Modified Tree Structure QRD-*M* in MIMO-OFDM Systems

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ABSTRACT: *In multiple input multiple output-orthogonal frequency division multiplexing (MIMO-OFDM) systems, QR decomposition-M algorithm (QRD-M) has suboptimal error performance. However, the QRD-M has still high complexity due to many calculations at each layer in tree structure. To reduce the complexity of the QRD-M, proposed QRD-M modifies existing tree structure by eliminating unnecessary candidates at almost whole layers. The method of the elimination is discarding the candidates which have accumulated squared Euclidean distances larger than calculated threshold. The simulation results show that the proposed QRD-M has same bit error rate (BER) performance with lower complexity than the conventional QRD-M.*

Keywords: Complexity, MIMO-OFDM, QRD-*M*, Squared Euclidean distance

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1. Introduction

In rich scattering wireless channel, multiple input multiple output-orthogonal frequency division multiplexing (MIMO-OFDM) system can provide high channel capacity without additional bandwidth or high transmit power by exploiting multipath fading. However, for accurate symbol estimation from several distorted transmitted symbols, MIMO-OFDM systems require complex receiver and design of this receiver is hard in reality. Maximum likelihood (ML) has been known to have optimal error performance. ML receiver estimates transmitted symbols by selecting candidates which have the smallest norm in all reference symbols. So, complexity of the ML is very high in huge MIMO-OFDM systems. QR decomposition-M algorithm (QRD-*M*) also has been known to have suboptimal error performance with very lower complexity than the ML. In the QRD-*M*, at each layer, only M candidates which have the smallest accumulated squared Euclidean distances are survived in tree structure. Although QRD-M has lower complexity than the ML, QRD-M also has high complexity when modulation order, M and the number of antennas increases in existing tree structure. So, the complexity of the QRD-M is also very high in huge MIMO-OFDM systems. Thus, this paper proposes reduced complexity QRD-M by modifying existing tree structure. At each layer, the candidates which are larger than threshold that is calculated at the first layer are eliminated. The calculation of the threshold depends on modulation order and the number of transmit antennas.

2. System Model

Fig. 1 shows MIMO-OFDM system model which has N_t transmit antennas and N_r receive antennas ($N_r > N_t$). At the transmitter, OFDM symbols vector $\mathbf{X} = [X_1\ X_2\ \ldots\ X_{Nt}]^T$ where $(.)^{\mathrm{T}}$ denotes transpose operator is generated by MIMO-OFDM encoder and these OFDM symbols go through rich scattering complex Rayleigh fading channel as follows, where H_{ij} $(1 \le i \le N_r,\ 1 \le j \le N_t)$

$$\mathbf{H} = \begin{bmatrix} H_{11} & H_{12} & \cdots & H_{1N_t} \\ H_{21} & H_{22} & \cdots & H_{2N_t} \\ \vdots & \vdots & \ddots & \vdots \\ H_{N_r1} & H_{N_r2} & \cdots & H_{N_rN_t} \end{bmatrix}, \qquad (1)$$

is channel coefficient from the j-th transmit antenna to the i-th receive antenna. So, received symbols vector $\mathbf{Y} = [Y_1\ Y_2\ \ldots\ Y_{Nr}]^T$ is as follows,

$$\mathbf{Y} = \mathbf{HX} + \mathbf{N}, \qquad (2)$$

where $\mathbf{N} = [N_1\ N_2\ \ldots\ N_{Nr}]^T$ is zero mean complex additive white Gaussian noise (AWGN) vector.

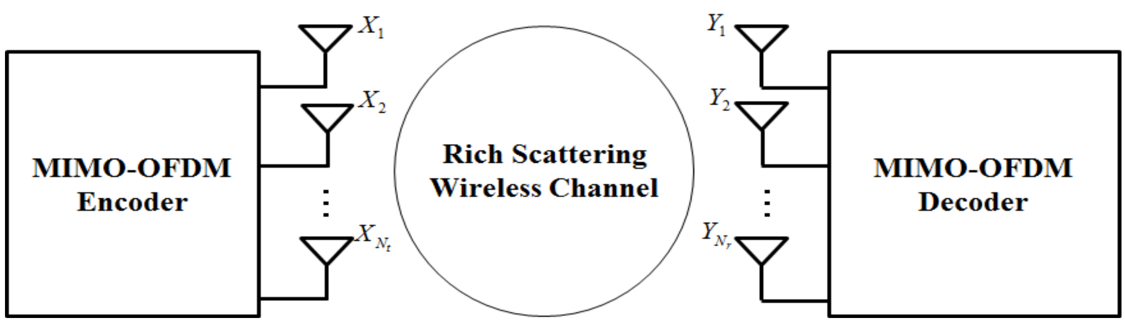

Figure 1. MIMO-OFDM system model

3. Proposed QRD-M

The proposed QRD-M has two stages, i.e. calculation of the threshold and modification of the existing tree structure. The proposed QRD-M also starts from QR decomposition like the conventional QRD-M as follows,

$$\mathbf{H} = \mathbf{QR}, \qquad (3)$$

where Q is $N_r \times N_r$ unitary quadrature matrix which is satisfied with $\mathbf{Q}^H\mathbf{Q} = \mathbf{I}$ where $(.)^H$ denotes Hermitian operator and $\mathbf{R}$ is $N_r \times N_t$ upper triangular matrix. So, the received symbols vector $\mathbf{Y}$ in Eq. (1) can be written as follows,

$$\mathbf{Y} = \mathbf{HX} + \mathbf{N} = \mathbf{QRX} + \mathbf{N}. \qquad (4)$$

For using the quadrature property of $\mathbf{Q}$, the left side of $\mathbf{Y}$ is multiplied by $\mathbf{Q}^H$ and resultant symbols vector $\mathbf{Z} = [Z_1\ Z_2\ \ldots\ Z_{Nr}]^T$ is as follows,

$$\mathbf{Z} = \mathbf{Q}^H\mathbf{Y} = \mathbf{RX} + \mathbf{Q}^H\mathbf{N}, \tag{5}$$

where $\mathbf{Q}^H\mathbf{N}$ is $N_r \times 1$ new noise vector which has same statistical property due to the quadrature property of $\mathbf{Q}$.

To calculate the threshold, squared Euclidean distances between Z_{Nt} and the l -th modulated reference symbol at the N_t-th layer $\boldsymbol{S}_{Nt,l}$ in constellation set $\mathbf{S}$ where it has $|C|$ elements is as follows,

$$E_{Nt,l} = \|Z_{Nt} - R_{NtNt} S_{Nt,l}\|^2. \tag{6}$$

In the result of Eq. (6), the proposed QRD-*M* selects P candidates which have small value in an ascending order where $P = \log_2|C|$ is the number of temporal candidates to calculate the threshold at the first layer. For each temporal candidate, M accumulated squared Euclidean distances are calculated at the $(N_t - 1)$ -th layer. The accumulated squared Euclidean distance between Z_{N_t}-1 and the l-th modulated reference symbol at the $(N_t - 1)$ -th layer from the p-th temporal candidate $S^p_{Nt-1,\,l}$ is as follows,

$$E^p_{Nt-1,l} = \|Z_{Nt-1} - (R_{Nt-1Nt-1}\, S^p_{Nt-1,l} + R_{Nt-1Nt} \hat{X}^p_{Nt})\|^2 + E^p_{Nt,l}, \tag{7}$$

where $\hat{X}^p_{Nt}$ is the p-th temporarily selected symbol at the N_t-th layer and $E^p_{Nt,l}$ is squared Euclidean distance between the p-th temporal candidate and $\mathbf{S}_{Nt,l}$. In the result of Eq. (7), candidate which has the smallest value is selected and these calculations are repeated until the first layer to obtain threshold. At the n-th layer, accumulated squared Euclidean distance $E^p_{n,l}$ is as follows,

$$E^p_{n,l} = \left\| Z_n - \left(R_{nn} S^p_{n,l} + \sum_{k=n+1}^{N_t} R_{nk} \hat{X}^p_k\right) \right\|^2 + E^p_{n+1,l}. \tag{8}$$

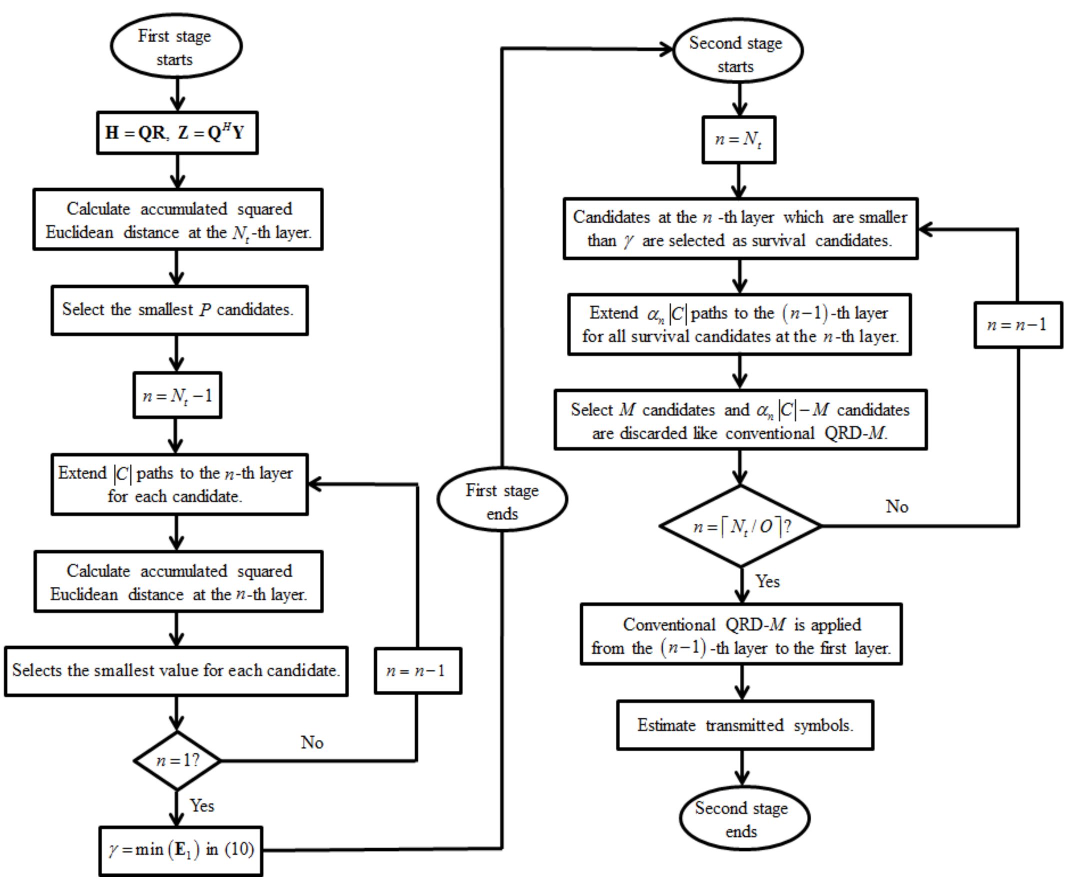

Figure 2. The flow chart of the proposed QRD-*M*

At the first layer, T accumulated squared Euclidean distances exist and they can be denoted as vector $\mathbf{E}_1$ as follows,

$$\mathbf{E}_1 = [E^1{}_1\, E^2{}_1 \ldots E^T{}_1], \qquad (9)$$

where $E^p{}_1$ is the p-th smallest accumulated Euclidean distance at the first layer.

And the threshold γ is obtained by selecting the minimum value in the $\mathbf{E}_1$ as follows,

$$\gamma = \min(\mathbf{E}_1) \qquad (10)$$

To reduce the whole complexity of the conventional QRD-*M*, existing tree structure is modified by comparing accumulated squared Euclidean distances with γ from the N_t-th layer to the $\lceil N_t/O \rceil$-th layer where O is modulation order. In Eq. (6), α_{Nt} candidates which are smaller than γ are survived in M candidates. Then, $\alpha_{Nt}|C|$ paths are extended to the (N_t - 1) -th layer and M candidates are survived and $\alpha_{Nt}|C|$ - M candidates are discarded like the conventional QRD-*M*. Likewise, α_{Nt-1} candidates which are smaller than γ are survived in M candidates at the (N_t-1)-th layer and M-α_{Nt-1} candidates are discarded. In this way, these comparisons are repeated until the $\lceil N_t/O \rceil$-th layer. Under the ($\lceil N_t/O \rceil$-1) -th layer, the conventional QRD-*M* is applied and the algorithm of the proposed QRD-*M* is complete by selecting the smallest one in M candidates as final path at the first layer. Fig. 2 shows flow chart of the proposed QRD-*M*.

4. Simulation Results

This section shows the simulation results about error performance and complexity. The number of used total subcarriers is 128 and length of cyclic prefix (CP) is 32. Also, the used modulation scheme is 16-quadrature amplitude modulation (QAM) and channel distribution is 7-path Rayleigh fading. Fig. 3 shows the error performances which are shown as bit error rate (BER) of the conventional and proposed QRD-*M* in 4×4 and 8×8 MIMO-OFDM system. The BER performances of the proposed QRD-*M* are

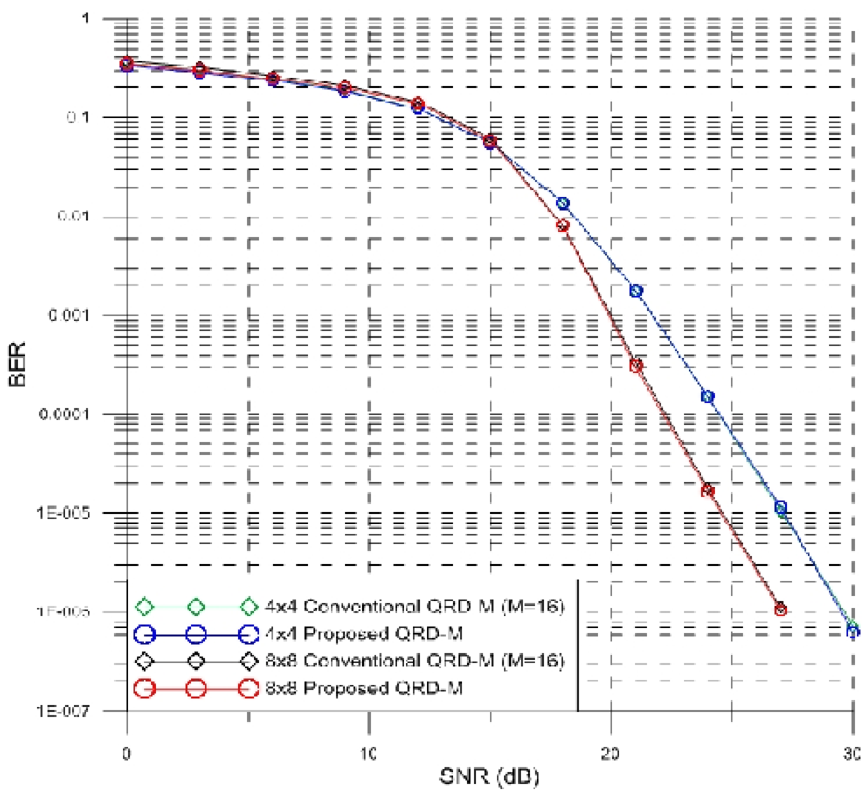

Figure 3. The BER performance of the conventional and proposed QRD-*M*

same with the conventional QRD-*M*. Therefore, the proposed QRD-M modifies the existing tree structure well without any loss of error performance. And the BER performance of the QRD-*M* is better than the QRD-*M* because more diversity gains are obtained when the number of antennas increases in non-linear detection scheme. Fig. 4 shows the complexity which is shown as average number of metric operations of the conventional and proposed QRD-*M* in MIMO-OFDM system. In MIMO-OFDM system, existing tree structures are modified from the 8-th layer to the second layer. The average number of metric operations of the proposed QRD-*M* is lower than the conventional QRD-*M* (*M*=16). Also, according to the increased signal to noise (SNR), the average number of metric operations decreases and nears to the conventional QRD-*M* (*M*=1).

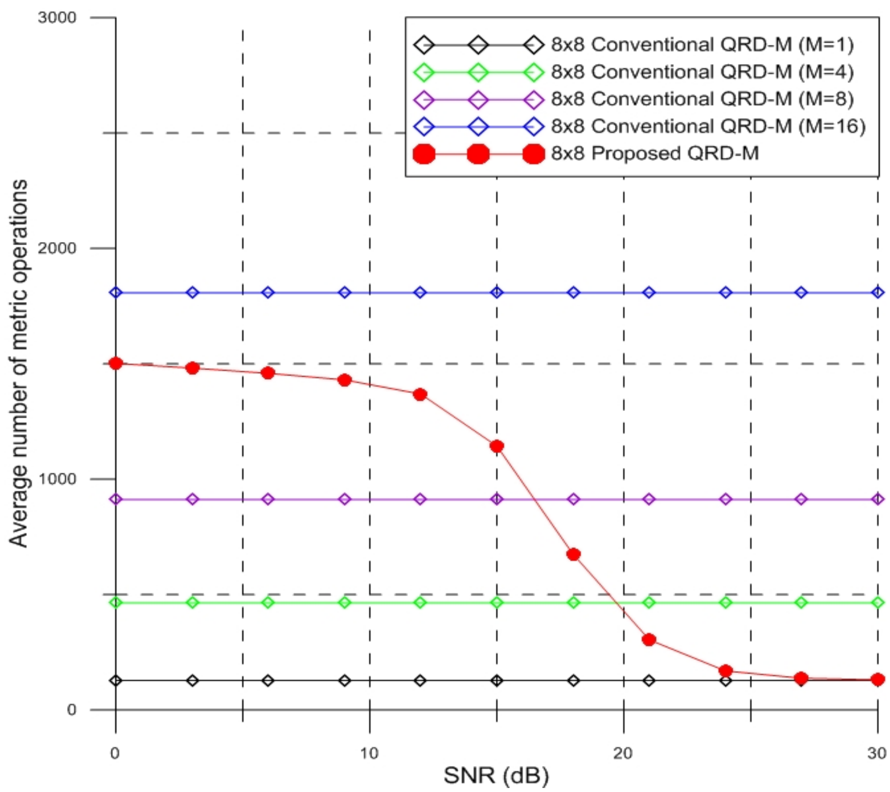

Figure 4. Average number of metric operations of the conventional and proposed QRD-*M*

5. Conclusion

This paper proposes the reduced complexity QRD-*M* by modifying the existing tree structure. To modify the existing tree structure, unnecessary candidates from the N_t-th layer to the $\lceil N_t/O \rceil$-th layer are eliminated by comparing accumulated Euclidean distances with threshold. As shown in simulation results, the average number of metric operations of the proposed QRD-*M* is lower than the conventional QRD-*M* (*M*=16) and it nears to the conventional QRD-*M* (*M*=1) according to the increased SNR. Thus, in huge MIMO-OFDM systems, the proposed QRD-*M* can be implemented well relative to the conventional QRD-*M*.

6. Acknowledgment

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References

[1] Yu, S. J., Song, Y. J., Song, H. K. (2011). Enhanced Lattice-Reduction aided detection for MIMO systems with QRD-M detector. *IEICE Electro. Exp.*, 8 (10) 767-772.

[2] Jeong, H. Y., Song, H. K. (2013). A Reduced MIMO Detector Using Post SNR Ordering. *IEICE Trans. Inf. &Syst.*, E96-D (6) 1398-1401.

[3] Yu, S. J., Ahn, J. K., Song, H. K. (2014). Channel-Adaptive Detection Scheme Based on Threshold in MIMO-OFDM Systems. *IEICE Trans. Inf. & Syst.*, E97-D (6) 1644-1647.

[4] Kim, J. J., Song, H. K. (2015). Improved Detection Scheme Based on Lattice-Reduction and Threshold Algorithm in MIMO-OFDM Systems. *IEICE Trans. Fund.*, E98-A (6) 1343-1345.