An Improved Low Complexity MIMO-OFDM Detection Algorithm

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Abstract. In this paper, V candidate symbols are considered at the first layer, then V probable streams are detected with complex LLL because of the complexity. Finally, the most probable stream is selected through a ML test. By using complex LLL, the proposed scheme can achieve more low complexity than QRD-M. Simulation results show that the proposed scheme provides similar performance as the QRD-M.

Keywords: MIMO-OFDM, V-BLAST, Lattice reduction aided detection

1 Introduction

The vertical Bell Laboratories layered space time (V-BLAST) [1] is an effective Multiple Input Multiple Output (MIMO) - Orthogonal Frequency Division Multiplexing (OFDM) architecture to provide spatial multiplexing and receiver diversity gain [2]. The Maximum Likelihood Detection (MLD) has been proved to achieve the optimal performance though it exponentially grows complexity by the number of transmit antennas and constellation level. To reduce the MLD complexity, the QR-decomposition M algorithm (QRD-M) scheme is proposed [3]. Although the QRD-M detection reduces the complexity and achieves near ML detection performance, the detection complexity of this scheme is still highly increased. The Lattice-Reduction-aided Detection (LRD) schemes [4] have been proposed to enhance the performance without too much complexity increase for MIMO system. LRD scheme considerably improves the performance of the zero forcing (ZF), but it still does not approach the optimal performance.

In this paper, we propose an efficient detection scheme for more accurate detection of transmitted data. In addition, if the first layer selects the suitable V value for requiring system, complexity can be further reduced.

2 System Description

We consider MIMO-OFDM system with N_T transmit antennas and N_R receive antennas. The OFDM symbol of m-th transmit antenna is represented as $\mathbf{X}_m =$

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$[X_m^{(0)}, X_m^{(1)} \ldots, X_m^{(K-1)}]$, where K denotes the number of subcarriers. After a data stream is divided into N_T substreams, OFDM symbols are transmitted over N_T transmit antennas simultaneously. The received signal model on the k-th subcarrier can be written as

$$\mathbf{Y}^{(k)} = \sum_{j=1}^{N_T} \mathbf{H}_j^{(k)} \cdot X_j^{(k)} + \mathbf{N}^{(k)} = \mathbf{H}^{(k)} \cdot \mathbf{X}^{(k)} + \mathbf{N}^{(k)}, \tag{1}$$

where j and i are transmit and receive antenna index respectively, $\mathbf{X}^{(k)} = [X_1^{(k)}, X_2^{(k)} \ldots, X_{N_T}^{(k)}]^T$ denotes the $N_T \times 1$ transmit symbol vector, $\mathbf{Y}^{(k)} = [Y_1^{(k)}, Y_2^{(k)}, \ldots, Y_{N_R}^{(k)}]^T$ is the $N_R \times 1$ receive symbol vector and $\mathbf{N}^{(k)} = [N_1^{(k)}, N_2^{(k)}, \ldots, N_{N_R}^{(k)}]^T$ denotes the $N_R \times 1$ complex Gaussian additive noise vector with variance σ_n^2. Finally, $\mathbf{H}$ is an $N_R \times N_T$ independent and identically distributed (i.i.d) random complex matrix of multipath channel.

3 Proposed Detection Scheme

In this section, we propose the improved performance detection scheme for MIMO-OFDM system. The basic idea is that V probable symbols are detected at the first layer, and then rest layer is detected with Complex LLL(CLLL). The CLLL can reduce the complexity about 50% compared with the conventional LLL [5]. Afterward, among the decoded substreams, the most probable stream is selected by ML test. The whole algorithm steps are described as follows

Step 1: The channel matrix is performed by QR decomposition, $\mathbf{H} = \mathbf{QR}$, where $\mathbf{R}$ is an upper triangular matrix and $\mathbf{Q}$ is an orthonormal matrix satisfied with $\mathbf{Q}^H\mathbf{Q} = \mathbf{I}$. By multiplying $\mathbf{Q}^H$, the $N \times 1$ output vector can be expressed as

$$\mathbf{Z} = \mathbf{Q^H Y} = \mathbf{Q^H H X} + \mathbf{Q^H N} = \mathbf{RX} + \tilde{\mathbf{N}}, \tag{2}$$

$$\begin{bmatrix} z_1 \\ z_2 \\ \vdots \\ z_N \end{bmatrix} = \begin{bmatrix} r_{1,1} & r_{1,2} \cdots & r_{1,N} \\ 0 & r_{2,2} \cdots & r_{2,N} \\ \vdots & \vdots \quad \ddots & \vdots \\ 0 & 0 \quad \cdots & r_{N,N} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix} + \begin{bmatrix} \tilde{n}_1 \\ \tilde{n}_2 \\ \vdots \\ \tilde{n}_N \end{bmatrix}. \tag{3}$$

Step 2: The first layer calculates metric values for the first symbol as $\|z_N - r_{N,N} \times \widehat{x}_{candi}\|^2$, where $\widehat{x}_{candi}$ denotes all possible constellation symbol and metric value is saved in memory. Therefore, C times metric calculations are performed, where C is constellation size. Then, metric values are ordered from the lowest to the largest value and only the number of $V(V \in C)$ symbols, which have the smallest metric values, is retained as $\widehat{\mathbf{X}}_{candi} = [x_1^{(1)}, \cdots x_1^{(v)}, \cdots x_1^{(V)}]$ [6].

Table 1. CLLL algorithm procedure.

Algorithm : CLLL Reduction Algorithm

```
Input : H, δ ∈ ((1/2),1]
Output : Q̃, R̃, U
[Q̃, R̃] = QR Decomposition(H)
m = size(H, 2)
U = I_m
k = 2
while (k ≤ m)
    for n = k−1 : −1 : 1
        μ = round(R̃(n,k) / R̃(n,n))
        if μ ≠ 0
            R̃(1:n,k) = R̃(1:n,k) − μR̃(1:n,n)
            U(:,k) = U(:,k) − μU(:,n)
        end
    end
    if δ|R̃(k−1,k−1)|^2 > |R̃(k,k)|^2 + |R̃(k−1,k)|^2
        R̃(:,k−1:k) = R̃(:,k:k−1)
        U(:,k−1:k) = U(:,k:k−1)
        α = R̃(k−1,k−1) / ||R̃(k−1:k,k−1)||, β = R̃(k,k−1) / ||R̃(k−1:k,k−1)||, Θ = [α* β; −β α]
        R̃(k−1:k,k−1:m) = ΘR̃(k−1:k,k−1:m)
        Q̃(:,k−1:k) = Q̃(:,k−1:k)Θ^H
        k = max(k−1,2)
    else
        k = k+1
    end
end
```

Step 3: Before V probable streams are detected with CLLL, it revises Eq.(3) as follows

$$\widehat{z}_k = z_k - r_{N,N} \times x_N \,(1 \leq k \leq M), \quad (4)$$

where M is $N - 1$. To detect rest symbols, the CLLL executes V times. The CLLL algorithm is shown in Table 1. V stream is $\widehat{\mathbf{x}} = [\widehat{\mathbf{x}}_k^{(1)}, \cdots, \widehat{\mathbf{x}}_k^{(v)}, \ldots \widehat{\mathbf{x}}_k^{(V)}]$.

Step 4: We perform the likelihood test using V stream. The likelihood test can be expressed as minimum Euclidean distance. Thus, we estimate transmitted symbols as following method

$$\widehat{\mathbf{X}}_{final} = \underset{\widehat{\mathbf{x}}^{(v)} \in \widehat{\mathbf{x}}}{\arg\min} \left\| \mathbf{Y} - \mathbf{H}\widehat{\mathbf{X}}^{(v)} \right\|. \quad (5)$$

4 Simulation Results

In this section, the proposed detection scheme is evaluated in terms of BER. It is assumed that the channel is frequency flat fading during one OFDM symbol period. Moreover, it is supposed that the channel state information (CSI) is

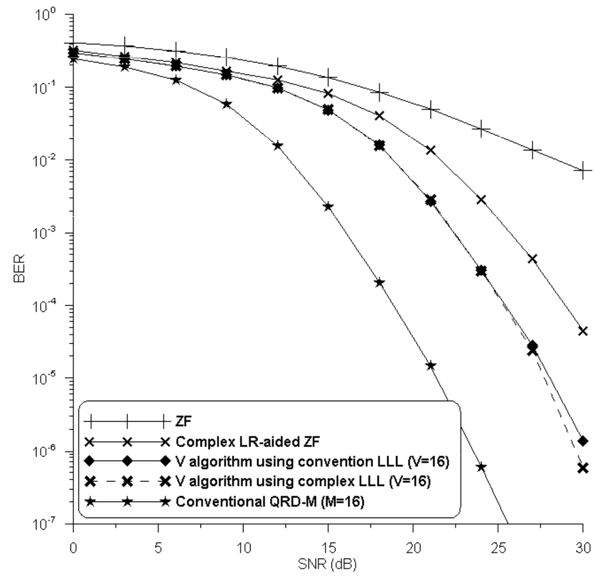

Fig. 1. BER performance of ZF, conventional LLL, QRD-M and proposed scheme

known to receiver perfectly. The proposed detection scheme considers MIMO-OFDM system with $N_T = N_R = 4$ and sets the number of subcarriers to 64.

Fig. 1 shows the BER performance of proposed scheme with $V = 16$, when 16-QAM modulation is used. The BER performance of QRD-M with $M = 16$ is also shown in Fig. 1. As expected, the proposed scheme has better performance than ZF and conventional LLL. ZF and conventional LLL have low error performance due to incorrect symbol at the first layer. However, the proposed scheme has better error performance because the proposed scheme has more accurate symbol at the first layer. Moreover, The proposed scheme can reduce the complexity up to 50% compared to the conventional LLL and the performance of proposed scheme has been improved than conventional V algorithm using LLL in the high SNR.

Finally, we acquire comparable error performance of QRD-M ($M = 16$). Although the performance is degraded, the degradation value is not high.

The complexity is about 21.7% of complexity of the QRD-M with 4×4 MIMO system. Although there are some performance degradations, the complexity of proposed detection scheme can be reduced less than two thirds. If the first layer selects the suitable V value, complexity can be further reduced.

5 Conclusion

The performance of MIMO-OFDM system with LRD scheme is limited by the first detected symbol due to error propagation. For this problem, the proposed detection scheme which can detect the first sub-stream more accurately has lower complexity than QRD-M. If the first layer selects the suitable V value for system, complexity can be reduced more than QRD-M. Therefore, proposed scheme can be effectively used for MIMO-OFDM receiver implementation requiring very low complexity.

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References

1. P. W. Wolniansky, G. J. Foschini, G. D. Golden and R. A. Valenzuela.: V-BLAST: An architecture for realizing very high data rates over the rich-scattering wireless channel. In: Proc. ISSSE'98, pp. 295–300 (1998)
2. M. S. Baek, Y. H. You and H. K. Song.: Combined QRD-M and DFE detection technique for simple and efficient signal detection in MIMO-OFDM systems. IEEE Trans. Wireless Commun, Vol. 8, No. 4, pp. 1632–1638 (2009)
3. K. J. KIM, J. Yue, R. A. Iltis and J. D. Gibson.: A QRD-M/Kalman filter-based detection and channel estimation algorithm for MIMO-OFDM Systems. IEEE Trans. Wireless Commun, Vol. 4, No. 2, pp. 710–721 (2005)
4. Berenguer. I, Adeane. J, Wassell. I.J, and Wang. X.: Lattice-reduction-aided receiver for MIMO-OFDM in spatial multiplexing systems. In: IEEE Personal, Indoor and Mobile Radio Communications (PIMRC 2004), Vol. 2, pp. 1517–1521 (2004)
5. Y. H. Gan, C. Ling and W. H. MOW. : Complex Lattice Reduction Algorithm for Low-Complexity Full-Diversity MIMO Detection. IEEE Trans. Signal process, Vol. 57, No. 7, pp. 2701–2710 (2009)
6. J. K. Ahn, S. J. Yu, E. Y. Lee and H. K. Song.: An improved lattice reduction aided detection scheme for MIMO-OFDM system. In: International Conference on Communications, Control and Signal Processing(ICCCSP 2011), No. 59, pp. 1431–1434 (2011).