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Generalized Likelihood Ratio Test Algorithm for Joint Channel Estimation and Data Detection for OSTBC MIMO System

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Abstract

In this work, we focus on the diversity techniques using orthogonal space time block coded (OSTBC) for multiple input multiple output (MIMO) setting. We consider the joint channel estimation and data detection (JCEDD) problem using exact Generalized Likelihood Ratio Test (GLRT). Constant and nonconstant modulus constellation can be successfully and blindly detected using our proposed fast algorithm. Our simulation results show that our scheme outperforms lest squared (LS-CEDD) scheme, and that it is simpler to implement.

1. Introduction

The need for more data has led to major advancements in wireless communication over the past decade. By taking advantage of the spatial diversity which afforded by using MIMO systems we can improve the efficiency of wireless communication systems. However, fading, which results in sporadic fluctuations in the received signal, is one of the greatest obstacles in MIMO wireless communications. In most cases, it is unrealistic to expect the receiver to be aware of the instantaneous fading coefficients. However, this presumption (knowing the CSI) fails when the channel changes quickly.

One of major issues which is required in order to ensure reliable communications, receivers are required to track and estimate the wireless communication channel (H), and hence accurately decode the transmitted data. This has led to significant advancements in wireless communication. It is common practice for transmitters to use training symbols sent by receivers to estimate channel state information (CSI). The transmission data rate may be reduced slightly if training symbols are used instead. It is difficult to estimate channel coefficients using training symbols in fast fading environments like mobile communication because the coherent time (T) can be too short to be track. When the channel is fading quickly, it is necessary to use a larger number of pilot symbols and to scarify a larger portion of the transmitted data stream, yet accurately estimate the channel.

Due to its full diversity gain and high transmitted data rates, MIMO communication schemes such as Alamouti's scheme [1] using orthogonal space-time block codes are very useful. Furthermore, it has been demonstrated that in the presence of perfect channel state information (CSI), transmitted diversity models reduce the impact of fast fading and have low-complexity GLRT receivers [2]. However, given the rapidity with which wireless channels evolve, it is not realistic to presume the perfect knowledge of the CSI at the receiver side. As a result, there has been a lot of focus on blindly detection algorithms for OSTBC MIMO systems operating over time-varying wireless channels [3, 4, 5]. differential algorithm, on the other side, does not required for both the transmitted and the receiver to be aware of the channel coefficients or the to use a. It was shown that blindly detection algorithms, however, improve system performance even more than differential modulation does [6, 7].

Existing blindly detection algorithms for OSTBC MIMO do not necessitate perfect knowledge of instantaneous channel coefficients are generally suboptimal. Iterative suboptimal detectors (cyclic detectors) are commonly used in blind OSTBC detectors, but they do not ensure global optimization. When exhaustive search is used, the computational complexity of ML or GLRT JCEDD is extremely high.

Sphere decoders and efficient maximization of rank deficient quadratic forms were both discussed thoroughly in the literature [8, 9, 10, 11] for performing ML non-coherent OSTBC detections for only constant-modulus constellations. The more efficient modules for higher spectral efficiency than constant modules constellation including quadrature amplitude modulation (16-QAM) and other non-constant-modulus constellations are neglected by these paradigms. Cholesky decomposition, an additional preprocessing step required by [8], increases the complexity of the whole detection process.

In this work, we present an innovative GLRT JCEDD algorithm for OSTBC MIMO systems. For OSTBC systems with general constellations, including non-constant-modulus constellations, our algorithm efficiently provides exact GLRT non-coherent detection. When compared to exhaustive search methods, our new algorithm significantly reduces the computational complexity required to achieve optimal detection performance.

2. Problem Formulation

For OSTBC wireless communication systems, we think about the difficulty of jointly estimating the channel and detecting the transmitted data over a block fading channel. For T OSTBC blocks, we'll assume the channel remains unchanged. The received signal for an OSTBC system with N received and M transmit antennas can be expressed as:

$$X = HS^{*} + V \qquad (1)$$

The dimensionality of each of equation 1 variable is as follows: the received signal X and the additive noise matrix is $N \times T$, the channel $H\ is\ N \times M$, the transmitted signal matrix S is $T \times M$, and $(\cdot)^{*}$ refers to conjugate transpose. The elements of the noise matrix are assumed to be i.i.d complex Gaussian random variables with zero mean and variance of σ^2. In an effort to condense the description, we match Alamouti's OSTBC scheme in [1] with two transmit antennas as it shown below. Yet, we highlight that generalization of our approach is possible for any number of transmitted antennas.

$$S^{*} = \underbrace{\begin{matrix} s_{1,1}^{*} & -s_{2,1} & \cdot & \cdot & s_{1,T}^{*} & -s_{2,T} \\ s_{2,1}^{*} & s_{1,1} & \cdot & \cdot & s_{2,T}^{*} & s_{1,T} \end{matrix}}_{T}$$

Where the transmitted input information signal $s_{i,j}$ $(1 \le i \le 2)(1 \le j \le T)$ of the i-th antenna and j-th position in the coherent block T. $\exists$ is the constellation that information signal $s_{i,j}$ were chosen from and hence the cardinality of the OSTBC signal will be $|\exists|^{MT}$. For simplicity we denote each of transmitted block in the transmitted data stream in T as S_j^* and hence the constellation will be Φ and the cardinality of the OSTBC will be $|\Phi|^T$ since $|\Phi| = |\exists|^2$, and we will denote each of the blocks then as $S_1^* = \Phi(1)$, $S_2^* = \Phi(2)$ and so on.

$$S_j^* = \begin{matrix} s_{1,j}^* & -s_{2,j} \\ s_{2,j}^* & s_{1,j} \end{matrix} \qquad (2)$$

For the purposes of this paper, we will assume that the channel matrix H is deterministic and unknown, and that the receiver has no prior knowledge of the channel coefficients for wireless communication. Given that the channel could potentially follow a Gaussian distribution with the i.i.d. variables, and further we assume that the channel is deterministic through a block of coherence time and thus unknown.

RLRT JCEDD in OSTBC MIMO wireless systems can be formulated as the following optimization problem with some manipulation.

$$\min ||X - HS^*||^2 = tr(XX^*) - \max tr((S^*S)^{\Upsilon} S^*X^*XS) \qquad (3)$$

Where the minimization is over both channel $(\widehat{H})$ with aforementioned distribution and transmitted signal which follow some constellation $|\exists|^{MT}$. The estimated channel using MMSE were used $\widehat{H} = (S^*S)^{\Upsilon}S^*X^*)^*$ and $(.)^{\Upsilon}$ is the pseudoinverse. Here T is the coherent time for one block and $tr(.)$ is the trace of a matrix.

As we divided the transmitted signal (S^*) over the coherent time T block as in equation (2), we can write (3) as follows:

$$R_S = \sum_{j=1}^{T} [tr(X_j X^*{}_j) - tr((S_j^* S_j)^{\Upsilon} S_j^* (X_j X_j^*)^* S_j)] \qquad (4)$$

Now we can distribute the summation over the two parts of equation (4). In addition, since the term of the received (X^*) signal is already known, hence we calculate the term $(X_j X^*{}_j = K_j)$ for each index j in advance before calculating the metric R_S for each block j.

$$R_S = \sum_{j=1}^{T} [tr(K_j) - tr((S_j^* S_j)^{\Upsilon} S_j^* K_j{}^* S_j)]$$

$$= \underbrace{\sum_{j=1}^{T} tr(K_j)}_{\widehat{K}} - \sum_{j=1}^{T} tr((S_j^* S_j)^{\Upsilon} S_j^* K_j{}^* S_j)$$

Where $\widehat{\boldsymbol{K}}$ is the calculation of the summation of the $tr(K_j)$ starting from block 1 till the j-th block. Now for any S_j^* and $K_j = (X_j X^*{}_j)$ which is the first j $(1 \le j \le T)$ time block of the transmitted signal (S^*) and the correlation matrix of the received signal K, we are ready to calculate the metric (R_{S_j}) for each block as follows:

$$R_{S_j} = tr(K_j) - tr\left((S_j^* S_j)^{\Upsilon} S_j^* K_j{}^* S_j\right)$$

$$= \widehat{K}_j - tr((S_j^* S_j)^{\Upsilon} S_j^* K_j{}^* S_j) \qquad (5)$$

Now we can use our version of GLRT algorithm for signal detection.

3. Depth-First Search Algorithm

Let's denote the constellation set of M number of antennas as $|\exists|^M$, and number each of its combinations as $1, 2, 3 \ldots \ldots |\exists|^M$. For any index t, $1 \leq t \leq |\exists|^M$, let $\Phi(\mathrm{t})$ is the block constellation set. Also, we can choose the search radius based on [10] for adequate number of transmit antennas and based on [11] for sufficiently large number of antennas.

Input: Predetermined received correlation matrix $\widehat{K}$ and K. Initial radius r, constellation $|\exists|^M$and a $1 \times T$ index vector I. Index t, $1 \leq t \leq |\exists|^M$, starting with $t = 1, r_t \dashrightarrow r$
$\mathrm{I(t)} = 1, \Phi(\mathrm{I(t)}) \dashrightarrow \hat{S}_j^*$

Use $equ.$ (5) to calculate $R_{\hat{S}_t}$, if $R_{\hat{S}_t} > r^2$ go to 3, else go to 4

Find the largest $1 \leq j \leq t$, such that $I(j) < |\Phi(\mathrm{t})|$.
If j exists, set $t = j$ and go to 5; else go to 6.
If $t = T$, save $\hat{S}_T^*$, update $R_{\hat{S}_T} \dashrightarrow r^2$, go to 3
else set $t = t + 1$, go to 1.
$I(t) = I(t) + 1$ and $\Phi(\mathrm{I(t)}) \dashrightarrow \hat{S}_j^*$. Go to 2.
If $\hat{S}_T^*$ exists in 4, then $\hat{S}_T^* \dashrightarrow S_T^*$, where S_j^* is the optimal solution.
Else set $r \dashrightarrow 2r$, $t = 1$, and go to 1

4. Simulation Results

In this section, we run simulations of our GLRT algorithm for OSTBC MIMO systems using BPSK and 16-QAM modulations. We compare the bet error rates (BER) of our GLRT JCEDD algorithm with those obtained using the scheme of iterative Least Square (LS-CEDD) scheme. The data in the channel matrix are treated as complex $i.i.d.$ random variables in the Gaussian distribution. Moreover, in order to resolve the issue of channel phase ambiguity, we presume that the receiver has a perfect knowledge of the first transmitted OSTBC, in other words, $T = 1$. In our simulation, we used Alamouti's OSTBC scheme with two transmitted antennas which can be extended into any number.

For fair comparison, we used the following procedure for LS joint change estimation approach. Throughout the first iteration, the LS estimate the channel elements by getting the advantage of known pilot block. Then, the LS uses the estimated channel to decode the rest (T-2) columns of the transmitted stream. For the iteration two, the LS uses the detected signal of the previous iteration to estimate the channel again and hence uses the estimated channel of the second iteration to detect the transmitted signal, and so on for k number of iterations.

Bit error rate (BER) as a function of signal-to-noise ratio (SNR) for BPSK OSTBC systems with M = 2 transmit antennas and N receive antennas is shown in figure 1 for both our technique and the LS iterative scheme. We used eight space-time blocks in each coherence time interval $T = 16$, of which there is always at least one pilot block that is known to the receiver. Thus, there are 14 bits of data being transmitted for every channel coherence interval T.

The complexity of our technique is substantially smaller than that of the exhaustive search blind detection algorithm, which investigates 2^{14} hypotheses for each channel coherence interval, and yet it gets the same exact error performance. Comparing our proposed method to an iterative (LS-CEDD) method, we find that ours provides markedly improved performance. Our GLRT approach obviously outperforms the iterative scheme in terms of SNR as N grows. For instance, our combine algorithm improves upon the iterative scheme by roughly 2 dB at BER= 10^{-6} when N = 6. For N = 4, the gain is around 1.5 dB at the same BER.

Our precise GLRT non-coherent detection approach for 16- QAM modulation is shown in Figure 2 to outperform the iterative LS-CEDD scheme in terms of symbol error rate (SER). The iterative LS performance is depicted by the dotted lines, while the solid lines indicate the GLRT's results. For simplicity, we will suppose that there are 7 OSTBC blocks in each channel coherence interval, with one of those blocks reserved for the pilot symbol. That's 48 $(2 * 4 * 6)$ bits of data sent in a single channel coherence interval, where N is chosen to be 4, and 6 respectively.

Obtaining this value by exhaustive search is nearly impossible due to the fact that there are 2^{48} hypotheses to test in comparison with $2*10^{14}$ hypotheses in our approach for each channel coherence interval. When comparing combined GLRT OSTBC to the iterative LS channel estimation approach, there is a gain of around 3.5 dB when SER= 10^{4}. Compared to LS-CEDD, this demonstrates the GLRT algorithm's superior performance.

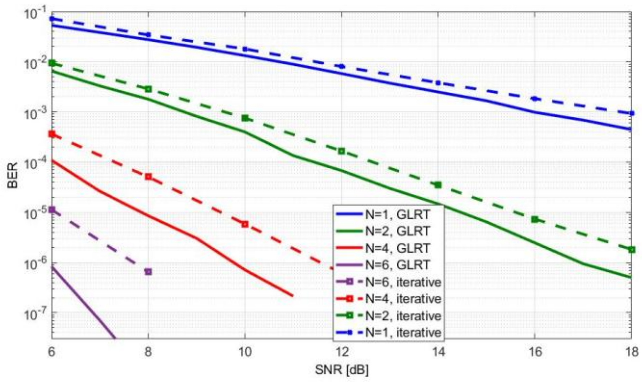

Fig 1. Optimal GLRT JCEDD BER over SNR for BPSK OSTBC MIMO Systems with M = 2 and T = 8.

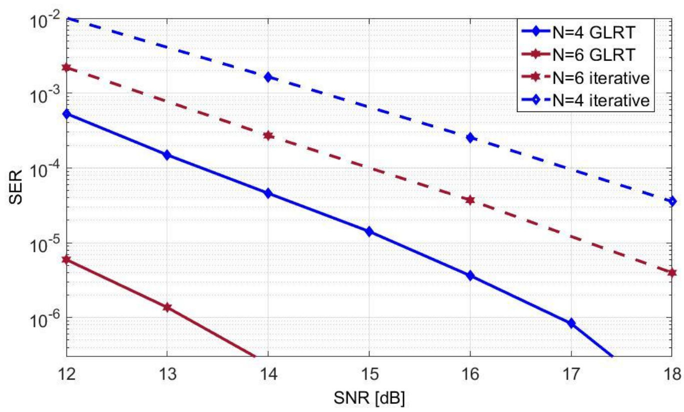

Fig 2. Optimal GLRT JCEDD BER over SNR for 16-QAM OSTBC MIMO Systems with $M = 2$ and $T = 7$.

5. Conclusion

In this research, we focus on the challenge of estimating OSTBC MIMO systems' channel characteristics and detecting their data simultaneously. Our innovative optimal GLRT approach is applicable to a wide variety of scenarios including non-constant modules. The simulation results show a dramatic increase in the efficiency of data detection compared to existing iterative algorithms.

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