Low-Complexity Adaptive Detector in Single-User MIMO System

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***Abstract*—This paper proposes low-complexity adaptive detector that uses different detector according to signal to noise ratio (SNR) in single-user (SU) multiple-input multiple-output (MIMO) wireless communications network. The proposed scheme uses decision feedback equalizer (DFE) detector [1] when the measured SNR is higher than target SNR which is required to obtain bit error rate (BER) 10^{-3} and uses combined QR decomposition (QRD)-*M* based on threshold and DFE detector when the measured SNR is lower than target SNR. The simulation results show that although the BER performance for the proposed scheme is lower than combined QRD-*M* and DFE, the required complexity is significantly decreased. Another important feature is that complexity for proposed scheme is steadily decreased by up to 99% as SNR increases.**

***Index Terms*— QRD-*M*, DFE, threshold, low-complexity**

I. Introduction

Recently, the demand for capacity of users has been increased due to rapidly growing wireless communications service. In this situation, multiple-input multiple-output (MIMO) system has attracted attention since MIMO system provides high capacity [2-3]. However, in MIMO systems, accurate detector is required by increasing the number of transmission streams. Maximum likelihood (ML) is optimal technique in MIMO system but computational complexity increases exponentially according to the number of transmit and receive antennas [4]. For low-complexity optimal detector, QR decomposition (QRD)-*M* was developed. However, computational complexity is high when the number of candidates *M* is large. In order to decrease the complexity for conventional QRD-*M*, combined QRD-*M* and decision feedback equalizer (DFE) [5] can be used. Combined QRD-*M* and DFE uses QRD-*M* at high layer and DFE at low layer to estimate the transmit symbols. Its complexity is lower than conventional QRD-*M* since the DFE is used at low layer. However, complexity for combined QRD-*M* and DFE is still high to be implemented in large MIMO system since the usage of QRD-*M* is large.

Thus, this paper proposes two schemes to reduce complexity. First, QRD-*M* based on threshold [6] is used instead of conventional QRD-*M* in combined QRD-*M* and DFE. QRD-*M* based on threshold calculates minimum accumulated squared Euclidean distance (ASED) at each layer and sets final minimum ASED to threshold. Then, the detector recalculates ASEDs at each layer and removes paths which have ASED greater than threshold. Complexity is reduced by eliminating unreliable paths in advance. Second, DFE detector is used when the measured signal to noise ratio (SNR) is higher than target SNR, and combined QRD-*M* based on threshold and DFE detector is used when the measured SNR is lower than target SNR.

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II. System Model

Fig. 1 shows single-user (SU) MIMO system which is consist of N_T transmitting antennas and N_R receiving antennas $(N_R \geq N_T)$. In this system model, received signal vector $\mathbf{y} \in \mathbb{C}^{N_R \times 1}$ is represented as follows:

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n}, \tag{1}$$

where $\mathbf{x} \in \mathbb{C}^{N_T \times 1}$ is transmit signal vector, $\mathbf{n} \in \mathbb{C}^{N_R \times 1}$ is additive white Gaussian noise(AWGN) vector with zero mean and variance σ^2, $\mathbf{H} \in \mathbb{C}^{N_R \times N_T}$ is Rayleigh flat fading channel matrix. A signal transmitted from the $j = \{1, 2, ..., N_T\}$-th transmitting antenna to the $i = \{1, 2, ..., N_r\}$-th receiving antenna goes through channel $h_{i,j}$. It is assumed that receiver knows $\mathbf{H}$ exactly.

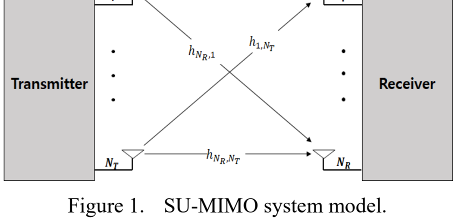

Figure 1. SU-MIMO system model.

III. Conventional QRD-*M* and Proposed Scheme

A. Conventional QRD-M

After QR decomposition of channel matrix $\mathbf{H}$, received signal is multiplied by $\mathbf{Q}^H$ using orthogonal matrix as follows:

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$$\mathbf{H} = \mathbf{QR}, \tag{2}$$

$$\mathbf{z} = \mathbf{Q}^H \mathbf{y}, \tag{3}$$

where **Q** is quadrature matrix and **R** is upper triangle matrix.

Equation (3) can be rewritten as follows:

$$\mathbf{z} = \mathbf{Rx} + \mathbf{n}$$

$$\begin{bmatrix} z_1 \\ z_2 \\ \vdots \\ z_{N_R} \end{bmatrix} = \begin{bmatrix} r_{1,1} & r_{1,2} & \cdots & r_{1,N_T} \\ 0 & r_{2,2} & \cdots & r_{2,N_T} \\ \vdots & 0 & \ddots & \vdots \\ 0 & \cdots & 0 & r_{N_T,N_T} \\ 0 & \cdots & 0 & 0 \\ \vdots & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{N_T} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_{N_R} \end{bmatrix}. \tag{4}$$

Conventional QRD-*M* calculates ASEDs at each layer and selects the minimum *M* paths among all possible paths. ASED with the $u = \{1, 2, ..., N_S\}$-th candidate symbol at the $k = \{1, 2, ..., N_T\}$-th layer is expressed as follows:

$$e_{k,u} = \left| z_k - \sum_{t=k+1}^{N_T} r_{k,t} \hat{x}_{t,p} - r_{k,k} s_u \right|^2 + \dot{e}_{k+1,p}, \tag{5}$$

where s_u is the u-th symbol among the N_s reference symbols, $e_{k,u}$ is the value of ASED when symbol s_u is selected at the k-th layer, $\hat{x}_{t,p}$ is the p-th survival path at the t-th layer, $\dot{e}_{k+1,p}$ is the value of the p-th survival path's ASED at the previous $(k+1)$-th layer.

B. Combined QRD-M and DFE

Combined QRD-*M* and DFE employs different detector according to layer. At high layer, the scheme uses QRD-*M* to estimate the transmit signal. On the other hand, DFE is used to estimate the transmit signal at low layer. Complexity for combined detector is not increased sharply like QRD-*M* due to usage of DFE, and it leads to significant complexity reduction. The Fig. 2 shows example using combined QRD-*M* and DFE.

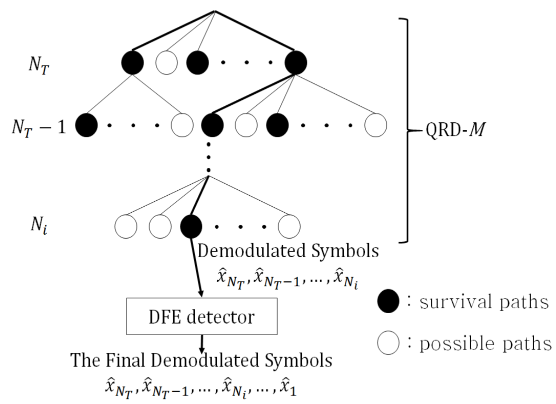

Figure 2. Example of combined QRD-*M* and DFE.

In this example, QRD-*M* detector estimates symbol from the N_T-th layer to the N_i-th layer and delivers demodulated symbols $\hat{x}_{N_T}, \hat{x}_{N_T-1}, \cdots, \hat{x}_{N_i}$ to DFE detector in the N_i-th layer. Then, DFE detector is operated from the next N_i-th layer. Advantage of this scheme is that the number of the layer using QRD-M can be adjusted to achieve the desired BER performance.

C. QRD-M Based on Threshold

As mentioned previously, complexity of QRD-*M* is high when *M* is large. For solving this problem, QRD-*M* based on threshold is used. QRD-*M* based on threshold works in two main stages. First, QRD-*M* based on threshold calculates ASEDs at each layer and extracts a path with minimum ASED. The minimum ASED is expressed as follows:

$$e_k = \min\{e_{k,1}, e_{k,2}, \cdots, e_{k,N_s}\}. \tag{6}$$

After repetition of the process, ASED value e_1 at the first layer is set to threshold value e_T. Second, ASEDs are recalculated at each layer and paths larger than e_T are removed. Advantage of this scheme is that complexity is dramatically reduced by removing unreliable paths in advance.

D. Proposed Scheme (Adaptive Combined QRD-M Based on Threshold and DFE)

Combined QRD-*M* based on threshold and DFE is similar to combined QRD-*M* and DFE except that QRD-*M* based on threshold is used at high layer instead of QRD-*M*. The Fig. 3 shows example of combined QRD-*M* based on threshold and DFE. As shown in the Fig. 3, QRD-*M* based on threshold is used to estimate the transmit signal from the N_T-th layer to the N_i-th layer. At the N_T-th layer, paths except for the first and last layers are removed since their ASEDs are larger than e_T. In this way, detector removes paths which are larger than e_T at each layer. The subsequent process is the same as combined QRD-*M* and DFE.

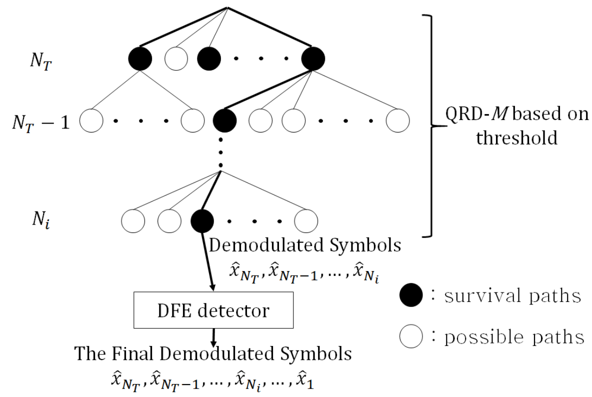

Figure 3. Example of combined QRD-*M* based on threshold and DFE.

Adaptive combined QRD-*M* based on threshold and DFE uses different detector according to SNR. DFE detector estimates symbol when SNR is higher than target SNR and combined QRD-*M* based on threshold and DFE detector estimates symbol when SNR is lower than target SNR. Fig. 4 shows the flow chart of proposed algorithm.

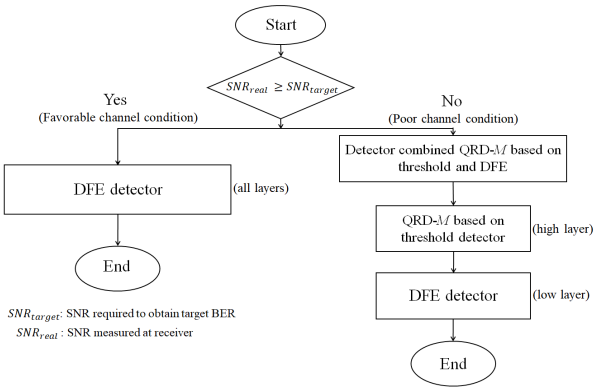

Figure 4. The flow chart of proposed scheme.

By using this proposed scheme, the BER required by the wireless communication system can be satisfied and the complexity of the system can be reduced. Also, when the required BER is high, the number of the layer using QRD-M based on threshold can be increased to satisfy the BER performance.

IV. SIMULATION RESULTS

In this section, we compare combined QRD-*M* and DFE with proposed scheme in the perspective of bit error rate (BER) performance and the number of complex multiplications. The simulation parameters are shown in Table I.

TABLE I. THE SIMULATION PARAMETERS

The number of Tx antennas	4, 8
The number of Rx antennas	4, 8
Fast Fourier transform(FFT) size	128
Guard interval(GI) size	32
Modulation	16-quadrature amplitude modulation(QAM)
Coding	Convolutional coding(code rate = 1/2)
Multi-path	7
M	16
N_i	3(4×4), 6(8×8)
Target BER	10^{-3}

For finding SNR which is required to obtain target BER in the simulation, the transmitter uses DFE detector. Then, receiver uses different detector according to target SNR which is delivered from the transmitter.

Fig. 5 shows BER performances for combined QRD-*M* and DFE and proposed scheme. As shown in the Fig. 5, BER performance for proposed scheme is degraded compared to the combined QRD-*M* and DFE when SNR is more than 18dB. Performance degradation occurs since the proposed scheme uses DFE detector when measured SNR is larger than target SNR. The interesting thing is that BER performance for proposed scheme is equal to the combined QRD-*M* and DFE, when SNR is lower than 18dB. This means that BER performance for QRD-*M* based on threshold is not degraded compared to the QRD-*M* since QRD-*M* based on threshold removes effectively unreliable paths.

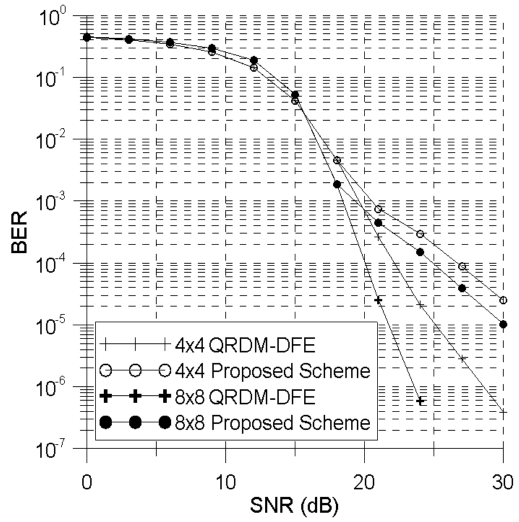

Figure 5. BER performances for the combined QRD-*M* and DFE and proposed scheme.

Fig. 6 shows the number of complex multiplications comparison for combined QRD-*M* and DFE and proposed scheme. In this simulation, the multiplication of two complex numbers is replaced to four real multiplications. Complexity for proposed scheme is decreased by 59% in 8×8 and 86% in 4×4 compared to the combined QRD-*M* and DFE when SNR is 15dB. Complexity for proposed scheme is decreased by up to 99% as SNR is increased since the more DFE detector is used when channel condition is favorable.

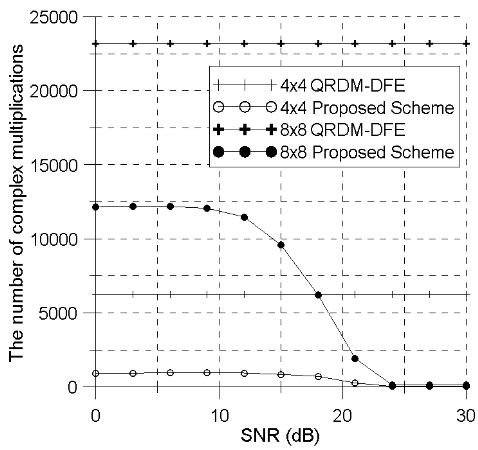

Figure 6. The number of complex multiplications for the combined QRD-*M* and DFE and proposed scheme.

V. CONCLUSION

This paper proposes adaptive combined QRD-M based on threshold and DFE. Simulation results show that BER performance for proposed scheme is the same as the combined QRD-M and DFE and complexity for proposed scheme is decreased compared to combined QRD-M and DFE when SNR is lower than target SNR. Although BER performance for proposed scheme is lower than the combined QRD-M and DFE when SNR is higher than target SNR, the complexity for proposed scheme is significantly decreased. Through the simulation results, proposed scheme is satisfied with the quality of wireless communication and it can be used well in large MIMO system.

Our further study is needed to increase BER performance with low complexity when SNR is lower than target SNR.

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