffer from short term fading and shadowing simultaneously. While simple models of short term fading are based on the Nakagami-m distribution, short term fading can also be described as a cascading process allowing the modeling of wireless channels having worse fading than what exists in Nakagami-m channels. Shadowing, on the other hand, has been traditionally modeled as a lognormal process, making the analysis of shadowed fading channels cumbersome. Taking note of the fact that the lognormal density arises out of a multiplicative process, it was shown that shadowing can also be modeled as a cascading process. Utilizing such a vision of shadowing, this work provides an overview of a unified cascaded approach to model wireless channels when short term fading and shadowing are simultaneously present. The degradation in such shadowed fading channels is estimated in terms of error rates and outage probabilities. Results are compared to those of the exact model based on lognormal density as well as random number simulation. Analysis demonstrates that error rates and outage probabilities obtained using the exact model (lognormal model for shadowing) agree very well with those obtained through the composite cascaded model as well as random number simulations.

Contents

1. Introduction

Short term fading treated as a cascading process allows the modeling of channel conditions that appear to be worse than those observed in typical Nakagami channels [1–3]. The notion that the received signal-to-noise in a fading channel is the result of a multiplicative process arising from several random variables forms the basis of cascading channels. Such cascading channels have also been used to model the fading seen in keyhole channels as well as amplify-and-forward relay channels [4,5]. While cascading accounts for the short term fading, the studies available in literature have not incorporated long term fading or shadowing in short term faded cascaded channels. Shadowing has generally been treated as a lognormal process and the simultaneous existence of fading and shadowing makes the average power in a short term fading channel random, modeled as a lognormal

* Tel.: +1 215 895 6632; fax: +1 215 895 1695.
E-mail address: shankapm@drexel.edu.

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variable [6–8]. Recently, it was shown that shadowing itself can be modeled in terms of a cascaded gamma process [9,10]. With the possibility of having the short term fading modeled as a cascaded N*gamma channel and shadowing modeled as another cascaded M*gamma channel [9], this work explores and reviews the use of a single composite cascaded model to describe the signal strength fluctuations in shadowed fading channels.

Following this introduction, the theoretical background essential for the development of the composite cascaded model is described. The performance analysis of coherent BPSK modem is studied next. The error rates and outage probabilities estimated using the exact model involving the use of a lognormal density and, the new composite cascaded model are estimated and compared to the results obtained through random number simulations. The final section offers a discussion on the potential applications of the composite cascaded model for shadowed fading channels in characterizing the signal degradation in wireless channels.

2. Theoretical background

The short term fading in a wireless systems can be described by modeling the channel as an N*gamma channel [3,9]. The probability density function $f_Z(z)$ of the signal-to-noise ratio Z in a cascaded channel is expressed as

$$f_Z(z) = \frac{1}{z\,\Gamma^N(m)} G_{0,N}^{N,0}\left(\frac{m^N}{Z_0} z \,\middle|\, \begin{matrix} - \\ m, .., m \end{matrix}\right), \quad m \ge \frac{1}{2},\; N = 1, 2, 3, \ldots. \tag{1}$$

In Eq. (1), m is the Nakagami parameter and $G_{0,N}^{N,0}\left(.\,\middle|\, \begin{matrix} .. \\ .. \end{matrix}\right)$ is the Meijer G function [11,12]. The average signal-to-noise ratio (SNR) is Z_0. Note that Eq. (1) is obtained by treating Z as the product of N independent and identically distributed gamma random variables [3]. The simple Nakagami-m channel is realized when $N = 1$ in Eq. (1). The amount of fading (AF) in a short term faded cascaded channel, AF_1, is [9,10]

$$AF_1 = \left(\frac{1+m}{m}\right)^N - 1. \tag{2}$$

As seen in Eq. (2), the cascaded model for short term fading can account for the increased levels of fading seen in wireless channels, with the performance levels deteriorating with increasing values of N, offering the flexibility that was not available with a simple Nakagami or gamma model [3,9,10].

In the absence of any shadowing, the average SNR Z_0 in Eq. (1) is deterministic. When shadowing is present concurrently with short term fading, the average SNR in Eq. (1) becomes a random variable [6,7,9]. Taking this into account, the density function of the SNR in Eq. (1) becomes

$$f_Z(z|y) = \frac{1}{z\,\Gamma^N(m)} G_{0,N}^{N,0}\left(\frac{m^N}{y} z \,\middle|\, \begin{matrix} - \\ m, .., m \end{matrix}\right), \quad m \ge \frac{1}{2},\; N = 1, 2, 3, \ldots. \tag{3}$$

The conditioning in Eq. (3) accounts for the randomness of the average SNR in short term fading and with $Y = y$ representing the average SNR (shadowing component). The pdf of the SNR in a cascaded channel where both short term fading and shadowing are present now becomes [6,9,13,14]

$$f(z) = \int_0^\infty f(z|y) f_Y(y)\,dy = \int_0^\infty \frac{1}{z\,\Gamma^N(m)} \times G_{0,N}^{N,0}\left(\frac{m^N}{y} z \,\middle|\, \begin{matrix} - \\ m, .., m \end{matrix}\right) f(y)\,dy. \tag{4}$$

In Eq. (4), $f_Y(y)$ is the density function of the shadowing component and it is expressed in terms of a lognormal pdf as [6–8]

$$f(y) = \frac{K}{\sqrt{2\pi\sigma^2 y^2}} \exp\left[-\frac{(10\log_{10} y - \mu)^2}{2\sigma^2}\right], \quad y \ge 0. \tag{5}$$

In Eq. (5), K is the logarithmic conversion factor given by [7,10]

$$K = \frac{10}{\log_e(10)}. \tag{6}$$

The severity of shadowing is measured in terms of the standard deviation σ (dB) of the associated Gaussian distribution and μ (dB) is the average SNR. The pdf of the SNR in a shadowed fading channel in Eq. (4) now becomes

$$f(z) = \int_0^\infty \frac{1}{z\,\Gamma^N(m)} G_{0,N}^{N,0}\left(\frac{m^N}{y} z \,\middle|\, \begin{matrix} - \\ m, .., m \end{matrix}\right) \times \frac{K}{\sqrt{2\pi\sigma^2 y^2}} \exp\left[-\frac{(10\log_{10} y - \mu)^2}{2\sigma^2}\right] dy. \tag{7}$$

The amount of fading, AF_2, when shadowing is present concurrently with fading becomes [7,10]

$$AF_2 = \left(\frac{1+m}{m}\right)^N \exp\left(\frac{\sigma^2}{K^2}\right) - 1. \tag{8}$$

Eqs. (2) and (8) illustrate the problems existing in cascaded and shadowed fading channels. The level (amount) of fading increases as the number of cascading components N goes up. The presence of shadowing only makes the channel conditions worse, pointing to serious problems in data transmission through these channels. Two quantitative measures of the channel performance characteristics are the error rates and outage probabilities. If we consider the example of coherent BPSK modem, the error rate, $p_e(Z_0)$, in an ideal (Gaussian) channel is given by [7]

$$p_e(Z_0) = \frac{1}{2}\operatorname{erfc}\left(\sqrt{Z_0}\right). \tag{9}$$

In Eq. (9), erfc (.) is the complementary error function [12]. When short term fading modeled as a cascading process is