Design of Concatenated Space-Time Block Codes Using Signal Space Diversity and the Alamouti Scheme

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***Abstract*—New full-rate space-time block codes achieving full diversity for quadrature amplitude modulation (QAM) using an even number of transmit antennas over quasi-static Rayleigh fading channels are proposed. The proposed codes are constructed by serially concatenating unitary rotating precoders with the Alamouti code. The coding advantage of the proposed code for a codeword pair corresponding to any distinct input pair is shown to be greater than or equal to that of the ST-CR code.**

***Index Terms*—Fading channels, multiple transmit antennas, space-time codes, wireless communication.**

I. Introduction

PROVIDING spatial diversity where traditional receive antenna diversity is not practically feasible, space-time codes have been one of the recent focal research topics in the wireless communication area. Tarokh *et al.* in [2] developed orthogonal space-time block codes (O-STBCs) based on orthogonal designs achieving full diversity and allowing simple maximum-likelihood (ML) decoding. Unfortunately, full-rate O-STBCs for general quadrature amplitude modulation (QAM) do not exist when the number of transmit antennas is larger than two [2], [3].

On a different note, Boutros *et al.* in [6] proposed a so-called multidimensional rotated QAM modulation scheme to be used in single antenna Rayleigh fading channels with QAM modulation. This scheme provides so called signal space diversity (SSD) [6] without bandwidth expansion. This is done by rotating and interleaving a vector of QAM modulated symbols via a real rotation matrix where the maximum obtainable diversity order is equal to the length of the vector.

Boutros' SSD scheme was applied to space-time coding in [7] and [8]. The space-time constellation-rotating (ST-CR) code proposed in [8] achieves minimum *coding advantage* [1] larger than the diagonal algebraic STBC proposed in [7]. This is due to the optimization over complex rotation matrices while the rotation matrices in [7] (and [6]) are constrained to be real. Both codes proposed in [7] and [8] are shown to achieve both full rate and full diversity.

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In this letter, we propose a class of full-rate, full-diversity STBCs for even number of transmit antennas constructed by serially concatenating the unitary rotating precoders in [5], [8] with the Alamouti code [3]. The proposed codes guarantee that the *coding advantage* as defined in [1], between a codeword pair corresponding to any distinct input pair, is greater than or equal to that of the ST-CR code of [8]. Particularly, for $N = 2^n$ transmit antennas, the minimum coding advantage of the proposed code is seen to be identical to that of the ST-CR code. However, the multiplicity of codeword pairs corresponding to the minimum coding advantage of the proposed code is observed to be significantly less than that of the ST-CR code, leading to significant performance improvements.

II. System Model

In this letter, we consider full-rate and delay-optimal [2] STBCs for systems with N transmit antennas under quasi-static Rayleigh fading channels. At the transmitter, M-ary QAM symbols normalized so as to have unit energy are grouped to form vectors of length N, $\mathbf{x} = [x_1, \ldots, x_N]^T$ which is then input to the space-time encoder to form a codeword matrix $\mathbf{S}(\mathbf{x}) = \{s_{tn}\}$ of size $N \times N$. Each row of $\mathbf{S}(\mathbf{x})$ is assumed to be normalized so that its norm averaged over all possible constellation points is unity. The codeword symbol s_{tn} is then transmitted on antenna n at time t.

The signals transmitted from different transmit antennas are assumed to experience independent Rayleigh fading. The channel is also assumed to be quasi-static in the sense that the channel do not vary significantly during the transmission of the code matrix. For simplicity, we only consider the case of one receive antenna. The receive matched filter output at time t is then given by $y_t = \sqrt{E_s}\sum_{n=1}^{N} h_n s_{tn} + n_t,\ t = 1, 2, \ldots, N$, where $E_s = E_b \log_2(M)$ and E_b are the average received symbol and bit energies, respectively. The channel coefficient h_n for the nth transmit antenna and the noise variable n_t at time t are modeled as i.i.d. zero mean complex Gaussian r.v.s with variances 1/2 and $N_0/2$ per dimension, respectively. Hence, the received vector $\mathbf{y} = [y_1, \ldots, y_N]^T$ is given by $\mathbf{y} = \mathbf{S}(\mathbf{x})\mathbf{h} + \mathbf{n}$ where $\mathbf{h} = [h_1, \ldots, h_N]^T$ and $\mathbf{n} = [n_1, \ldots, n_N]^T$. Assuming perfect knowledge of $\mathbf{h}$, ML decoding is performed at the receiver by choosing $\hat{\mathbf{x}}$ such that $\mathbf{S}(\hat{\mathbf{x}})\mathbf{h}$ is closest to $\mathbf{y}$ in terms of Euclidean distance.

III. Conventional ST-CR Codes

The ST-CR encoder of [8] first generates an N dimensional rotated vector $\mathbf{r} = [r_1, \ldots, r_N]^T$ by multiplying the input vector