An Approach to Eliminate Ambiguity of Blind ML Detection for Orthogonal Space-Time Block Codes

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ABSTRACT

In the blind Maximum-likelihood (ML) detection for Orthogonal Space-Time Block Codes (OSTBC), the problem of ambiguity in determining the symbols has been a great concern. A solution to this problem is to apply semi-blind ML detection, *i.e.*, the blind ML decoding with pilot symbols or training sequence. In order to increase the performance, the number of pilot symbols or length of training sequence should be increased. Unfortunately, this leads to a significant decrease in system spectral efficiency. This work presents an approach to resolve the aforementioned issue by introducing a new method for constructing transmitted information symbol. Thus, by transmitting information symbols drawn from different modulation constellation, the ambiguity can be easily eliminated in blind detection. Also, computer simulations are implemented to verify the performance of the proposed approach.

Keywords

Blind ML Detection, Orthogonal Space-Time Block Codes, Identification, MIMO System, Wireless Communication

I. Introduction

RECENTLY Orthogonal Space Time Codes [1]-[3], approaches to exploit diversity gain in Multiple-Input Multiple-Output (MIMO) system, have been a very attractive research topic for enhancing system performance and coping with the requirements of next generation wireless communication systems. With the orthogonal property, the OSTBCs not only provide the full diversity but also allow the simple maximum-likelihood (ML) decoding algorithm when CSI is perfectly known to the receiver. Practically, the CSI can be obtained at the receiver via training signals. In order to achieve a sufficient accuracy, however, a long training period may be required. Consequently, a noticeable reduction in data rate can be observed, especially in fast and relative fast fading channels.

The significant decrease in spectral efficiency resulted from training signal can be minimized by employing the blind and semi-blind detection methods [4]-[6]. Unfortunately, in the blind Maximum-likelihood (ML) detections, the problem of an ambiguity in determining the symbols has been a great concern [4]-[7]. A solution to this problem is to apply the semi-blind ML detection, *i.e.*, the blind ML decoding with pilot symbols or training sequence. In order to increase the performance, however, the number of pilot symbols or the length of training sequence should be increased. This, in turn, leads to a significant decrease in system spectral efficiency.

This work presents an approach to resolve the aforementioned issue by introducing a new method for constructing the transmitted information symbols. The information bits in the same block are differentially mapped into different modulation constellation. Therefore, with the independent sets of transmitted symbols, the ambiguity can be easily eliminated in blind detection.

The remaining part of this paper is organized as follows. The system model is presented in section II. Section III gives the details of the proposed method. The computer simulation result is illustrated in section IV to verify the proposed decoders. Finally, conclusion of our work is given in section V.

II. System Model

Consider a multiple antenna system with n_T transmit and n_R receive antennas, referred to as (n_T, n_R) system. Let $C(s_p)$ be the p^{th} OSTBC codeword that resulted by mapping information symbol vector $s_p = [s_{p,1} s_{p,2} \cdots s_{p,K}]^T$, whose entries are drawn from some complex M-PSK constellation Ω $(M = 2,4,8,\ldots)$, into a code matrix with code length L. Then, an orthogonal space-time code block can be expressed as:

$$C(s_p) = \sum_{k=1}^{K} (A_k Re(s_{p,k}) + jB_k Im(s_{p,k})) \quad (1)$$

where $Re()$ and $Im()$ respectively denote the real and imaginary parts, $j = \sqrt{-1}$. A_k and B_k are $n_T \times L$ real-valued dispersion matrices satisfying the following conditions [6]:

$$\begin{cases} A_k A_k^H = I_{n_T}; B_k B_k^H = I_{n_T} \\ A_k A_n^H = -A_n A_k^H (k \neq n) \\ B_k B_n^H = -B_n B_k^H (k \neq n) \\ A_k B_n^H = B_n A_k^H \end{cases} \quad (2)$$

The OSTBC given in (1) has the following property, so called orthogonal property:

$$C(s_p) C^H(s_p) = \|s_p\|^2 I_{n_T} \quad (3)$$

where $\|.\|^2$ denotes the 2-norm.

The received signal corresponding to the p^{th} transmitted code block, $p = 1,2,\ldots,Q$, is given as:

$$Y_p = HC(s_p) + W_p \quad (4)$$

Where H is the $n_R \times n_T$ channel matrix, W_p is an $n_R \times L$ additive white Gaussian noise (AWGN) matrix with covariance matrix $E\{W_p W_p^H\} = \sigma^2 I_{n_R}$.

In case the CSI is perfectly known at the receiver, the ML detection of s_p is given by:

$$\hat{s} = \arg\min_{s \in \Omega} \| Y - HC(s_p)\|_F^2 \quad (5)$$
$$= \arg\min_{s \in \Omega} \sum_{k=1}^{K} \|s_{p,k} - \widetilde{s_{p,k}}\|^2$$

where the decision statistic of transmitted symbol $s_{p,k}$ is computed as:

$$\widetilde{s_{p,k}} = \frac{Re(Tr(Y^H H A_k)) - jIm(Tr(Y^H HY))}{\|H\|_F^2}$$

(6)

in (6), $Tr()$ denotes the trace operator.

It can be seen that (5) can be decoupled into K terms, where each term depends on exactly one complex symbol. Consequently, the detection of $s_{p,k}$ becomes simply.

$$\widehat{s_{p,k}} = \arg\min_{s \in \Omega} \|s_{p,k} - \widetilde{s_{p,k}}\|^2 \quad (7)$$

In case the CSI is not available at the receiver, the blind ML detector is given by [4]:

$$\hat{s} = \arg\min_{H, s \in \Omega} \sum_{p=1}^{Q} \| Y_p - HC(s_p)\|_F^2 \quad (8)$$

III. Proposed Approach

In this section, we first briefly summarize the cyclic ML for blind detection, which is used as a realization of (8), for complete viewpoint. Let us define:

$$\mathbf{h} = vec(\mathbf{H})$$
$$\mathbf{s}' = \left[\Re\{\mathbf{s}_1\}^T \cdots \Re\{\mathbf{s}_Q\}^T \ \Im\{\mathbf{s}_1\}^T \cdots \Im\{\mathbf{s}_Q\}\right]^T$$
$$\mathbf{F}_p^{(a)} = \left[vec\left(\mathbf{Y}_p \mathbf{A}_1^H\right) \cdots vec\left(\mathbf{Y}_p \mathbf{A}_K^H\right)\right]$$
$$\mathbf{F}_p^{(b)} = \left[-jvec\left(\mathbf{Y}_p \mathbf{B}_1^H\right) \cdots -jvec\left(\mathbf{Y}_p \mathbf{B}_K^H\right)\right]$$
$$\mathbf{F} = \left[\mathbf{F}_1^{(a)} \cdots \mathbf{F}_Q^{(a)} \ \mathbf{F}_1^{(b)} \cdots \mathbf{F}_Q^{(b)}\right]$$

We can re-express (8) as:

$$\hat{s} = \arg\min_{h, s \in \Omega} \|F - hs'\|_F^2 \quad (9)$$

The minimization problem in (9) implies that must be minimized jointly with respect to h and s'. Neglecting the constraint that s' belongs to a finite alphabet, the minimum is achieved when h and s' are respectively equal to lest and right singular vectors of F. Mathematically, we have

$$\tilde{h}\widetilde{s'}^T = \lambda_1 u_1 v_1 \quad (10)$$

where λ_1 is the largest singular value of F , u_1 and v_1 are the associated right and left singular vectors. Based on (10), the initial estimate of h and thus F can be achieved.

From that the blind cyclic ML detector is given as follows:

Initialization Step: Compute an initial estimate of H, i.e., $\hat{H}$, based on (10).

Iterative Step:

1. Use the latest estimate of H in (7) to detect each transmitted symbols. After this step, we obtain $\hat{s}_p$.

2. Using the orthogonal property of OSTBCs in (3), the channel is re-estimated as:

$$\hat{H} = \frac{\sum_{p=1}^{Q} Y_p C(\hat{s}_p)}{\sum_{p=1}^{Q} \|\hat{s}_p\|_2^2}$$

3. Iterate until convergence or until a given number of iteration has been carried out.

In this work we consider the ambiguity in detection of (8) or (9) in case there is no pilot signal. We can see that $\{H, s\}$ is the unique ML solution if and only if we can not find another solution, denoted by $\{\tilde{H}, \tilde{s}\}$, such that:

$$HC(s_p) = \tilde{H}C(\tilde{s}_p)(p = 1, 2, ..., P) \quad (11)$$

One solution with the aid of antenna array is given in [8]. Herein, we see that, if the searching set Ω does not contain any vector s' such that $s' = ks$ for any $k \neq 0$, we can avoid the ambiguity. Thus, we propose a new approach to construct Ω satisfying that there does not exist $s' = ks$ for any $k \neq 0$. The new set of Ω is constructed as follows. For OSTBC for n_T transmit antennas transmitting symbols, the first $(n-1)$ symbols are directly mapped, while the last one is differential mapped based on information bit of $(n-1)$ previous symbol. For the sake of clarity of the explanation, let us assume that we construct transmitted symbol set for OSTBC Alamouti for $(2,2)$ system use BPSK and 8-PSK modulation constellations. Instead of independently mapping two information bits on BPSK, we use three information bits. The first information bit is directly mapped in to BPSK constellation to get symbol s_1, then the information of this bit together with the remaining two information bits are differential mapped into 8-PSK constellation to get symbol s_2, and $s = [s_1 s_2]^T$. Note that, herein, we use differential mapping, not directly mapped. Therefore, it always guarantees that there does not exist $s' = ks$ for any $k \neq 0$.

Ⅳ. Computer Simulations

In this section, we verify performance of the proposed decoder by applying it to $(3,3)$ system with the complex-valued rate $\frac{3}{4}$ OSTBC [9]. The modulation schemes are BPSK and 8-PSK. The first two symbols are resulted from the directly mapping of two information bits, the last one is resulted from differential mapping the first two information bits and the last one. The frame length is set to 48. The channel is assumed to remain constant within each frame, and changes randomly from one frame to the next. The channel gains are randomly generated according to and i.i.d. zero-mean complex Gaussian distribution with variance 0.5 per dimension.

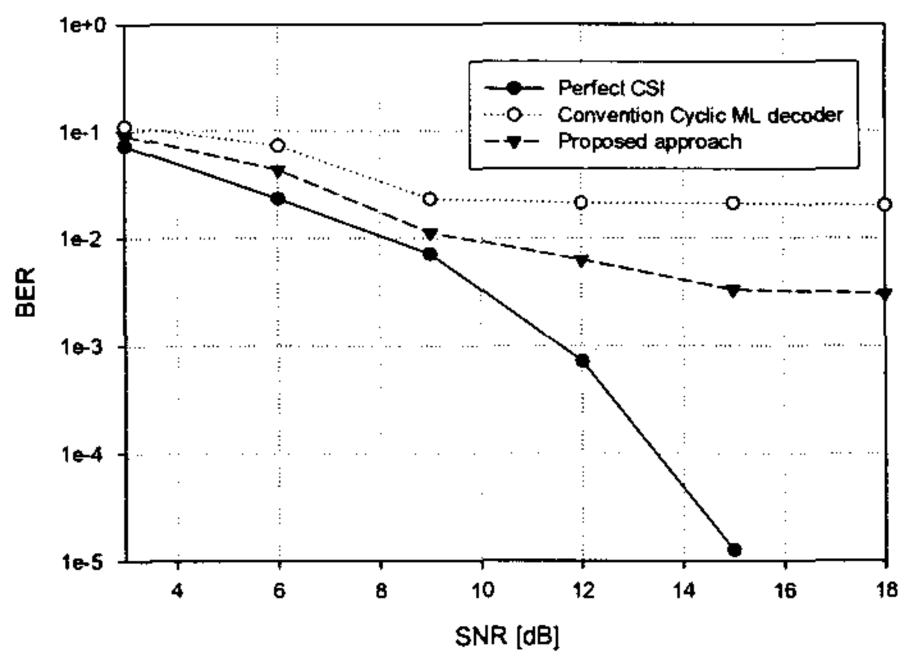

Figure 1. BER performance of the proposed approach with (3,3) system using complex-valued code rate 3/4 OSTBC.

As can be seen from Figure 1, the proposed method although also suffers from irreducible error floor, its BER is much lower than that of conventional cyclic ML decoder.

Ⅴ. Conclusion

In this work, a novel approach for constructing the transmitted symbol sets to avoid ambiguity in blind ML decoding has been presented. We differentially map the input information bits into the different modulation constellations, leading to the separable transmitted symbol sets. Therefore, the pilot signals or training sequence can be reduced or eliminated. Consequently, the reduction of spectral efficiency is lightened.

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