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Performance analysis of modulation diversity with OSTBC transmission over Nakagami-*m* fading channels

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ABSTRACT

In this paper performance of modulation diversity with multiple-input multiple-output transmission is studied over flat Nakagami-*m* fading channels with arbitrary fading parameter *m*. In the system, orthogonal space-time block coding and maximal ratio combining like combiner are used for transmission and reception, respectively. Exact pairwise error probability expression is derived to observe performance of the system. Moreover, in order to obtain the diversity order of the system, asymptotic pairwise error probability expression is also derived. Optimum rotation angles are analytically obtained for binary and quadrature phase shift keying modulations. Theoretical results are validated by Monte Carlo simulations.

1. Introduction

Diversity techniques are useful to combat the effects of fading that have disruptive effects on the performance of the wireless communication systems. Antenna, time and frequency diversity or combinations of these techniques improve the error performance of communication systems significantly. Antenna diversity can be implemented at the transmitter and/or receiver side [1]. Space Time Block Coding (STBC) [2,3] is the most common transmit diversity technique, which does not require channel state information at the transmitter. Orthogonal STBCs (OSTBC) have a simple decoding scheme and achieve full diversity order [2,3]. Additionally, Maximal Ratio Combining (MRC) is the optimum receive diversity technique, which maximizes the received Signal-to-Noise Ratio (SNR) [1].

A different kind of diversity technique from antenna diversity is signal space diversity, also known as modulation diversity, which uses rotated signal constellation and component interleaving at the transmitter, and component de-interleaving at the receiver [4,5]. In the signal constellation of conventional modulation techniques such as M-ary Phase Shift Keying (M-PSK), any symbol always has one common in-phase or quadrature component with the other symbols (as shown in Fig. 1 for Quadrature Phase Shift Keying (QPSK)). For this reason, component interleaving alone does not improve the error performance of the system considerably. However, by using rotated signal constellation, in which there is no common component between any two symbols (as shown in Fig. 1), together with component interleaving, which has components affected by independent fading coefficients, diversity gain can be obtained [6,7].

Error performance of OSTBC has been investigated in [8] and exact Symbol Error Probability (SEP) expressions have been derived for Independent Identically Distributed (i.i.d.) Nakagami-*m* channels. In addition, in [8] error performance of OSTBC has been studied for i.i.d. keyhole Nakagami-*m* fading channels by numerical integration. Asymptotic SEP performance of OSTBC has been examined in [9] for Independent Non-identically Distributed (i.n.d.) Nakagami-*m* fading channels.

Modulation diversity with Alamouti scheme has first been presented in [10]. Authors of [10] have investigated the performance of the system by simulations for Rayleigh fading channels and obtained optimum rotation angle for QPSK. Performance of modulation diversity with Alamouti scheme has also been investigated by simulations in [11] in the presence of channel estimation errors for Rayleigh fading channels. In [12], the system proposed in [10] has been studied based on asymptotic Pairwise Error Probability (PEP) approach over Rayleigh fading channels. In [13], authors have considered modulation diversity with Orthogonal Frequency Division Multiplexing (OFDM) and OSTBC transmission studied by simulations for two; three and four transmit antennas and Rayleigh fading channels. In [14], modulation diversity has been adapted to Vertical Bell Labs Layered Space-Time (VBLAST) with OFDM system, and the authors have investigated performance of the system with

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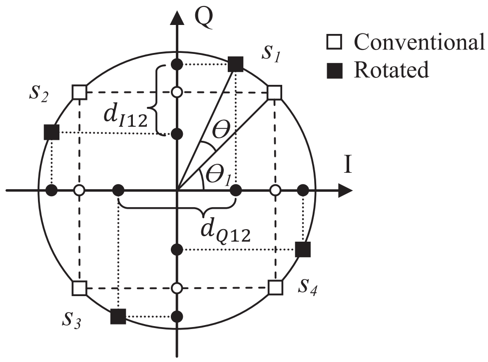

Fig. 1. Signal constellations of conventional and rotated QPSKs.

simulations over Rayleigh fading channels. In [15], authors have studied modulation diversity with bit interleaved coded modulation, spatial division multiplexing and OFDM, and obtained performance results via simulations over Rayleigh fading channels. In [16], authors have introduced a system in which modulation diversity and VBLAST are used and the components of the n-dimensional signal constellation are transmitted over n-transmit antennas by using Space-Time (ST) encoder. Modulation diversity has been simulated with coded Multiple-Input Multiple-Output (MIMO) system in which components of rotated n-dimensional signal constellation are transmitted over n-transmit antennas by using ST encoder in [17]. In [18], ST coding from Coordinate Interleaved Orthogonal Design (CIOD) has been designed and its performance has been analyzed in detail over Nakagami-m fading channels in [19].

In this paper, performance of modulation diversity technique with OSTBC transmission (i.e., space-time block codes from orthogonal design but not CIOD) is investigated for Nakagami-m fading channels. In the system, OSTBC and MRC like combiner are considered as transmission and reception techniques, respectively. We obtain exact PEP expression of the system for flat Nakagami-m fading channels with arbitrary fading parameter m. In addition, we derive the asymptotic PEP expression to obtain the diversity order of the system, and validate theoretical results by Monte Carlo simulations. Optimum rotation angles of Binary Phase Shift Keying (BPSK) and QPSK modulations are analytically obtained.

The remainder of this paper is organized as follows. In Section 2, the system model is described. Performance analysis is presented in Section 3. In Section 4, numerical and simulation results are given. Finally, conclusions are drawn in Section 5.

2. System model

In this paper, the system given in Fig. 2 is considered. In the system, OSTBC and MRC like combiner are employed as the transmission and reception schemes, respectively. The transmitter and receiver are equipped with N_t transmit and N_r receive antennas, respectively.

At the transmitter, rotated constellation mapper generates in-phase (s_I) and quadrature (s_Q) components of the symbols from rotated signal constellation which can be denoted in vector form as $\mathbf{s} = (s_I, s_Q)$ and in the complex form as $s = s_I + js_Q$ where $j = \sqrt{-1}$. Component interleaver independently interleaves the in-phase and quadrature components. The symbols at the output of the component interleaver ($x = x_I + jx_Q$) are encoded by OSTBC encoder. After encoding, the OSTBC codeword $\mathbf{X}$, which is $N_t \times T$ dimensional matrix, where N_t and T denote number of transmit antennas and block length of codeword, respectively. The OSTBC codeword X whose elements are the linear combinations of the N symbols $(x_1, x_2, \ldots, x_N)$ is transmitted over transmit antennas with the transmission rate $R = N/T$. The transmitted signals experience i.i.d. and quasi-static Nakagami-m fading phenomena in which the fading coefficients are constant over the whole OSTBC codeword transmission. Let $\mathbf{H}$ denote the $N_r \times N_t$ dimensional channel matrix between the transmitter and receiver, then the received signal can be expressed as

$$\mathbf{Y} = \mathbf{HX} + \mathbf{W}. \tag{1}$$

In (1), $\mathbf{Y}$ denotes the received signal matrix with size $N_r \times T$ and $\mathbf{W}$ is the $N_r \times T$ dimensional Additive White Gaussian Noise (AWGN) matrix whose elements are i.i.d. complex Gaussian random variables with zero mean and a power spectral density of $N_0/2$ per dimension. By using equivalent Single-Input Single-Output (SISO) model [8], output of the OSTBC combiner can be expressed as

$$y = x\|\mathbf{H}\|_F + w, \tag{2}$$

where $\|\cdot\|_F$ denotes Frobenius norm operator, and w is the complex AWGN with zero mean and variance N_0N_tR. The signal vector $\mathbf{r}$ at the output of the component de-interleaver can be written for a given symbol $\mathbf{s} = (s_I, s_Q)$ as

$$\mathbf{r} = (r_I, r_Q) = (s_I g_1 + w_I, s_Q g_2 + w_Q), \tag{3}$$

where r_I and r_Q are in-phase and quadrature components of the received vector, respectively. In (3), $g_1 = \|\tilde{\mathbf{H}}_1\|_F$ and $g_2 = \|\tilde{\mathbf{H}}_2\|_F$ are the channel coefficients for SISO model affecting the in-phase and quadrature components of the symbols, respectively, where $\tilde{\mathbf{H}} = \tilde{\mathbf{H}}_1 + j\tilde{\mathbf{H}}_2$ is the de-interleaved version of $\mathbf{H}$. With the use of component interleaver and component de-interleaver at the transmitter and receiver, respectively fading coefficients g_1, g_2 which affect the in-phase and quadrature components of the symbols, become independent. In (3), w_I and w_Q are independent Gaussian random variables with zero mean and variance $N_0N_tR/2$. The Maximum Likelihood (ML) detector decides on the received symbols by using the following metric

$$\hat{\mathbf{s}} = \underset{\mathbf{s}_i}{argmin}(\|\mathbf{r} - \mathbf{g} \odot \mathbf{s}_i\|_F^2), \tag{4}$$

where $\mathbf{g} = (g_1, g_2)$ and $\mathbf{s}_i$, $i = 1, 2, \ldots, M$ is the ith symbol of the rotated signal constellation, and M is the level of the modulation. In (4), $\odot$ denotes component-wise product. For a transmitted symbol $\mathbf{s}$, the ML detector makes an erroneous decision if it decides in favor of $\hat{\mathbf{s}}$ which is different from $\mathbf{s}$.

3. Performance analysis

3.1. Exact pairwise error probability

For a signal at the output of the ML detector PEP can be expressed as

$$\begin{aligned} Pr(\mathbf{s} \to \hat{\mathbf{s}}) &= Pr(\|\mathbf{r} - \mathbf{g} \odot \hat{\mathbf{s}}\|_F^2 < \|\mathbf{r} - \mathbf{g} \odot \mathbf{s}\|_F^2) \\ &= Pr(\|\mathbf{r} - \mathbf{g} \odot \hat{\mathbf{s}}\|_F^2 < \|\mathbf{w}\|_F^2), \end{aligned} \tag{5}$$

where $\mathbf{w} = (w_I, w_Q)$. Similar to [6,7] the conditional PEP can be obtained as

$$\begin{aligned} Pr(\mathbf{s} \to \hat{\mathbf{s}}|\gamma_1, \gamma_2) &= Q\left(\sqrt{\frac{1}{2N_0}(g_1^2 d_{Iij} + g_2^2 d_{Qij})}\right) \\ &= Q\left(\sqrt{\frac{\gamma_1 + \gamma_2}{2}}\right), \end{aligned} \tag{6}$$

where $Q(\cdot)$ is the Gaussian Q-function expressed as $Q(x) = (1/\sqrt{2\pi})\int_x^\infty e^{-t^2/2}dt$ and also defined by Craig's formula, $Q(x) =$