A New Decoding Algorithm in MIMO-ZP-OFDM Systems

Rui Kang, ChaoXiong Xu, HaoChen, and HongBo Xu

Department of Electronics and Information, Huazhong Normal University,
Wuhan 430079,China

Abstract. In order to adapt for a high-rate transmission and improve the performance of operation, in this paper, a new low complex sphere decoding (SD) algorithm is proposed in the MIMO-ZP-OFDM systems. It is an approximate optimization algorithm and can be used in the space-time coding and uncoded multiple-antenna systems. ML sequence detection compared with SD algorithm the latter can reduce the complex and keep the performance of systems, especial for high-rate transmission operation and the occasion of transmit antenna beyond receive antenna. Simulation results show that the efficiency and superiority of this algorithm.

Keywords: OFDM, MIMO, sphere decoding, ZP.

1 Introduction

In recent years, "wireless and wideband" have become a hot topic of research in wireless communication. The MIMO-OFDM technique greatly improves the peak margin of noise, interference, and multipath by applying array antennas to the realization of space diversity in the transmission system. However, the optimal maximum likelihood (ML) detection incurs prohibitively high complexity and is not suitable for practical implementation, suboptimal detection algorithms are usually employed. A lot of efforts have been put into the search for algorithms achieving ML or near-ML performance with lower complexity. Recently, a new algorithm, sphere decoding, has been proposed to be applied to multiple-antenna system the sphere decoding algorithm thought was firstly proposed in 1981 as a method of find the shortest vector for lattice [1]. In 1993, E. Viterbo and J.Bountros first applied this method to communication problem in an essay on trellis decoding[2]. Sphere decoding was an algorithm that speeds up ML algorithm by limiting the region of search. It[3]-[5] can achieve an exact maximum likelihood (ML) performance with a moderate complexity by confining the search space inside a hypersphere with a given radius, centered at the received signal vector. Sphere decoding was originally designed for lattice decoding, and lately it has been shown to be applicable to space-time coded MIMO systems, resulting in lower decoding complexity. The sphere decoding algorithm was introduced in [6] assuming a single-antenna, real-valued fading channel model. Later results [7-8] generalized the algorithm to complex valued MIMO channels. A reduced complexity algorithm was proposed in [9], where the signal coordinates were sorted according to their partial metrics and explored in this order. In [10], the sphere decoding algorithm was applied to equalize frequency selective MIMO

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channels. All of these works considered uncoded MIMO systems and assumed quasi-static, flat fading channels. At present, sphere decoding has been widely applied to MIMO-OFDM system as well as the MIMO system[11], but mainly on the condition that the transmit antenna and the receive antenna are the same , or the receive antenna is greater than the transmit antenna[12]. Based on this, this paper proposes adopting an improved thought of sphere decoding which effectively induces the complicity of decoding and fits the condition that transmit antenna is greater than receive antenna.

In this work, the rest of this paper is organized as follows. Section II is devoted to the introduction of MIMO-ZP-OFDM system model; section III briefly explains sphere decoding, its improved arithmetic and its application in this model; section IV presents the simulation result while sections V gives the conclusion.

2 System Model

In this MIMO-ZP-OFDM system , the system adopts M_T transmit antennas and M_R receive antennas ($M_T \geq M_R$).The data stream, after constellation mapping, is divided into M_T subchannel, and is turned into OFDM through IFFT operation before being added zero-postfix (ZP) and transmit by their corresponding antenna. Zero-padded OFDM (ZP-OFDM), which prepends each OFDM symbol with zeros rather than replicating the last few samples, has been proposed. The reason that ZP is adopted here is that it is Toeplitz matrix which ensures the reversibility of matrix, and can at the same time ensure the performance of the system as the diagonal matrix of channel transmit function being zero values. On the contrary, if the CP is adopted, when the diagonal matrix of channel transmit function being zero values, thus the performance of the system will decrease. The antennas of transmit get the frequency signal through FFT after ZP is got rid of, then the channel parameter got through channel estimation makes MIMO detection in order to get the information data of the original antenna, and finally restored the original signal through the improved sphere decoding.

We assume that there are L multipath channels and each of channel time delay is l, for $l = 0,1,\cdots,L-1$, τ_l denotes l th delay time. Each OFDM block includes N subchannel and the length of the zero-postfix is greater than the delay spread to eliminate the effect of the ISI. Duration of each OFDM block, the channel characteristic is assumed invariable, and the system is synchronous.

Then the received signal can be written as

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n}$$
$$\mathbf{H}_{M_T,M_R}(f) = \sum_{l=0}^{L-1} h_{M_T,M_R}(l) e^{-j2\pi f \tau_l} \tag{1}$$

For transmitted symbols $\mathbf{x}=[x_1,x_2,\cdots x_{M_T}]^T$ ($[\cdot]^T$ denotes the transpose of a matrix or vector) where $x_i \in I_q^{M_T}$ denotes the transmitted signal vector whose elements are chosen from q-PAM constellation given by Iq={odd integer j|-q+1⩽j⩽q−1}; $\mathbf{H}$ is an $M_R \times M_T$ matrix; for received signal $\mathbf{y} = (y_1, y_2, \cdots y_{M_T})^T$,where y_j is denotes jth signal; $\mathbf{n}$ is the additive white Gaussian noise (AWGN) matrix, with zero mean and variance σ^2. In this paper, we assumed that antenna is independent. The received signal can be written as

$$\begin{bmatrix} \Re(\mathbf{y}) \\ \Im(\mathbf{y}) \end{bmatrix} = \begin{bmatrix} \Re(\mathbf{H}) & \Im(\mathbf{H}) \\ -\Im(\mathbf{H}) & \Re(\mathbf{H}) \end{bmatrix} \cdot \begin{bmatrix} \Re(\mathbf{x}) \\ \Im(\mathbf{x}) \end{bmatrix} + \begin{bmatrix} \Re(\mathbf{n}) \\ \Im(\mathbf{n}) \end{bmatrix} \tag{2}$$

where $\Re(\cdot)$ is the real part, and $\Im(\cdot)$ is the imaginary part of a complex number. $\hat{\mathbf{y}} = [\Re(\mathbf{y})\Im(\mathbf{y})]^T$ is the $2M_R \times 1$ real-valued received signal vector; $\hat{\mathbf{x}} = [\Re(\mathbf{x})\Im(\mathbf{x})]^T$ is the $2M_T \times 1$ real-valued transmit symbol vector ; and $\hat{\mathbf{n}} = [\Re(\mathbf{n})\Im(\mathbf{n})]^T$ is the $2M_R \times 1$ real-valued noise vector, also

$$\hat{\mathbf{H}} = \begin{bmatrix} \Re(\mathbf{H}) & \Im(\mathbf{H}) \\ -\Im(\mathbf{H}) & \Re(\mathbf{H}) \end{bmatrix}$$

3 Sphere Decoding and Improved Algorithm

The idea of SD is to perform minimization on the same metric, but the search is restricted to the points found within the sphere of radius centered around the received signal. That is to say SD algorithm instead of searching all possible vectors for finding **x** in the optimization problem, sphere decoders search over a hyper-sphere of radius R centered on the received signal vector to find an appropriate solution. In other words, we look for vectors **x** which satisfies $\|\mathbf{y} - \mathbf{Hx}\|^2 \le R^2$. Any time a point is actually found in the sphere, the radius of the search sphere is lowered to the distance of this point to the center. The algorithm is continued until no point is found inside the search sphere. In this paper, we take example for 4-PAM, The principle of SD algorithm is presented in Fig 1.

This paper is based on the fundamental algorithms and signal decoders in MIMO system[13] in the complex low complexly SRRC(Smart Radius Reduction Control) algorithm that propose a new method applicable to the condition that transmit antenna is greater than receive antenna.

Assuming the initialize radius is r, $\hat{\mathbf{x}}$ must satisfy the following inequality as

$$r^2 \ge \|\hat{\mathbf{y}} - \hat{\mathbf{H}}\hat{\mathbf{x}}\|^2 \qquad \hat{\mathbf{H}} = \mathbf{QR} \tag{3}$$

Here, **R** and **Q** are the $2M_T \times 2M_T$ upper triangular matrix and the $2M_R \times 2M_T$ unitary matrix, respectively, obtained by the Q-R factorization of the real-valued channel matrix $\hat{\mathbf{H}}$.

Using $\hat{\mathbf{H}} = \mathbf{QR}$, (3)can be rewritten as

$$r^2 \ge \|\mathbf{Q}^T \cdot \hat{\mathbf{y}} - \mathbf{R} \cdot \hat{\mathbf{x}}\|^2 = \|\mathbf{Q}_1^T \cdot \hat{\mathbf{y}} - \mathbf{R} \cdot \hat{\mathbf{x}}\|^2 + \|\mathbf{Q}_2^T \hat{\mathbf{y}}\|$$

And $\tilde{\mathbf{y}} = \mathbf{Q}^T \cdot \hat{\mathbf{y}}$, the matrices $\mathbf{Q}_1$and $\mathbf{Q}_2$ represent the first $2M_T$ an last $2M_R$-$2M_T$ orthogonal columns of **Q**, then we obtain

$$\|\mathbf{Q}_2^T \hat{\mathbf{y}}\| \le \|\tilde{\mathbf{y}} - \mathbf{R} \cdot \hat{\mathbf{x}}\|^2 \le r^2 \Rightarrow r^2 - \|\mathbf{Q}_2^T \hat{\mathbf{y}}\| \ge \sum_{j=1}^{2M_R} \left| \tilde{y}_j - \sum_{i=j}^{2M_T} r_{j,i} \hat{x}_i \right|^2$$

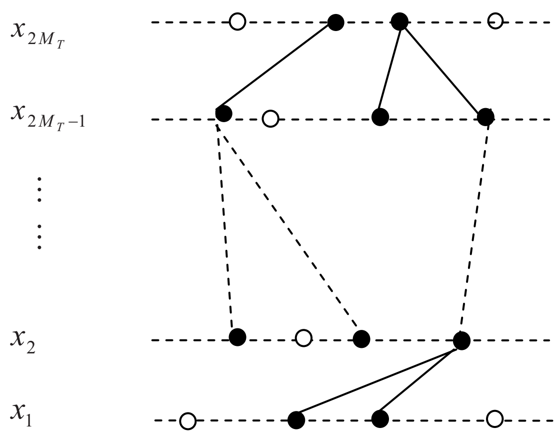

Fig. 1. Example tree formed by sphere decoder

The radius can be reduced by ZF-DFE estimated gradually and simplified calculation purposes.

The new idea of SD[13] proposed a further simplified, in this paper, this method is applied to MIMO-ZP-OFDM systems, and according to [14] made this method improvements. For simplicity, we first consider the 2-PAM constellation where the elements of x take the values from {±1}. Firstly, we partition $\tilde{y}_j - \sum_{i=j}^{2M_T} r_{j,i}\hat{x}_i$ into two subsets $\tilde{y}_j - \sum_{i=j}^{2M_T} r_{j,i}\hat{x}_i \geq 0$ and $\tilde{y}_j - \sum_{i=j}^{2M_T} r_{j,i}\hat{x}_i < 0$ according to their signs, then assumed $e_0^0 = [\tilde{y} - r\hat{x}]$, $e_f^{(i)} = e_0^{(i-1)} + r_i\hat{x}_i$ $(i \in [1, 2M_T])$and solved above two kind of situations, separately. For *i*th detection we intend to find the smallest value $e_r^{(i)}$, making formula to meet $(\tilde{x}_i^v, r^v) = (\arg\min_{x_i^v \in I_q^{(i)}} \|e_r^{(i)}\|_{\tilde{x}_i^v = \tilde{x}_i^v})$, where $e_r^{(i)} = e_0^{(i-1)} + r_i(\hat{x}_i - \tilde{x}_i^v)$. If $r^v < r$, the current initial radius and the current estimate are updated by the new radius and the corresponding estimate, and $e_0^{(i)} = e_0^{(i-1)} + r_i(\hat{x}_i - \tilde{x}_i^v)$.

From the above, we can see that this improvement in the SD algorithm and the original SD methods of further simplifying the iterative steps, which improves the speed of operation that is more applicable to high-speed data transmission system.

4 Simulation Results

In our section, we present our simulation results for both the ML algorithms and for SD algorithms in the MIMO-ZP-OFDM systems. The simulated system has N=128 subcarriers occupying 20MHz bandwidth and all the 64 subcarriers are used for data transmission. we consider a channel of length $l = 6$ and 4-QAM modulations and deal with using 2 transmit and 1 receive antennas and using 4 transmit and 2 receive

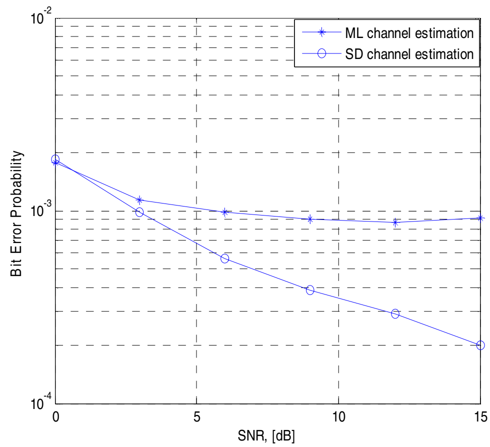

Fig. 2. Comparisons of BER performance according to the different method

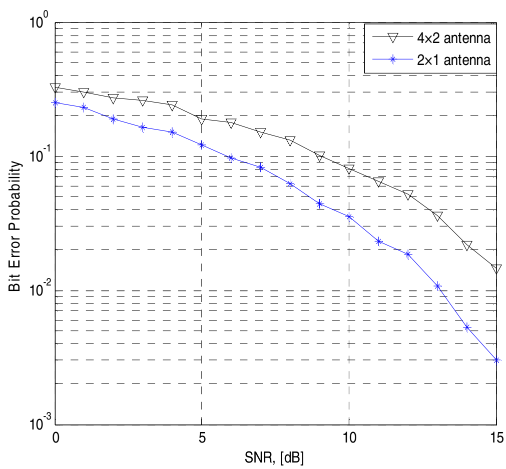

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Fig. 3. Comparisons of BER performance according to the different values of antennas

antennas, respectively, the spatial domain channel **H** are assumed to be identically and independently distributed with zero mean and variance σ^2.

In Fig.2 the analytical and simulated BER results of the proposed ML algorithms and SD algorithms, respectively. According to the simulation results can be seen using this improved SD algorithm is superior to ML algorithm to the performance of systems.

In Fig. 3 shows the performance of this system with the different transmit antennas and receive antennas. Through simulation, we can see this improved algorithm applied to the transmitter antennas more than receiving antenna, but for the larger of transmit and the receiver antenna, the performance of system will be affected.

5 Conclusions

This paper proposes a new decoding method to be applied to the MIMO-ZP-OFDM system. This method is an expansion of SD algorithm in multiple-antenna system. It is applicable not only to the condition that the transmit antenna is greater than receive antenna, but also vice versa. The simulation result shows that it has the property of high speed and low complicity, thus is more applicable to the high speed data transmission system.

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