A Novel Closed-Loop Quasi-Orthogonal Space-Time Block Coding Scheme for Long-Code WCDMA

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Abstract

Quasi-orthogonal space-time block codes (QO-STBCs) are proposed for long-code WCDMA systems which exploit the subspace structure of the long-code WCDMA transmission. QO-STBCs achieve full code rate at the expense of loss in diversity gain. In this paper, we propose a feedback method for QO-STBCS in WCDMA to achieve full diversity and full code rate. The bit error rate (BER) performance for the proposed algorithm is compared with other conventional methods for typical quasi-static channels. Simulation results show that the proposed feedback method yields a significant improvement in BER performance over open-loop schemes.

1. Introduction

In this work we propose a novel combination of closed-loop quasi-orthogonal space-time block coding and a long-code wideband code division multiple access (WCDMA) scheme to exploit spatial diversity in future wireless communication systems. For a mobile communication system, a key parameter is the system capacity. Multiple antennas at the transmitter and receiver in the system have been recognized as a major technology breakthrough to increase the capacity of a wireless communication network. Alamouti first proposed a space-time (ST) code for two transmit antennas and two symbol periods in [1], which showed that ST technology can enhance bandwidth efficiency. Orthogonal Space-Time Block Code (O-STBCs) are a very important kind of ST Code due to their ability to provide optimal transmit diversity by requiring only simple linear processing at the receiver [2]. However, full-rate O-STBCs for complex constellations exist only for two transmit antennas. For higher transmit diversity levels, O-STBCs exist only with code rate less than one, which implies a loss of bandwidth efficiency[3]. To achieve full-rate transmission while retaining much of the orthogonality benefits, Quasi-Orthogonal Space-Time Block Codes (QO-STBCs) have been proposed. In this work, we derive a special feedback method for QO-STBC to achieve full diversity and full code rate.

Next, we focus upon long-code WCDMA as it is part of the 3G standard. The combination of WCDMA and STBC is a very interesting approach to combat the impairments of wireless multiuser channels and thereby increase capacity. A modified version of the Alamouti scheme has been preiously explored for a WCDMA system in [4]. In [5], a transmit diversity technique based on O-STBC has been proposed for a CDMA system. In our work, the QO-STBC with feedback method for a WCDMA system is considered with a practically inspired number of antennas both at the base station and the mobile station.

The remainder of this paper is organized as follows. Section 2 describes the data model of the quasi-orthogonal space-time block coded WCDMA system which exploits the subspace structure. A transmit antenna phase rotation method based on feedback are presented in Section 3. In Section 4, we develop the simulations and results.

2. Data Model

We consider a quasi-orthogonal space time block code asynchronous WCDMA communication system with four transmit antennas and one receiver antenna, and that a base-station has K users with aperiodic spreading sequences of spreading gain G, and slotted transmissions of M symbols per slot. We will consider a quasi-static time-varying channel for each transmit and receiver antenna pair, i.e., that the channel doesn't change in a slot period. Here, an FIR channel model with channel impulse response $\{h(i), i \in \{0,\cdots,L_h\}\}$ has been considered. A QO-STBC structure was presented earlier in [3]. The code matrix was proposed as follows.

$$\text{QO} = \begin{bmatrix} s_1 & s_2 & s_3 & s_4 \\ -s_2^* & s_1^* & -s_4^* & s_3^* \\ -s_3^* & -s_4^* & s_1^* & s_2^* \\ s_4 & -s_3 & -s_2 & s_1 \end{bmatrix} \tag{1}$$

This is an extension of the well-known Alamouti 2×2 scheme [2]

$$\text{A} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \tag{2}$$

for four transmit antennas, where $s_i^*, i = 1, 2$ denote complex conjugates of the symbols s_1 and s_2. The channel's transmission paths $h_{i,l}$, where $i = 1, 2, 3, 4$, and $l = 1, \cdots L$, are assumed to be resolvable and independent complex valued random variables with zero mean and unity variance, where *i* denotes the transmit antenna index and *l* denotes the multipath index.

At the transmitter, the *ith* user's data sequences are denoted $\{s_{i,m}^{(1)}\}_{m=1}^{Mi}$, $\{s_{i,m}^{(2)}\}_{m=1}^{Mi}$, $\{s_{i,m}^{(3)}\}_{m=1}^{Mi}$ and $\{s_{i,m}^{(4)}\}_{m=1}^{Mi}$, one for each transmitter, in each slot, where *Mi* denotes the slot size for user *i*. The data for user *i* is quasi-orthogonal space-time encoded as:

$$s_{i,m}^{(1)} = s_{i,m},\ s_{i,m+1}^{(1)} = s_{i,m+1},\ s_{i,m+2}^{(1)} = s_{i,m+2},\ s_{i,m+3}^{(1)} = s_{i,m+3};$$
$$s_{i,m}^{(2)} = -s_{i,m+1}^*,\ s_{i,m+1}^{(2)} = s_{i,m}^*,\ s_{i,m+2}^{(2)} = -s_{i,m+3}^*,\ s_{i,m+3}^{(2)} = s_{i,m+2}^*;$$
$$s_{i,m}^{(3)} = -s_{i,m+2}^*,\ s_{i,m+1}^{(3)} = -s_{i,m+3}^*,\ s_{i,m+2}^{(3)} = s_{i,m}^*,\ s_{i,m+3}^{(3)} = s_{i,m+1}^*;$$
$$s_{i,m}^{(4)} = s_{i,m+3},\ s_{i,m+1}^{(4)} = -s_{i,m+2},\ s_{i,m+2}^{(4)} = -s_{i,m+1}\ s_{i,m+1}^{(4)} = s_{i,m}^*,\ \text{m = 1,5,9,}\ldots Mi\text{-1}, \tag{3}$$

where $s_{i,m}$ is the input data sequence, $s_{i,m}^{(j)}$, j=1,2,3,4, denote the encoded data sequence for transmit antenna j. Following this, signals from each transmit antenna are all spread by the same spreading code.

We also assume that the transmitted signal is corrupted by other user interference and additive noise in the channel. This gives us the long-code WCDMA system model as illustrated in FIGURE1.

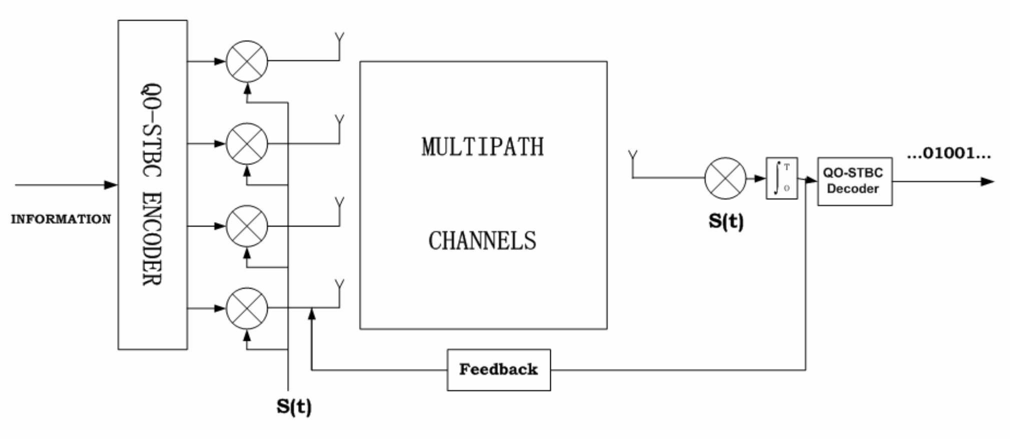

FIGURE 1. Baseband Representation of the Proposed Closed-loop Feedback System

To increase temporal diversity, the receiver signal is typically sampled at the rate T_F faster than or equal to the chip rate T_C. In this case, we let the receiver signal $y(t)$ pass through the chip-matched filter, and sample it at the chip rate. Stacking the chip rate samples, we obtain the discrete-time received signal vector.

The receiver segment y_{im} which corresponds to the *mth* symbol of user *i* will be considered first. y_{im} is given by

$$y_{im} = T_{im}[h_i^{(1)}s_{i,m}^{(1)} + h_i^{(2)}s_{i,m}^{(2)} + h_i^{(3)}s_{i,m}^{(3)} + h_i^{(4)}s_{i,m}^{(4)}], \tag{4}$$

where T_{im} is the Toeplitz matrix whose first column is made of $(m-1)G_i + d_i$ zeros followed by the code vector c_{im} (the mth segment of G_i chips of the spreading code of user i) and additional zeros that make the size of y_{im} the total number of chips of the entire slot plus max{ d_i, i=1,….,K} .

Including all users and the noise, we have

$$y = THs + w \tag{5}$$

$$T := [T_1, ..., T_K]$$

$$H := diag(I_{M_1} \otimes H_1, ..., I_{M_K} \otimes H_k), \tag{6}$$

where w is a vector representing the additive white Gaussian noise. And we will assume the receiver knows the spread code c, the paths L_i, and the delay coefficients D_i of all users.

3. Close-loop System by Phase Rotation

The output of the decorrelator is given in vector from by

$$z = T^{\dagger}y = \vartheta(H)s + n = diag(I_{Mi} \otimes H_1, ..., I_{MK} \otimes H_K)s + n; \tag{7}$$

Where $n = T^{\dagger}w$ is now colared. The four subvectors corresponding to four consecutive symbols m, $m+1$, $m+2$, $m+3$ of the user i are given by

$$z_{i,m}=\begin{bmatrix} h_i^{(1)} & h_1^{(2)} & h_i^{(3)} & h_i^{(4)} \end{bmatrix}\begin{bmatrix} s_{i,m} \\ -s_{i,m+1}^* \\ -s_{i,m+2}^* \\ s_{i,m+3} \end{bmatrix}, \quad z_{i,m+1}=\begin{bmatrix} h_i^{(1)} & h_1^{(2)} & h_i^{(3)} & h_i^{(4)} \end{bmatrix}\begin{bmatrix} s_{i,m+1} \\ s_{i,m}^* \\ -s_{i,m+3}^* \\ -s_{i,m+2} \end{bmatrix}$$

$$z_{i,m+2}=\begin{bmatrix} h_i^{(1)} & h_1^{(2)} & h_i^{(3)} & h_i^{(4)} \end{bmatrix}\begin{bmatrix} s_{i,m+2} \\ -s_{i,m+3}^* \\ s_{i,m}^* \\ -s_{i,m+1} \end{bmatrix}, \quad z_{i,m+3}=\begin{bmatrix} h_i^{(1)} & h_1^{(2)} & h_i^{(3)} & h_i^{(4)} \end{bmatrix}\begin{bmatrix} s_{i,m+3} \\ -s_{i,m+2}^* \\ s_{i,m+1}^* \\ -s_{i,m} \end{bmatrix}$$

Now rewriting these four sub vectors $z_{i,4n-3}$, $z_{i,4n-2}$, $z_{i,4n-1}$, $z_{i,4n}$ as:

$$Z=\begin{bmatrix} z_{i,m} \\ z_{i,m+1}^* \\ z_{i,m+2}^* \\ z_{i,m+3} \end{bmatrix}=\begin{bmatrix} h_i^{(1)} & h_i^{(2)} & h_i^{(3)} & h_i^{(4)} \\ h_i^{*(2)} & -h_i^{*(1)} & h_i^{*(4)} & -h_i^{*(3)} \\ h_i^{*(3)} & h_i^{*(4)} & -h_i^{*(1)} & -h_i^{*(2)} \\ h_i^{(4)} & -h_i^{(3)} & -h_i^{(2)} & h_i^{(1)} \end{bmatrix}\begin{bmatrix} s_{i,m} \\ -s_{i,m+1}^* \\ -s_{i,m+2}^* \\ s_{i,m+3} \end{bmatrix} \tag{8}$$

Where z and h are all $Lh\times 1$ column vectors, we let $Lh=5$, $z_{i,m}=\begin{bmatrix} z_{i,m,1} & z_{i,m,2} & . & . & z_{i,m,5} \end{bmatrix}^T$, and $h_i^{(1)}=\begin{bmatrix} h_{i,1}^{(1)} & h_{i,2}^{(1)} & . & . & h_{i,5}^{(1)} \end{bmatrix}^T$.

Applying matched filtering at the receiver , we can obtain the overall matrix as follows:

$$\Delta = H^H H = \begin{bmatrix} \lambda & 0 & 0 & \partial \\ 0 & \lambda & -\partial & 0 \\ 0 & -\partial & \lambda & 0 \\ \partial & 0 & 0 & \lambda \end{bmatrix} \tag{9}$$

where $\lambda=\sum_{l=0}^{L-1}\sum_{i=1}^{4}\left|h_{i,l}\right|^2$, and $\partial = 2\sum_{l=0}^{L-1}\mathrm{Re}\left\{h_{1,l}^* h_{4,l} - h_{2,l}^* h_{3,l}\right\}$. From (9), it is clear that some nonzero off-diagonal terms appear, which lead to some diversity loss. In order to achieve full diversity, we can use feedback bit to rotate the phases to eliminate or reduce the off-diagonal element.

Consider that the signals from the fourth transmit antennas are rotated by phasor θ, then

$$\partial' = \mathrm{Re}\left\{\sum_{l=0}^{L-1} h_{1,l}^* h_{4,l} e^{j\theta} - \sum_{l=0}^{L-1} h_{2,l}^* h_{3,l}\right\} \tag{10}$$

and we can easily to find the rotated phasor parameter θ after trigonometric manipulations (let $\alpha' = 0$) [6].

4. Simulated System Performance

In this section, we evaluate the bit error rate performance of the proposed schemes in quasi-static flat fading channels. The fading is constant within a frame and changes independently from frame to frame. We consider a QO-STBC WCDMA system with feedback in a four transmit antennas and one receive antennas system. For this closed-loop system, we have simulated the BER against E_b / N_o using BPSK users with equal power. The parameters: spread gain=32, symbols=100, slotsize=320, delay$\in$ [0,23], two asynchronous active users, channel length Lh=5 are used for the simulations shown in FIGURE 2. We can see, for example, that there is more than 5dB improvement in the proposed method at BER 10^{-4}.

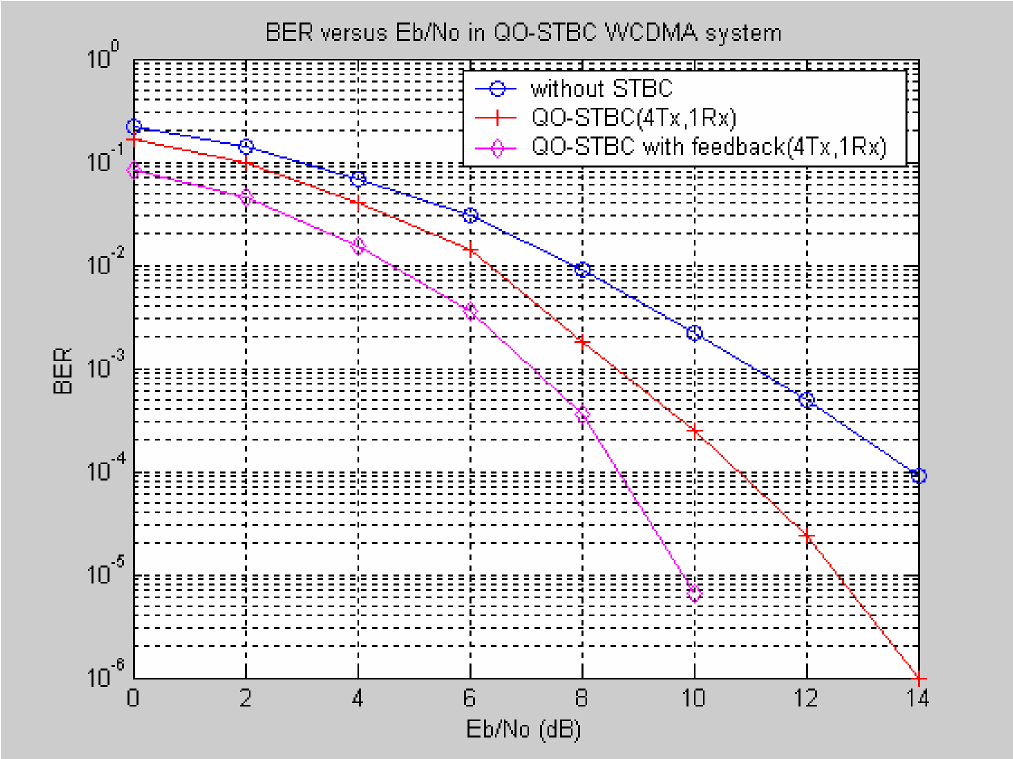

FIGURE 2 BER Performance Versus SNR in a QO-STBC WCDMA system with feedback

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