Precise Analysis and Evaluation of OFDM Systems over a Mobile Frequency-Selective Nakagami-m Fading Channels

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ABSTRACT

In this article, the symbol error probability (SEP) of OFDM systems using M-ary coherent demodulation communicating over time-varying sum of Nakagami-m fading channels is analyzed. The focus of this article is on the evaluation of OFDM signals in mobile radio applications, such as IEEE 802.11a, IEEE 802.16a, and digital video broadcasting (DVB) systems. The time variations of the channel during one OFDM symbol interval destroy the orthogonality of the adjacent subcarriers and generate power leakage among the subcarrier, known as inter-carrier interference (ICI). We first present an integral solution for the probability density function (PDF) of the sum of Nakagami-m random vectors (RVs). Second, we used this PDF expression to obtain an exact closed form for the error probability. The error rate analysis is then extended to systems using multichannel reception with maximal ratio combining (MRC). Based on Jakes’ model for Doppler effects, and an exponential multipath intensity profile, numerical results for the error probability are illustrated for several mobile speeds. An interesting observation was concluded that depending on the number of the channel taps, the error rate performance does not necessarily improve with increasing Nakagami-m fading parameter.

Keywords: Doppler Spreading; ICI; OFDM; MRC; Sum of Nakagami-m Random Phase Vectors

INTRODUCTION

Orthogonal frequency-division multiplexing (OFDM) has recently received increased attention due to its capability of supporting high-data-rate communication in a frequency-selective fading environment that causes inter-symbol interference (ISI). In the OFDM system, serial data stream is split into parallel streams that modulate a group of orthogonal subcarriers. Compared to single carrier modulation, OFDM symbols have relatively long time duration, but a narrow bandwidth. Consequently, OFDM is robust to channel multipath dispersion and results in a decrease in the complexity of equalizers used in high delay spread channels or high data rate requirements.

However, the increased symbol duration makes an OFDM system more sensitive to
the time variations of mobile radio channels. In particular, the effect of Doppler spreading destroys the orthogonality of the subcarriers, resulting in inter-carrier interference (ICI) due to power leakage among subcarriers.

The combination of OFDM with diversity techniques has become popular in wireless communications. This is due to the fact that diversity techniques can dramatically improve the system performance over fading channel, especially in a frequency-flat fading environment. In a noise-limited system, it is well known that maximum ratio combining (MRC) provides the best system performance (Lu, Tjhung, Adachi, & Huang, 2000). Although, in the presence of interference, MRC is no longer the optimum combining scheme, its performance is comparable to that of an optimum combiner, and MRC is employed in many practical wireless communication systems (Aalo et al., 2005). Instead of using complicated equalizers as in the conventional single carrier system, the ISI in OFDM can be eliminated by adding a guard interval which greatly simplifies the receiver structure.

The Rayleigh and Rician fading model has been widely used to represent fading environments. For example, Glavieux, Cochet, and Picart (1994) considered the performance of an OFDM binary frequency-shift keying (OFDM-BFSK) scheme in underwater communication scenarios assuming Rayleigh and Rician fading channels. More recently, Lu et al. (2000) studied the performance of an OFDM M-ary differential phase keying (OFDM-MDPSK) scheme in Rician fading channel with diversity reception. However, propagation conditions in some wireless systems may not be well described by this model, for example, microcellular system, where the fading is not as severe as Rayleigh fading (Beaulieu & Chaeng, 2005). The Nakagami-\(m\) (Nakagami, 1960) distribution was employed as another useful and important model for characterizing the amplitude of the fading channel. Both theoretical and practical importance of the Nakagami-\(m\) channel motivated intensive research into studying the performance of various communication systems operating in such a channel. For example, Eng and Milstein (1995) studied the performance of a direct-sequence code-division multiple-access (DS-CDMA) system in Nakagami-\(m\) fading channels. Alouini and Goldsmith (1998) used the moment generating function (MGF) technique to study the error performance of coherent modulations over Nakagami-\(m\) channels. More recently, Yang and Hanzo (2002) investigated the performance of multicarrier DS-CDMA in Nakagami-\(m\) fading channels. Nevertheless, previous works that studied transmission of an OFDM signal over multipath Nakagami-\(m\) channel assumed that the frequency-domain channel response samples are also Nakagami-\(m\) distributed with the same fading parameter as the time-domain channel (Scaglione, Barbarossa, & Giannakis, 2000), and there are no experimental results presented in the literature that support this assumption. Consider an N-point fast Fourier transform (FFT) used to determine the sample frequency-domain response from the sampled time-domain response. In the case of Rayleigh fading, the faded signal samples have a joint complex Gaussian distribution. Then, the application of the FFT represents a linear transformation of jointly Gaussian random variables (RVs) and yields jointly Gaussian RVs (Papoulis, 1991). Thus, one expects a frequency response sample to have a Rayleigh fading distribution when the time-domain signal is Rayleigh faded. However, sum of Nakagami-\(m\) random phase vectors do not, in general, have a Nakagami-\(m\) distributed envelope. Therefore, it is not expected that the frequency-domain samples can be assumed to be a Nakagami-\(m\) distribution when the time-domain signals is Nakagami-\(m\) faded, except for \(m = 1\), which is the special case of Rayleigh fading. Kang, Yao, and Lorenzelli (2003) claimed that the distribution of the frequency-domain channel impulse response can be approximated by another Nakagami-\(m\) distribution with a new fading parameter different from the time-domain fading parameter. In this article, we will use an exact mathematical analysis to show that such Nakagami-\(m\) approximations can be unreliable. In addition, in this article we focus on providing
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