Performance Evaluation for Forward-Link Cellular DS-CDMA over Frequency-Selective Nakagami Multipath Fading Channels

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Abstract. The bit-error rate (BER) for a forward-link cellular direct-sequence code-division multiple-access (DS-CDMA) system is evaluated. This analysis takes into account the effects of multi-cell interference resulting from Nakagami multipath fading, frequency selectivity, path loss and mobile user spatial distribution. Exponentially decaying multipath intensity profile (MIP) is adopted in the model to investigate its significance on the overall performance. In order to evaluate the BER performance efficiently, saddlepoint integration (SPI) is applied in the analysis. By fixing the number of resolvable multipaths and varying the number of fingers for the RAKE receiver, it can be shown that the capacity of a DS-CDMA cellular system increases almost linearly with the number of RAKE fingers.

Keywords: cellular CDMA, forward link, Nakagami fading, frequency-selective channels.

1. Introduction

As code-division multiple access (CDMA) [1] promises to provide higher capacity and service quality as compared to either frequency-division multiple access (FDMA) or time-division multiple access (TDMA), this multiple-access technique has become increasingly popular for use in mobile communications. One of the most important features of CDMA is its capability of mitigating multipath interference, where a RAKE receiver is usually employed at the receiving end to optimally combine diversity components. Another attribute of CDMA is that precise time coordination is not required among transmitters, which facilitates asynchronous transmission.

The performance of direct-sequence CDMA (DS-CDMA) systems has been investigated extensively in the literature. Borth et al. [2] and Geraniotis [3] considered the effects of multiple-access interference (MAI) over a single-path Rician-faded channel. Trabelsi and Yongaçoğlu [4] analyzed the bit-error rate (BER) performance for asynchronous DS-CDMA over multipath fading channels. Geraniotis and Pursley [5] reported the performance of coherent DS-CDMA communications over Rician-faded channels. Turin [6] investigated the effects of multipath and fading on the performance of DS-CDMA systems using the average received signal-to-noise (SNR) ratio, thus bypassing a detailed analysis based on a specific fading statistic. Note that either Rayleigh or Rician fading was assumed in the above studies. However, as pointed out by Suzuki [7], Nakagami fading may be more suitable to fit the urban empirical data. In fact, Nakagami distribution [8] can be used to study various degrees of fading conditions, including the situations which are more severe than the Rayleigh fading. A more recent paper by Eng and Milstein [9] presented the analysis of a coherent DS-CDMA system over Nakagami-faded channels by approximating the combined distribution for the
sum of squares of Nakagami random variables (RVs) as the squares of another Nakagami RV. It should be emphasized that all the analyses cited above are only confined to a single-cell case. In this paper, we would like to extend the forward-link performance analysis to a multi-cell DS-CDMA environment.

Stüber and Kchao [10] studied the area-averaged BER performance of a DS-CDMA cellular system, without considering the exact locations of mobiles. Milstein et al. [11] presented the worst-case BER results of cellular CDMA by assuming the targeted mobile located at the boundary of the cells. Cheah et al. [12, 13] extended the analysis to arbitrary mobile locations over a single-path Rayleigh-faded channel. Oh and Li [14] and Oh et al. [15] generalized the results to Rician-faded and Nakagami-faded channels. In order to ensure a more accurate and reasonable situation, mobile users are assumed to be randomly located within each cell in our study.

In this paper, we further extend the analysis in [14, 15] to frequency-selective Nakagami multipath fading. This analysis which takes into account of path loss, Nakagami multipath fading, frequency selectivity and mobile user spatial distribution in a DS-CDMA cellular system is not yet available in the literature to the best knowledge of the authors. In particular, we employ saddlepoint integration (SPI) to evaluate the cellular BER performance. SPI has been demonstrated to be an efficient way to analyze the BER performance for one-path DS-CDMA cellular systems [14] and many other applications [16–19]. It is, therefore, interesting to see how this technique can be adopted in a frequency-selective Nakagami multipath fading channel.

The next section presents the forward-link model and BER expressions. The SPI technique is introduced in Section 3 to simplify the BER expressions for frequency-selective Nakagami multipath fading. Numerical results and conclusions are given in Sections 4 and 5, respectively.

2. Forward-Link Analysis

A typical DS-CDMA cellular system with 25 cells is shown in Figure 1. The choice of square cells is due to mathematical convenience and this option should not affect the qualitative nature of the results [20]. The 2-layer structure around Cell 1 is used to capture the MAI of surrounding cells. K users are uniformly distributed in each unit-length square cell. Base stations are located at the centers of the cells and, in particular, the center of Cell 1 is chosen as the origin (0, 0). All signal components that arrive from the same base station are assumed to travel through the same paths and, thus, fade in unison [11]. The signals from different base stations received by the tagged mobile are attenuated with path loss exponent, \( r \), ranged from 2 to 4 [21]. The signal branch from each resolvable path experiences an exponentially decaying multipath intensity profile (MIP). Note that the MIP is valid for a single-cell case [9]. Since the measured results by Turin et al. [22] showed that the multipath spread depends almost totally on the local environment of the receiver. It is, therefore, reasonable to assume that each path is attenuated by the path loss followed by this exponentially decaying MIP in a cellular environment. The received signal of the tagged mobile in Cell 1 is given as