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A simple low-complexity algorithm for generalized spatial modulation

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ABSTRACT

Generalized spatial modulation (GSM) is an extension of spatial modulation which is significant for the next generation communication systems. Optimal detection process for the GSM is the maximum-likelihood (ML) detection which jointly detects the antenna combinations and transmitted symbols. However, the receiver is much more complicated than SM due to inter-antenna interference and/or increased number of combinations. Therefore, the computational complexity of the ML detection grows with the number of transmit antennas and the signal constellation size. In this letter, we introduce a novel and simple detection algorithm which uses sub-optimal method based on the least squares solution to detect likely antenna combinations. Once the antenna indices are detected, ML detection is utilized to identify the transmitted symbols. For obtaining near-ML performance while keeping lower complexity than ML detection, sphere decoding is applied. Our proposed algorithm reduces the search complexity while achieving a near optimum solution. Computer simulation results show that the proposed algorithm performs close to the optimal (ML) detection resulting in a significant reduction of computational complexity.

1. Introduction

Spatial modulation (SM) [1] is a newly arisen method for multiple-input multiple-output (MIMO) transmission techniques where the information is transmitted via the classical PSK/QAM symbols and the active antenna indices [2]. In the SM scheme, only a single transmit antenna is activated during the transmission. Since the SM symbols are conveyed by only one transmit antenna, one radio frequency chain is used at the transmitter and inter-channel interference (ICI) is removed. On the other hand, transmission rate is limited due to the use of single antenna.

Generalized spatial modulation (GSM) mitigates this problem by activating more than one transmit antenna [3,4]. In GSM, information is both transmitted with the combination of transmit antennas and PSK/QAM symbols. Hence the transmission rate is increased with the use of multiple active transmit antennas.

This advantage comes at a price. The GSM receiver is much more complicated than the SM scheme since the inter-antenna interference arises during the transmission. The optimum performance can be achieved with the maximum likelihood (ML) signal detection but computational complexity increases with exhaustive search.

Previous works in the literature investigate this problem in order to find low-complexity detectors with near-ML performance. In [4], a maximal ratio combining (MRC) algorithm is introduced to detect the active antenna indices. After determining the antennas, PSK/QAM symbols are estimated. In [5], a decorrelator based detection algorithm is presented. Although it reduces the receiver complexity, bit error rate (BER) performance is much higher than the ML detection. In [6], an ordered block minimum mean square error (OB-MMSE) detector which is based on a block MMSE processing method is proposed. In [7], this OB-MMSE detector is improved using concentrated ML algorithm to avoid redundant computations. In [8], Gaussian approximation and QR projection is used to detect the antenna subset index. After detecting the antenna subset index, classical ML detector is used to identify the transmitted symbol. The advantage of Bayesian compressive sensing, which uses the inherent sparsity of GSM signals, is investigated in [9]. This algorithm, which is called enhanced Bayesian compressive sensing (EBCS), includes two stages where in the first stage, the active antenna indices are estimated with the help of hyper-parameter vector and the BCS algorithm reconstructs the transmitted signal. In the second stage, re-estimation is designed to check and correct the errors from the first stage. Block Diagonalization and GSM is combined in a downlink multiuser MIMO scenario in [10]. In [11], two low-complexity detection algorithms using sequential Monte Carlo technique are presented. Additionally, in order to search low complexity algorithms, sphere decoding (SD)

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algorithms are investigated in [12–14]. Moreover, complexity of SD for GSM is improved in [15] using tree search SD and path search SD algorithms. In [16], fixed-complexity SD for soft detection of GSM is proposed. On the other hand, low-complexity adaptive spatial modulation (ASM) scheme based on sphere search is introduced in [17]. In ASM, since each error vector includes up to two nonzero elements, the search process for error vectors obey the symbol detection rule in GSM. Based on this rule, sphere search process is applied to ASM which is similar to that of SD receiver for GSM.

In this letter, we propose a new and simple detection algorithm which reduces the computational complexity of GSM. The algorithm can be split into two stages: in the first stage, least squares (LS) estimate of the transmitted signal is used to find the optimum solution candidates of the antenna combinations. The N best estimate of antenna combinations are selected in order to reduce the search space. In the second stage, this reduced set and the LS estimates of transmitted symbols based on this set are then sent to the optimal ML detector to find the correct antenna combinations and PSK/QAM symbols. To obtain a near-ML performance but for less complexity, PSK/QAM symbols set is reduced using SD. It is shown that the proposed algorithm obtains near-ML performance with a significant computational complexity reduction.

The rest of the letter is organised as follows. In Section 2, the system model is given. In Section 3, the proposed novel and simple detection algorithm is introduced. Computer simulation results are presented in Section 4. Finally, Section 5 concludes this letter.

2. System model

Let us consider a MIMO system where the number of transmit antennas is N_t and the number of receive antennas is N_r. MIMO channel matrix composed of channel fading coefficients can be given as $\mathbf{H} \in \mathbb{C}^{N_r \times N_t}$. Each element of the above matrix is modeled as an independent and identically distributed complex Gaussian random variable with $\mathcal{CN}(0, \sigma_h^2)$ and the channel obeys the Rayleigh flat fading model.

In GSM, $m_a = \lfloor \log_2 \binom{N_t}{N_{act}} \rfloor$ bits are mapped to the index of antenna combinations where N_{act} is the number of activated transmit antennas, $\binom{\cdot}{\cdot}$ is the binomial coefficient and $\lfloor . \rfloor$ is the floor operation. Additionally, $m_s = N_{act} \log_2(M)$ bits are mapped to the PSK/QAM symbols, $s_l, l = 1, \ldots, M$ where M is the constellation size, and hence totally $m = m_a + m_s$ bits are allocated for a GSM symbol. Since the antenna combinations must be an order of two, any $N_c = 2^{m_a}$ combinations can be used for the transmission. For instance, there are $\binom{5}{2} = 10$ antenna combinations for $N_t = 5$ and $N_{act} = 2$, but only $N_c = 8$ antenna combinations can be used (any 8 out of 10 can be selected). Let the total information bits be $m = 7$. First three bits are mapped to antenna combinations, i.e., first and third antennas, and remaining four bits are mapped to two 4-PSK/QAM symbols to construct the GSM transmitted symbol as

$$\mathbf{x} = [s_1 \quad 0 \quad s_2 \quad 0 \quad 0]^T \tag{1}$$

where T is the transpose operation.

The received signal can be written as

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n} \tag{2}$$

where $\mathbf{n} \in \mathbb{C}^{N_r \times 1}$ is the additive white Gaussian noise (AWGN) vector whose entries are modeled as $\mathcal{CN}(0, N_0)$ with noise spectral density $N_0/2$ per dimension.

The detector at the receiver, which has the ideal channel state information, detects the GSM symbol applying the ML decision rule as

$$\hat{\mathbf{x}} = \arg \min_{\mathbf{x} \in \mathbb{S}} \|\mathbf{y} - \mathbf{H}\mathbf{x}\|^2 \tag{3}$$

where $\mathbb{S}$ is the set of all possible antenna combinations and PSK/QAM symbols, and $\|.\|$ represents the Euclidean norm.

3. New simple detection algorithms

ML detection in (3) can be rewritten in another form as

$$\left[\hat{i}, \hat{\mathbf{s}}\right] = \arg \min_{i,\mathbf{s}} \|\mathbf{y} - \mathbf{H}_i \mathbf{s}\|^2 \tag{4}$$

where $\mathbf{s} = [s_1, s_2, \ldots, s_{N_{act}}]^T$ is the transmitted symbol vector, i is the index of antenna combinations set where $i \in 1, 2, \ldots, N_c$. $\mathbf{H}_i$ is composed of active antenna columns of $\mathbf{H}$. (4) has an excessive computational complexity that grows exponentially with the number of transmit antennas. One of the low complexity solution is the sub-optimal solution which is also called Zero Forcing (ZF) solution. This sub-optimal solution is based on the Least Squares solution of the ML detection,

$$\mathbf{s}_i^{LS} = \left(\mathbf{H}_i^H \mathbf{H}_i\right)^{-1} \mathbf{H}_i^H \mathbf{y} \tag{5}$$

where $(.)^H$ is the Hermitian operation. We have to emphasize that this solution is conditioned to the correct information about i.

In this letter, we propose a new and simple reduced complexity detection algorithm based on the LS solution in (5).

3.1. Low complexity detection algorithm

By adding and substracting the LS solution, $\mathbf{s}_i^{LS}$, from $\mathbf{s}$ in (4) and considering the fact that the error $\mathbf{y} - \mathbf{H}_i \mathbf{s}_i^{LS}$ is in the null space of $\mathbf{H}_i$, one can obtain another version of the cost function in (4) as

$$\left[\hat{i}, \hat{\mathbf{s}}\right] = \arg \min_{i,\mathbf{s}} \left\{ \|\mathbf{y} - \mathbf{H}_i \mathbf{s}_i^{LS}\|^2 + (\mathbf{s}_i^{LS} - \mathbf{s})^H \mathbf{H}_i^H \mathbf{H}_i (\mathbf{s}_i^{LS} - \mathbf{s}) \right\}. \tag{6}$$

Assuming that the LS solution would be close to the true solution, the last term in (6) can be ignored which leads to the reduced cost function

$$\left[\hat{i}, \hat{\mathbf{s}}\right] = \arg \min_{i} \|\mathbf{y} - \mathbf{H}_i \mathbf{s}_i^{LS}\|^2 \tag{7}$$

which only depends on i. After some algebra over the reduced cost function in (7), the minimization problem can be re-expressed as

$$\hat{i} = \arg \max_{i} \left\{ \mathbf{y}^H \mathbf{H}_i \left(\mathbf{H}_i^H \mathbf{H}_i\right)^{-1} \mathbf{H}_i^H \mathbf{y} \right\}. \tag{8}$$

PSK/QAM symbols are then solved with the quantization (slicing) operation which quantizes the detected sample to the nearest ideal constellation point, after the detection of the active antennas, $\hat{\mathbf{s}} = Q\left\{\mathbf{s}_{\hat{i}}^{LS}\right\}$.

In [4], detected antenna combinations are found similar to (8) where only a single result which is the maximum of (8) is selected. The ML detection, on the other hand, searches not only the maximum value but also all possible outputs which are as many as 2^{m_a} in addition to PSK/QAM symbol constellation points. Hence, the complexity grows with the number of transmit antennas and high modulation orders.

One possible way to diminish the ML complexity is reducing the number of combinations to be tested. Accordingly, we take the N best estimate of (8) to find the optimum i