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Capacity and error probability performance analysis for MIMO MC DS-CDMA system in η–μ fading environment

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ABSTRACT

In this paper, we investigate the effect of multiple input multiple output (MIMO) systems on the performance of the multicarrier direct sequence code division multiple access (MC DS-CDMA) system operating over independent identically distributed (i.i.d) η–μ flat fading environment in terms of average error probability and average channel capacity. We derive the instantaneous signal to interference noise ratio (SINR) at the output of the receiver. Hence, based on moment generating function (MGF) approach, we obtain the probability density function (PDF) of the instantaneous SINR. Closed form expressions of average error probabilities for the system are developed and expressed in Appell's and Lauriccella's hypergeometric functions. Furthermore, we achieve exact expression of average channel capacity for the system. Finally, we validate our results using Monte Carlo simulation technique and also compare with those already available in the literature.

1. Introduction

Multicarrier direct sequence code division multiple access (MC DS-CDMA) is a digital modulation and multicarrier technique which results from a combination of orthogonal frequency division multiplexing (OFDM) and direct sequence code division multiple access (DS-CDMA). Due to the research on it for the last decade or more, the MC DS-CDMA system has become an important multicarrier communication system for the fourth generation (4G) wireless communication system [1]. The operation of this system is based on time domain spreading code or combination of time domain and frequency domain spreading codes respectively. Hence, original data stream is serial to parallel converted and spread using spreading code in time domain and then each subcarrier is modulated differently with each of the data stream [2]. The frequency separation between two adjacent subcarraiers is $1/T_c$, where T_c is the chip duration. Furthermore, the application of multiple input multiple output (MIMO) systems to wireless communication systems (MC DS-CDMA) can substantially increase the channel capacity and lower the symbol or bit error probability without any increase in the transmission power or expansion of the required bandwidth. On the other hand, wireless communication systems will be highly complex in structure and costly due to the involvement of multiple radio frequency (RF) devices. Therefore, the hand held mobile terminals may accommodate a small number of antennas due to the size and power limitation [3]. In this case, the antennas are connected to both ends forming multiple input multiple output MC DS-CDMA (MIMO MC DS-CDMA) system. Thus, at the transmitter end, space time coding is utilized to spread information across the antennas and allow the receiver to achieve transmit diversity. This, however, maximizes the diversity gain of the wireless communication system over fading channels [4]. The space time block codes (STBC) are employed to orthogonalize the MIMO wireless channels; i.e., STBC simplify maximum-likelihood decoding by decoupling the vector detection problem into a simpler scalar detection problem [5]. Therefore, the operation of the system is of special interest for the asynchronous reverse link of wireless mobile communication system based on Alamouti techniques [6].

In [7], the performance of MC DS-CDMA system is investigated using space time spreading in forward link when random signature sequences are employed. Yang and Hanzo [8], examined the issues of parameters design and bit error rate (BER) performance of broadband multicarrier DS-CDMA system over frequency selective Rayleigh fading channels using space time spreading assisted transmit diversity. The operation of the system is based on time domain spreading, time domain and frequency domain spreading combined was considered. Sourour and Nakagawa [9], proposed a new multicarrier direct sequence code division multiple access system and investigated its BER performance analysis based on conventional matched filter receiver and RAKE receiver for each subcarrier.

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In [10], Yang and Hanzo studied the BER performance of the generalized MC DS-CDMA system over multipath Nakagami-*m* fading channels. The effect of space between two adjacent subcarriers on the system performance was also considered. The comparison based on the operations of MC DS-CDMA, multitone (MT) DS-CDMA and orthogonal multicarrier (OMC) DS-CDMA systems over multipath Nakagami-*m* fading channels was also taken into account. Elnoubi and Hashem [11] examined the BER performance of MC DS-CDMA system over MIMO Nakagami-*m* multipath fading channels. The impact of the RAKE receiver in conjunction with MRC was also considered. In [12], Han and Paichard investigated the influence of imperfect channel estimation on MIMO MC CDMA system performance in terms of bit error rate. Closed-form expression for BER using MGF technique was derived. Yang [13] studied the BER performance of the multiantenna MC DS-CDMA system over correlated time selective Rayleigh fading channels. The space time spreading technique based on the family of orthogonal variables spreading factor code was proposed in order to attain time diversity. In [14], Lodhi et al. looked into the performance of STBC and cyclic delay diversity for MC CDMA system operating over Nakagami-*m* fading channels with correlated subcarriers. Closed-form expression of average BER (ABER) for M-ary digital modulation techniques was derived. The authors [15] derived new expression for probability density function of the sum of non-identical independent squared η–μ random variables and apply it to consider the performance of the asynchronous DS-CDMA system over η–μ fading channels. The evaluation of the system operation was in terms of outage probability, average channel capacity and average error probability respectively. Sagias et al. [16] explored the performance of the DS-CDMA system over Rayleigh fading channel based on average Shannon capacity. Generalized selection combining method for RAKE receiver was employed.

As can be seen from many reported literature on performance of MC DS-CDMA system over fading channels, the fading distributions employed mostly are Rayleigh, Rician, Nakagami-q, Nakagami-*m* and Weibull respectively. In this paper we investigate the performance of MIMO MC DS-CDMA system in terms of average error probability and ergodic channel capacity over independent identically distributed (i.i.d) η–μ fading channels. We derive the instantaneous signal to interference noise ratio (SINR) at the output of the receiver. Hence, we employ moment generating function (MGF) based method for obtaining the probability density function (PDF) of the instantaneous SINR. In addition, we derive the closed form expressions of average error probabilities for the system by averaging the coherent digital modulation techniques over the PDF of the instantaneous SINR and express them in Appell's hypergeometric or Lauricella's hypergeometric functions, respectively. These closed-form expressions are new. Furthermore, the average channel capacity is achieved by averaging the Shannon Hartley capacity over the PDF of the instantaneous SINR of the received signal.

The remainder of the paper is organized as follows. System and channel models are described in the next section. In Section 3, we discuss in detail the derivation of the instantaneous signal to interference noise ratio (SINR) and its probability density function (PDF). The derivation of the average error probability for the system is carried out in Section 4 while that of average channel capacity is outlined in Section 5. Numerical results and discussion are placed in Section 6. Finally, we conclude the paper in Section 7.

2. System and channel model

2.1. Transmitted signal

In this section, we consider multicarrier direct sequence code division multiple access system employing M_t transmit antennas and N_r receive antennas respectively. Therefore, this system is called multiple input multiple output MC DS-CDMA system. Basically, the system operation assumption depends on channel state information (CSI) known at the receiver while the transmitter utilizes space time block codes (STBC) for the receiver to achieve transmit diversity. As illustrated in Fig. 1, the input data are first serial to parallel converted to U (2) substreams. Then, the symbols in each substream are spread in time domain and mapped to M_t transmit antennas [2]. Thus, each subcarrier signal is multicarrier modulated by invoking inverse fast Fourier Transform (IFFT) and then summation of the modulated signals is carried out and transmitted. On the other hand, we assume that each subcarrier signal experiences independent η–μ flat (the bandwidth of each subcarrier is sufficiently low for each subcarrier signal to experience flat fading) fading. In this case, let us suppose that the system MIMO MC DS-CDMA uses two transmit antennas and N_r receive antennas respectively. Hence, we also suppose two symbols say $s_k^1(t)$ and $s_k^2(t)$ to be transmitted simultaneously based on Alamouti technique [6] from transmit antenna 1 and transmit antennas 2 at the same first time slot. At the second time slot, the complex conjugate of symbol $-s_k^2(t)$ is transmitted from antenna 1 and complex conjugate of symbol $s_k^1(t)$ is transmitted from antenna 2 simultaneously. Furthermore, we also presume that the channel from either of the transmitters to any of the receivers experience frequency non-selective η–μ fading. The two transmitted symbols of user k are represented by

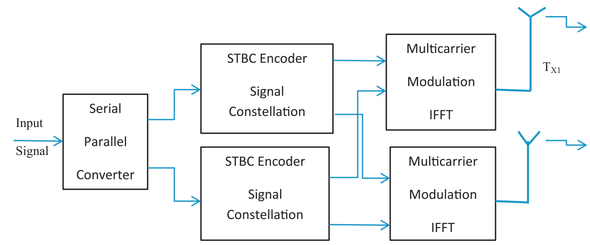

Fig. 1. System transmitter block diagram.

$$
\begin{aligned}
s_k^1(t) &= \sum_{i=1}^{q}\sum_{j=1}^{U}\sqrt{\frac{2P}{M_tU}}\,c_k^1(t)b_k^1(t)\cos(2\pi f_{ij}t+\phi_{ij}^1)\\
s_k^2(t) &= \sum_{i=1}^{q}\sum_{j=1}^{U}\sqrt{\frac{2P}{M_tU}}\,c_k^2(t)b_k^2(t)\cos(2\pi f_{ij}+\phi_{ij}^2)
\end{aligned}
\qquad (1)
$$

where $b_k^1(t)$ and $b_k^2(t)$ are odd and even data stream transmitted by the kth user, where $b_u^k(t)=\sum_{n=-\infty}^{\infty}b_u^k[n]P_{T_s}(t-nT_s)$, $b_u^k[n]\in\{+1,-1\}$ denotes binary data sequence modulating the uth subcarriers, T_s is the symbol duration, $P_{Ts}(t)$ is a rectangular pulse uniformly distributed in interval [0, T_s), $c_k^1(t)$ and $c_k^2(t)$ represent spreading codes in time domain in transmitters 1 and 2, respectively, where $c_k(t)=\sum_{n=-\infty}^{\infty}c_k[n]\psi(t-nT_c)$ is the spreading code waveform of user k and T_c is the chip duration, where $c_n^k\in\{+1,-1\}$, with equal probability, while $\psi(t)$ is a rectangular chip waveform of T-domain spreading sequence which is defined over the interval [0, T_c). Hence, the relationship $\sum_{n=0}c_k^i[n]c_k^j[n]=0$, for $i\neq j$ is obeyed [8]. U is the number of subcarriers, q is the number of bits in the data stream, P is the transmitted power, f_{ij} is the carrier frequency of the ith bit at jth subcarrier, and ϕ_{ij} is the phase introduced by the multicarrier modulations. The channel between the transmitter and the receiver during one time slot is assumed to be invariant; i.e., the conditions of the two symbols during this interval of time slot remain unchanged. But the characteristics of the channel vary after another interval of the time slot or another symbol frame.