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A TWO-STEP INTERFERENCE CANCELLATION TECHNIQUE FOR A MIMO-OFDM SYSTEM WITH FOUR TRANSMIT ANTENNAS

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ABSTRACT

In this paper a new two-step interference cancellation (IC) technique for an orthogonal frequency division multiplexing system with multiple transmitter and receiver antennas linked over a frequency selective channel is explored. We first utilize a recently proposed type of full code rate space-time block code, which is quasi-orthogonal space-time block code (QO-STBC) scheme to exploit temporal and spatial diversity within a multiuser environment with k co-channel users. We adopt four transmit antennas for each user and two antennas in the receiver. Our scheme has a combined interference suppression scheme based on minimum mean-square error (MMSE) and maximum likelihood (ML) detector, followed by an interference cancellation step. The frame error rate (FER) performance for the proposed algorithm is compared with orthogonal space-time block codes (O-STBC) for two transmitter antennas and extended orthogonal space-time block codes (EO-STBC) in quasi-static and slow fading frequency selective channels. Simulation results show that the proposed method yields a significant improvement in FER performance.

Index Terms— MIMO-OFDM, QO-STBC, full-rate, interference cancellation, two-step.

1. INTRODUCTION

With the rapid growth of digital communication in recent years, the need for high-speed data transmission has been increased. Orthogonal frequency division multiplexing (OFDM), as a multicarrier modulation technique, is implemented to keep up with the demand for more communication capacity. The processing power of modern digital signal processors has increased to a point where OFDM has become feasible and economical, some examples of current applications using OFDM include GSTN (General Switched Telephone Network), DSL and ADSL modems, DAB (Digital Audio Broadcasting) radio, DVB-T (Terrestrial Digital Video Broadcasting), HYPERLAN (High Performance Local Area Network Standard), and the wireless networking standards IEEE 802.11a, IEEE 802.g, IEEE 802.16a [1], [2], [3]. A multiple

input multiple output (MIMO) technique, such as by exploiting a space-time block code (STBC), has been recognized as an available technology to increase the capacity in a wireless communication network. Among many proposed STBC designs, it is possible to achieve full diversity and full code rate for both real and complex signal constellations in Alamouti's STBC with two transmit and two receive antennas. The other STBCs proposed in [4] for more transmit antennas enjoy the full diversity at full code rate only for real signal constellations. It is further proved that a full-rate O-STBC for complex constellations under the orthogonal assumption does not exist for more than two transmit antennas [4]. To achieve the full code rate, however, with a small loss in performance, quasi-orthogonal designs have been proposed in [5]. The extended orthogonal space-time block code (EO-STBC) which is proposed in [6] is another full code rate STBC, which can also support full code rate and high diversity performance.

By exploiting the temporal and spatial structure of a STBC, which Alamouti first proposed in [7] for two transmitter antennas and two symbol periods, multiuser detection for frequency selective fading channels has been achieved by combining with an OFDM scheme [8]. By selecting the MIMO scheme for all users, we will achieve more diversity gain to achieve better performance. It is, however, not always possible to allow multiple users to access the same channel simultaneously. Therefore, it is crucial to design a receiver structure to suppress co-channel interference. MMSE interference cancellation and maximum likelihood decoding techniques can be designed that exploit the structure of a STBC to suppress the interference from a co-channel terminal [8].

In this paper, we successfully extend such full rate STBCs to a MIMO-OFDM multiuser system. Moreover, a novel two-step IC method will be considered for an uplink system with K co-channel users over a frequency selective channel. In the proposed transceiver scheme, the number of transmit antennas per user is four, and two antennas will be adopted in the receiver. The proposed full-rate STBC is evaluated through simulation and results show the performance enhancement by the proposed IC method.

The remainder of this paper is organized as follows. Section 2 describes the data model of the MIMO-OFDM system

which exploits four antennas at each transmit terminal user and two antennas in the receiver. Linear MMSE interference suppression and ML decoding are presented in section 3. A two-step interference cancellation approach is proposed in section 4. In section 5, we present the simulations and Section 6 concludes the paper.

2. DATA MODEL

Consider a block or vector transmission OFDM system, where K synchronous users are communicating with a base station. We employ four antennas in each transmit terminal and two antennas in receiver. The baseband system structure is illustrated in Fig.1. The IFFT-FFT blocks implicitly include the addition/removal of the cyclic prefix.

Fig.1 The baseband model of a MIMO-OFDM system

When the i th terminal user transmits the four consecutive block vectors $S_1^i, S_2^i, S_3^i, S_4^i$ according to QO-STBC [4], the symbols matrix becomes:

$$QO = \begin{bmatrix} S_1^i & S_2^i & S_3^i & S_4^i \\ -(S_2^i)^* & (S_1^i)^* & -(S_4^i)^* & (S_3^i)^* \\ -(S_3^i)^* & -(S_4^i)^* & (S_1^i)^* & (S_2^i)^* \\ S_4^i & -S_3^i & -S_2^i & S_1^i \end{bmatrix} \quad (1)$$

where $S = [s(0), \dots, s(N-1)]^T$, is an N length size block of transmit symbols, and $(\cdot)^T, (\cdot)^*$ denote respectively transpose and conjugate operations. The output of the space-time encoder is then modulated by an IFFT into an OFDM symbol sequence, then transmitted through a frequency selective channel $h_{n,j}$ with maximum order q for the n th transmit antenna and j th receiver antenna pair. We assume $H_{1,j}^i(k), H_{2,j}^i(k), H_{3,j}^i(k), H_{4,j}^i(k)$ denote the channel frequency responses of the k th tone, related to the channel from the four transmit antennas in each terminal to the j th receive antenna,

where $k = 0, 1, \dots, N-1$. The k th tone signal picked up by each receive antenna during the time slot 1, 2, 3, 4 can be written as:

$$\begin{bmatrix} r_{1,j}(k) \\ r_{2,j}(k) \\ r_{3,j}(k) \\ r_{4,j}(k) \end{bmatrix} = \begin{bmatrix} \eta_{1,j} \\ \eta_{2,j} \\ \eta_{3,j} \\ \eta_{4,j} \end{bmatrix} +$$

$$\begin{bmatrix} \sum_{i=1}^K [H_{1,j}^i(k)s_1^i(k) + H_{2,j}^i(k)s_2^i(k) + H_{3,j}^i(k)s_3^i(k) + H_{4,j}^i(k)s_4^i(k)] \\ \sum_{i=1}^K [H_{2,j}^i(k)(s_1^i(k))^* - H_{1,j}^i(k)(s_2^i(k))^* + H_{4,j}^i(k)(s_3^i(k))^* - H_{3,j}^i(k)(s_4^i(k))^*] \\ \sum_{i=1}^K [H_{3,j}^i(k)(s_1^i(k))^* + H_{4,j}^i(k)(s_2^i(k))^* - H_{1,j}^i(k)(s_3^i(k))^* - H_{2,j}^i(k)(s_4^i(k))^*] \\ \sum_{i=1}^K [H_{4,j}^i(k)s_1^i(k) - H_{3,j}^i(k)s_2^i(k) - H_{2,j}^i(k)s_3^i(k) + H_{1,j}^i(k)s_4^i(k)] \end{bmatrix} \quad (2)$$

where $\eta(k)$ denotes the frequency domain representation of the noise at the k th tone. For simplicity of notation, we define $r_j(k) = [r_{1,j}, r_{2,j}, r_{3,j}, r_{4,j}]^T$, $S(k) = [S_1^i(k), S_2^i(k), S_3^i(k), S_4^i(k)]^T$, $\eta_j(k) = [\eta_{1,j}, \eta_{2,j}, \eta_{3,j}, \eta_{4,j}]^T$, and

$$\tilde{H}_j^i(k) = \begin{bmatrix} H_{1,j}^i(k) & H_{2,j}^i(k) & H_{3,j}^i(k) & H_{4,j}^i(k) \\ (H_{2,j}^i(k))^* & -(H_{1,j}^i(k))^* & (H_{4,j}^i(k))^* & -(H_{3,j}^i(k))^* \\ (H_{3,j}^i(k))^* & (H_{4,j}^i(k))^* & -(H_{1,j}^i(k))^* & -(H_{2,j}^i(k))^* \\ H_{4,j}^i(k) & -H_{3,j}^i(k) & -H_{2,j}^i(k) & H_{1,j}^i(k) \end{bmatrix} \quad (3)$$

We rewrite equation (2) as:

$$r_j(k) = \sum_{i=1}^K \tilde{H}_j^i(k) S^i(k) + \eta_j(k), k=0, \dots, N-1 \quad (4)$$

In the next, only two terminal users will be considered for simplicity of the research. Consider that all the receiver antennas in the k th tone receive signal can be represented in matrix form as follows:

$$\begin{bmatrix} r_1(k) \\ r_2(k) \end{bmatrix} = \begin{bmatrix} \tilde{H}_1^1(k) & \dots & \tilde{H}_1^K(k) \\ \tilde{H}_2^1(k) & \dots & \tilde{H}_2^K(k) \end{bmatrix} \begin{bmatrix} S^1(k) \\ S^2(k) \\ \vdots \\ S^K(k) \end{bmatrix} + \begin{bmatrix} \eta_{10}(k) \\ \eta_{20}(k) \end{bmatrix} \quad (5)$$

Then we rewrite equation (5) as:

$$r''(k) = H''(k) S''(k) + \eta''(k) \quad (6)$$

where $r''(k)$ is the 8×1 column vector corresponding to the overall receiver signals at all receive antennas, $H''(k)$ has a code matrix of size 8×8 , $S''(k)$ is the transmitting

signal vector with dimension 8×1 including all users at the k th tone, and $\eta''(k)$ is the noise vector with 8 elements.

3. LINEAR MMSE IC SUPPRESSION AND ML DECODING

For simplicity, we only consider the two users case in this paper. The receive signal at the receive antenna during four sequential symbol times is given by:

$$\begin{aligned} r_1(k) &= \tilde{H}_1^1(k)S^{(1)}(k) + \tilde{H}_1^2(k)S^{(2)}(k) + \eta_1(k) \\ r_2(k) &= \tilde{H}_2^1(k)S^{(1)}(k) + \tilde{H}_2^2(k)S^{(2)}(k) + \eta_2(k) \end{aligned} \quad (7)$$

assume that we want to define the i th user terminal, where $i=1,2$. We use an MMSE interference cancellation and maximum likelihood decoder which is given in [8] to estimate the transmitted symbols. The cost function for the user 1 to minimize the mean square error caused by co-channel interference and noise has been given by: $J(w) = E\{\|S^{(1)} - w r''(k)\|^2\}$, where $E\{\cdot\}$ denotes the expectation operation. By using the standard minimization technique: $\frac{\partial J(w)}{\partial w} = 0$, it can be shown that the weights w_{4i-3} , w_{4i-2} , w_{4i-1} , w_{4i} , corresponding to user i , can be computed respectively, as:

$$\begin{aligned} w_{4i-3} &= M^{-1}h_{4i-3}; & w_{4i-2} &= M^{-1}h_{4i-2}; \\ w_{4i-1} &= M^{-1}h_{4i-1}; & w_{4i} &= M^{-1}h_{4i}; \end{aligned}$$

where $M = E\{r''r''^*\} = \tilde{H}(k)\tilde{H}(k)^* + \frac{1}{\Gamma}I_{2m}$, $\Gamma = Es/N_0$ is the signal to noise ratio, h_{4i} is the $4i$ th column vector of $\tilde{H}(k)$, then the maximum likelihood decoding equation can be written as:

$$\tilde{S}^{(i)}(k) = \arg \min_{[S_n^{(i)}] \in S} \left\{ \sum_{n=1}^4 \|w_{4i-4+n}^* r''(k) - \tilde{S}_n^{(i)}(k)\|^2 \right\}; \quad (8)$$

So the reliability functions of all symbols from the i th user terminal will given by:

$$\Delta_i = \sum_{n=1}^4 \|w_{4i-4+n}^* \tilde{r}''(k) - \tilde{S}_n^{(i)}(k)\|^2; \quad (9)$$

where $r''(k)$ is the overall receiver signals at all receive antennas, $\tilde{S}_n^{(i)}$ includes all possible symbol pairs of the i th user in the transmit signal.

4. TWO-STEP APPROACH FOR IC AND ML DECODING

If the original performance is not good enough, there is another arithmetic step that can be used, that is two-step IC. In this two-step approach, the receiver decodes signals from two terminal users using the linear MMSE decoding

scheme, we define these two block symbols as $\tilde{S}^1(k)$, $\tilde{S}^2(k)$. Without loss of generality, let us assume that we are interested in decoding the symbols from the first terminal user, then:

$$\begin{cases} r_1(k) - \tilde{H}_1^1(k)\tilde{S}^{(1)}(k) = \tilde{H}_1^2(k)\tilde{S}^{(2)}(k) + \eta_1(k) \\ r_2(k) - \tilde{H}_2^1(k)\tilde{S}^{(1)}(k) = \tilde{H}_2^2(k)\tilde{S}^{(2)}(k) + \eta_2(k) \end{cases} \quad (10)$$

Now we decode these equations and obtain the signal $\tilde{\tilde{S}}^2(k)$ corresponding with $\tilde{S}^1(k)$.

$$\tilde{\tilde{S}}^2(k) = \arg \min_{\tilde{S}^2} \sum_{n=1}^2 \|r_n(k) - \tilde{H}_n^1(k)\tilde{S}^{(1)}(k) - \tilde{H}_n^2(k)\tilde{\tilde{S}}^{(2)}(k)\|^2 \quad (11)$$

The reliability function of the pair of result $\{\tilde{S}^1(k), \tilde{\tilde{S}}^2(k)\}$ is given by:

$$\Delta(\tilde{S}^{(1)}) = \sum_{n=1}^2 \|r_n(k) - \tilde{H}_n^1(k)\tilde{S}^{(1)}(k) - \tilde{H}_n^2(k)\tilde{\tilde{S}}^{(2)}(k)\|^2 \quad (12)$$

Similarly, using $\tilde{S}^2(k)$ to estimate $\tilde{\tilde{S}}^1(k)$, the equation and the corresponding reliability function are easy to write from equations (10) and (11)

$$\tilde{\tilde{S}}^1(k) = \arg \min_{\tilde{S}^1} \sum_{n=1}^2 \|r_n(k) - \tilde{H}_n^1(k)\tilde{\tilde{S}}^{(1)}(k) - \tilde{H}_n^2(k)\tilde{S}^{(2)}(k)\|^2 \quad (13)$$

$$\Delta(\tilde{S}^{(2)}) = \sum_{n=1}^2 \|r_n(k) - \tilde{H}_n^1(k)\tilde{\tilde{S}}^{(1)}(k) - \tilde{H}_n^2(k)\tilde{S}^{(2)}(k)\|^2 \quad (14)$$

To achieve better performance, we select the smaller of between the two values $\Delta_1 + \Delta(\tilde{S}^{(1)})$ and $\Delta_2 + \Delta(\tilde{S}^{(2)})$. If $(\Delta_1 + \Delta(\tilde{S}^{(1)})) < (\Delta_2 + \Delta(\tilde{S}^{(2)}))$, we choose the symbol pair $\{\tilde{S}^1(k), \tilde{\tilde{S}}^2(k)\}$, otherwise $\{\tilde{S}^2(k), \tilde{\tilde{S}}^1(k)\}$ is used.

5. SIMULATION AND RESULTES

We adopt QO-STBC and EO-STBC techniques with four antennas in each transmit terminal and two receive antennas in our proposed two-step interference cancellation MIMO-OFDM scheme. During simulation, we assume the transmitter power of each user is the same. The system parameters that we have considered are the following: the signal bandwidth is 1 MHz, which is divided into 128 subcarriers by OFDM operation, and the data modulation is considered to be QPSK for all subcarriers, where each user data stream contains 256 symbols. In order to make the tones orthogonal to each other, IFFT operation is 128us, the guard interval is set to 22. Quasi-static frequency selective channels and slow fading channels are assumed, we let the multipath channels have 6 taps for each transmit-receive

Fig.2 FER performance comparison of the proposed two-step interference cancellation scheme for various STBC over the quasi-static frequency selective channel

Fig.3 FER performance comparison of the proposed two-step interference cancellation scheme for various STBC over the slow fading frequency selective channel

antenna pair, and the channel fading is assumed to be uncorrelated among different transmitting antennas of different users. We assume the perfect knowledge of the channel state information at the receiver at any time.

Fig.2 and Fig.3 show the frame error rate performance comparison of the proposed two-step interference cancellation scheme for various STBC over the quasi-static frequency selective channel and slow fading frequency selective channel with the maximum Doppler frequency $f_D = 20\text{Hz}$. Moreover, it is observed that the simulation result allow to quantify the performance advantage alliance using full-rate STBC with four transmit antennas in MIMO-OFDM system, especially is QO-STBC. I.e. in fig.2, at $\text{FER} 10^{-3}$, there is near 4dB improvement in the second step inter-fERENCE cancellation scheme. In addition, our scheme can get increase near 6dB improvement compare which is adopted O-STBC system.

6. CONCLUSION

In this paper, we address the design of two-step interference cancellation scheme for a MIMO-OFDM wireless communication system which adopt full-rate STBC in the transmission, where four transmit antennas in each terminal user and two receive antennas in receiver are exploited. The receiver is based on linear MMSE interference suppression in the first step and a two-step interference cancellation approach is also considered. Simulation results show a considerable performance improvement of the proposed full-rate STBC over the two-step interference cancellation methods in both quasi-static and slow fading channel.

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