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The Low Complexity QRD-M Detection Method with Threshold for Immersive Signage Systems

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Abstract: The detection step is an important research area and various detection methods have been studied in the multiple input multiple output-orthogonal frequency division multiplexing (MIMO-OFDM) systems. The way to mitigate excessive complexity of maximum likelihood (ML) detection algorithm is to use a breadth-first tree search (BFTS) algorithm such as QR decomposition-based M-algorithm (QRD-M). However, the complexity of the QRD-M for practical implementation is still high. In this paper, the low complexity QRD-M detection algorithm based on eliminates the survival paths is proposed in the MIMO-OFDM systems. The proposed detection algorithm performs eliminating survival paths method according to threshold based on accumulated squared Euclidean distance (ED) by LR-aided DFE. From the simulation results, the proposed detection algorithm shows error performance and complexity.

Keywords: **MIMO-OFDM, BFTS, QRD-*M*, lattice-reduction.**

I. BACKGROUND

Multiple input multiple output-orthogonal frequency division multiplexing (MIMO-OFDM) systems have been widely used in various parts of a wireless communication areas for higher data rates required by up-to-date applications or users [1]. The MIMO-OFDM systems enable higher capacity through efficient use of spatial diversity by simultaneously transmits and receives parallel data streams without sacrificing bandwidth [2]. The MIMO-OFDM systems have been adopted in up-to-date wireless standards such as a downlink transmission scheme of long term evolution (LTE), and immersive data transmission in digital signage network. In particular, high reliability and low implementation complexity are required for high-quality media because digital signage network is built in public places where a large number of people are concentrated. In the MIMO-OFDM receiver, the detection step is an important research area and various detection methods have been studied. The maximum likelihood (ML) detection algorithm is optimal for detection problems in MIMO systems, but its complexity increases exponentially when the number of transmit antennas is large or modulation order is high. The way to mitigate excessive complexity is to use a breadth-first tree search (BFTS) algorithm such as QR decomposition-based *M*-algorithm (QRD-*M*) [3]-[5]. However, the complexity for practical implementation is still high.

In this paper, the QRD-*M* detection with reduced complexity is proposed. The proposed detection algorithm calculates the threshold to reduce complexity by eliminating the survival paths. Thus, the unnecessary survival paths among the *M* survival paths of QRD-*M* can be eliminated. First, the proposed detection algorithm calculates the threshold by lattice reduction (LR)-aided decision feedback equalizer (DFE) at each layer [6], [7]. Second, the accumulated squared Euclidean distances (ED) for QRD-*M* algorithm are compared with the threshold. Next, removes paths greater than the threshold among *M* survival paths. Repeat the path elimination process until the first layer for low complexity. The simulation results that the proposed detection algorithm improves error performance with low complexity than conventional QRD-*M* with low *M*.

II. METHODS

A. System Model

Figure 1 shows a typical MIMO-OFDM systems designed with the N_T transmit antennas and N_R receive antennas where N_R is equal to or greater than N_T. Each sub-stream is for transmission to a Q-quadrature amplitude modulation (Q-QAM) scheme with the equal power. That is, the average power of each modulation symbols is normalized to 1. After that, each data stream is OFDM modulated by inverse fast Fourier transform (IFFT) and then inserted cyclic prefix (CP) for each symbol. The CP prevents the inter-symbol interference (ISI) and inter-carrier interference (ICI) that may occur between consecutive OFDM symbols by delay spread of the channel. The receiver performs the inverse procedure of the transmitter. After the transmitted signal is received, the CP is removed and a fast Fourier transform (FFT) is performed.

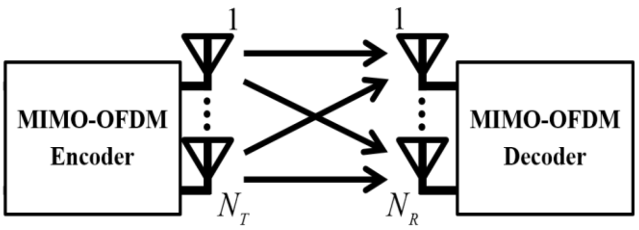

Fig. 1: MIMO-OFDM system model

The received signal can be expressed as follows

$$\mathbf{y} = \mathbf{Hx} + \mathbf{n}, \quad (1)$$

where $\mathbf{x} = [x_1\ x_2 \cdots x_{N_T}]^T$ is the $N_T \times 1$ vectors of transmitted signals, $\mathbf{y} = [y_1\ y_2 \cdots y_{N_R}]^T$ is the $N_R \times 1$ vectors of received signals, and $\mathbf{n}$ is the $N_R \times 1$ complex additive white Gaussian noise (AWGN) vector with zero mean and σ^2 variance. The channel matrix $\mathbf{H}$ is $N_R \times N_T$ complex-valued Rayleigh fading channel matrix as follows,

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N_T} \\ h_{21} & h_{22} & \cdots & h_{2N_T} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_R 1} & h_{N_R 2} & \cdots & h_{N_R N_T} \end{bmatrix}. \quad (2)$$

In this system, it is assumed that the channel estimation in the receiver side is perfect.

B. Conventional QRD-M

This section explains the conventional QRD-*M* detection. The QRD-*M* detection starts from QR decomposition. The channel matrix $\mathbf{H}$ is decomposed into the $N_R \times N_T$ unitary matrix $\mathbf{Q}$ and $N_T \times N_T$ upper triangular matrix $\mathbf{R}$.

$$\mathbf{H} = \mathbf{QR}. \quad (3)$$

By pre-multiplying the $\mathbf{y}$ by $\mathbf{Q}^H$,

$$\mathbf{Q}^H\mathbf{y} = \mathbf{Q}^H\mathbf{QRx} + \mathbf{Q}^H\mathbf{n}, \quad (4)$$

$$\hat{\mathbf{y}} = \mathbf{Rx} + \mathbf{n}', \quad (5)$$

where $\hat{\mathbf{y}} = \mathbf{Q}^H\mathbf{y}$, $\mathbf{n}' = \mathbf{Q}^H\mathbf{n}$ has the same statistical noise properties as $\mathbf{n}$ and $(\cdot)^H$ denotes the Hermitian transpose. Using equation (5), $\hat{\mathbf{y}}$ is defined as a formula that uses the properties of $\mathbf{R}$ and performs the BFTS algorithm. In the N_T-th layer, the BFTS algorithm starts by calculating the squared ED metrics for candidates $\mathbf{c} = [c_1\ c_2 \cdots c_J]$ of the transmit symbol $\hat{y}_{N_T}$ where $\mathbf{c}$ is reference symbols and J is the number of the reference symbols. The N_T-th layer metrics are calculated as

$$\tilde{E}^J_{N_T} = \left|\hat{y}_{N_T} - R_{N_T,N_T} c_J\right|^2, \quad (6)$$

where $\tilde{\mathbf{E}}_{N_T} = [\tilde{E}^1_{N_T}\ \tilde{E}^2_{N_T} \cdots \tilde{E}^J_{N_T}]$ is the squared ED between $\mathbf{c}$ and y_{N_T}. Define candidate group with all *M* survival paths generated as a result of (6) and proceed to the (N_T-1)-th layer. From the (N_T-1)-th layer to the first layer, the accumulated squared ED is calculated by the follows

$$\tilde{E}^J_i = \left|\hat{y}_i - (R_{i,i}c_J + \sum_{k=i+1}^{N_T} R_{i,k}\hat{x}_k)\right|^2 + \tilde{E}_{i+1}, \quad i = N_T-1, N_T-2, \ldots, 1, \quad (7)$$

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Where $\hat{x}_k$ is estimated symbol at the $(i+1)$-th layer. Equation (7) implies the QRD-*M* algorithm computes the accumulated squared ED for each layer using an *M* survival paths with a small accumulated squared ED. In the first layer, a candidate signal with the smallest accumulated squared ED is detected as the final estimated signal.

C. Proposed Detection Algorithm

The proposed detection algorithm achieves better implementation complexity as a threshold by the LR-aided DFE. The LR technique creates a reduced lattice basis $\tilde{\mathbf{H}} = \mathbf{HT}$, where $\mathbf{T}$ is an unimodular matrix. With the new channel matrix $\tilde{\mathbf{H}}$ generated by the complexed Lenstra-Lenstra-Lovasz (LLL) lattice basis reduction algorithm [8] the received signal model in the (1) can be rewritten as

$$\mathbf{y} = \mathbf{HT}(\mathbf{T}^{-1}\mathbf{x}) + \mathbf{n} = \tilde{\mathbf{H}}\mathbf{z} + \mathbf{n}. \quad (8)$$

The LR-aided detection finds an estimate $\hat{\mathbf{z}}$ of the transmitted signal vector in the z-domain using either the linear of DFE detection [9], [10]. The procedure of the LR-aided DFE is as follows,

$$\tilde{\mathbf{Q}}^H\mathbf{y} = \tilde{\mathbf{Q}}^H\tilde{\mathbf{Q}}\tilde{\mathbf{R}}\mathbf{z} + \tilde{\mathbf{Q}}^H\mathbf{n}, \quad (9)$$

$$\hat{\mathbf{y}} = \mathbf{Rz} + \mathbf{n}'. \quad (10)$$

Then, the estimated signals of each layer are obtained through the following recursive algorithm.

$$\hat{z}_i = Quan\left[\frac{1}{\tilde{R}_{i,i}}(\hat{y}_i - \sum_{j=i+1}^{N_T}\tilde{R}_{i,j}\hat{z}_j)\right], \quad i = N_T, N_T-1, \ldots, 1. \quad (11)$$

The threshold for each layer is calculated based on estimated signal $\hat{z}_i$ as follows,

$$\gamma_i = |\hat{y}_i - \hat{z}_i| + \gamma_{i+1}, \quad i = N_T-1, N_T-2, \ldots, 1, \quad (12)$$

where γ_i is the threshold of the i-th layer, and the threshold is used from the (N_T-1)-th layer to first layer. Prior to performing the QRD-*M* algorithm, the threshold for survival paths removal is obtained and the path with accumulated squared ED greater than the threshold is eliminated. After, the procedure of the proposed BFTS algorithm proceeds as follows. In the N_T-th layer, calculation is performed on all the paths and the process proceeds to the (N_T-1)-th layer. In the (N_T-1)-th layer, the survival paths having the accumulated squared ED larger than the threshold γ_{N_T-1} among the *M* survival paths are removed, and then the process proceeds to the next layer. After eliminating the paths, define the number of remaining paths as M_R, and perform the algorithm after resetting to $M = M_R$. If the number of survival paths in each layer is less than $M_R/4$, reset to $M = 2M_R$. From (N_T-1)-th layer to the first layer, the BFTS algorithm is performed based on the newly defined *M* and accumulated threshold for each layer. In the first layer, in the same scheme as the QRD-*M* algorithm, a candidate signal with the smallest accumulated squared ED is detected as the final estimated signal. By performing the above algorithm, the proposed detection algorithm can be achieved low complexity.

III. RESULTS

A. *Simulation Results*

This section presents simulation results comparing the bit error rate (BER) performance and implementation complexity of the proposed detection algorithm and the conventional QRD-*M* detections with various *M* values. In this paper, it is assumed that the channel estimation in the receiver is perfect in MIMO-OFDM systems. Also, this paper assumes that the channel is a Rayleigh fading channel of 7 multi-paths. The channel matrix $\mathbf{H}$ is designed as a complex Gaussian channel with zero mean and unit variance. Table 1 shows the parameters used in the simulation.

Table 1: Simulation parameters in the MIMO-OFDM system

FFT/IFFT Size	128
CP Size	32
Modulation scheme	16-QAM
Noise	Additive White Gaussian Noise
Channel Model	Rayleigh Fading Channel

Multi-path	7
M value of the conventional QRD-M	8, 12, 16
Number of transmit antennas	8
Number of receive antennas	8

Figure 2 illustrates the BER performance of the proposed detection algorithm and the conventional QRD-*M* detection algorithm with $M=8$, 12 and 16, respectively. The QRD-*M* detection algorithm using $M=16$ shows optimal performance similar to ML detection algorithm. The QRD-*M* detection algorithm with $M=8$ and 12, respectively, shows BER performance degradation as signal-to-noise ratio (SNR) increases. The proposed detection algorithm shows a BER performance difference of about 1dB by the compared QRD-*M* ($M=16$) detection algorithm, and BER performance degradation does not occur as the SNR increases. Therefore, it can be concluded that the BER performance of the proposed detection algorithm is comparable with QRD-*M* ($M=16$) detection algorithm. Also, it shows superior BER performance than QRD-*M* detection algorithms using low *M* value.

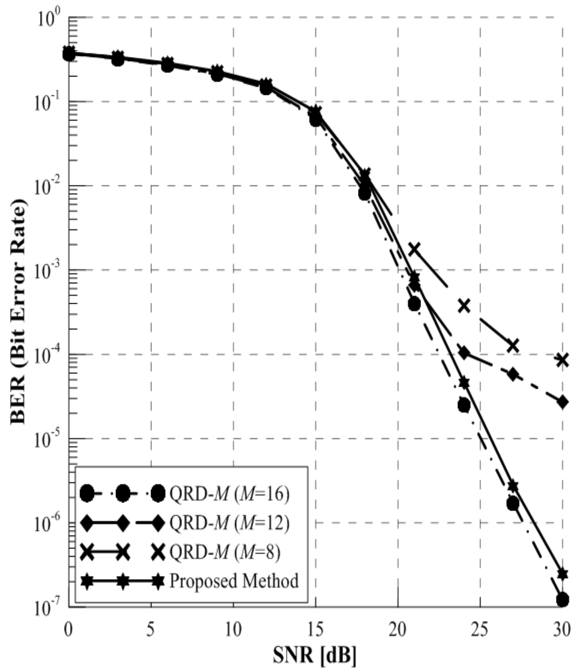

Fig. 2: BER performance of conventional QRD-*M* detection algorithms and proposed detection algorithm

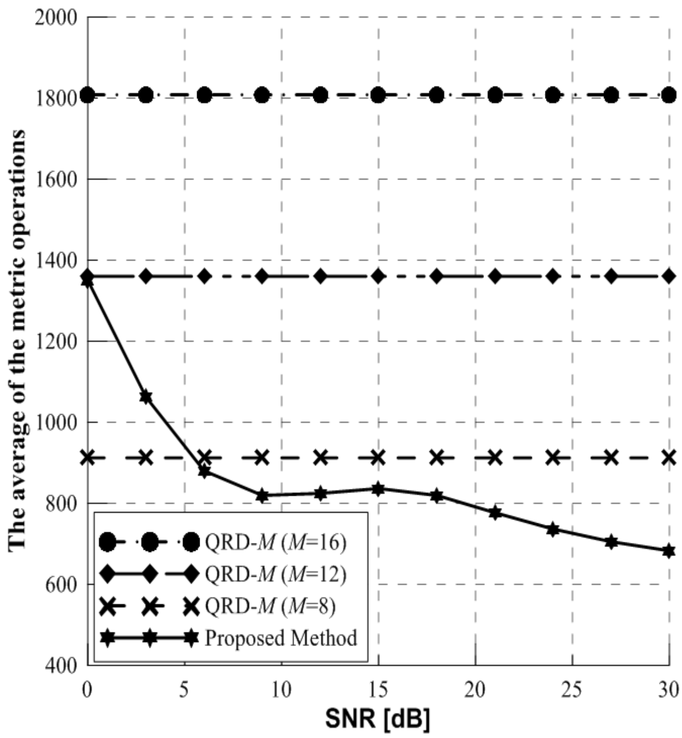

Fig. 3: The average number of metric operations of conventional QRD-*M* detection algorithms and proposed detection algorithm according to the SNR

Figure 3 illustrates the average number of metric operations to compare complexity for each detection algorithm according to the SNR. Considering the above-mentioned performance, the proposed detection algorithm shows a considerable reduction in complexity. The proposed detection algorithm has low complexity because it eliminates unnecessary paths. The proposed detection algorithm has lower metric operations than QRD-*M* with $M=12$, 16 detection algorithms in all SNRs. As shown in Figure 3, when the SNR is about 5dB, the complexity of the proposed detection algorithm becomes lower than that of the QRD-*M* ($M=8$) detection algorithm. Considering both the BER performance and the improved complexity performance, the performance of the proposed detection algorithm is superior to that of the conventional QRD-*M* detection algorithm.

IV. CONCLUSION

This paper proposes a detection algorithm for immersive data transmission in internet of Signage (IoS) environment of digital signage network. The basic idea of the detection algorithm proposed in this paper is to reduce the complexity by eliminating unnecessary paths. The proposed detection is proposed as an efficient detection method that reduces computational complexity while providing performance comparable to the QRD-*M* ($M = 16$) detection method. The proposed detection algorithm uses the LR-aided DFE scheme to define thresholds and removes the survival paths having the accumulated squared ED larger than the thresholds among the *M* survival paths. As a result, the proposed detection algorithm has lower complexity than the QRD-*M* detection algorithm with a low *M* and shows a BER performance corresponding to an optimal QRD-*M* ($M = 16$) detection algorithm. The simulation results in the MIMO-OFDM systems show that it can provide a trade-off between complexity and BER performance.

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