LETTER

A Reduced MIMO Detector Using Post SNR Ordering*

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SUMMARY In this letter, a novel adaptive detector that combines DFE and QRD-M is proposed for MIMO-OFDM system. QR decomposition (QRD) is commonly used in many MIMO detection algorithms. In particular, sorted QR decomposition (SQRD) is an advanced algorithm that improves MIMO detection performance. The proposed detector uses SQRD to achieve better performance. To reduce the computational complexity, the received layers of each subcarrier are ordered by using the post SNR and are detected by DFE and QRD-M detector based on the order. Therefore, the proposed detector structure is varied according to the channel state. In other words, the proposed detector achieves a good tradeoff between complexity and performance. A simulation confirms the substantial performance improvements of the proposed adaptive detector with only slightly greater complexity than the conventional detector.

key words: MIMO-OFDM detection, Combining detector, DFE, QRD-M

1. Introduction

Orthogonal frequency division multiplexing (OFDM) [1] has many advantages compared with conventional single-carrier communication systems and technology. In particular, OFDM is robustness against multipath fading and high spectral efficiency. Because of these advantages, OFDM is currently the most appropriate modulation scheme for high-speed data transfer.

The goal of current wireless communication systems is to achieve fast data transfer in the limited frequency resources. The multiple-input multiple-output (MIMO) [2] system has the advantage that can send large amounts of data, eliminating the need to increase the frequency. However, during high-speed transmission, MIMO systems have the disadvantage of intersymbol interference and frequency selective fading. In order to overcome the problem, the combination of OFDM and MIMO as MIMO-OFDM has come up with a most prospective solution for future wireless mobile communications.

The main problem for the MIMO-OFDM system is detector complexity. Very sophisticated detectors are needed

to accurately recover each transmitted stream. To meet system requirement, a lot of detectors have been proposed [3]–[5].

The Vertical Bell Laboratories Layered Space Time (V-BLAST) scheme is a popular transceiver structure which has relatively good performance. In the V-BLAST scheme, the complexity of the optimal maximum-likelihood (ML) detector [6] increases exponentially with the modulation order and the number of transmit antennas.

The QR decomposition with an M-algorithm (QRD-M) detector approaches the MLD performance with a lower computational complexity [7]. In order to achieve close-to-MLD performance, the M value needs to be sufficiently large. Thus, its computational complexity is slightly higher.

The other suboptimal detector is the decision feedback equalization (DFE) detector; it has lower complexity than QRD-M detector. The DFE detector based on QR-decomposition offers low complexity, but has poor performance.

In this letter, a combination of DFE and QRD-M detector that optimizes the tradeoff between performance and complexity is proposed. According to the channel state, the D values which divide the received layers of each subcarrier are determined. In other words, depending on the D value, the proposed detector is adaptive detector. In addition, according to the D value, the proposed combining detector by using the adaptive M values of QRD-M detector can achieve low complexity.

2. System Model

The OFDM symbol of i -th transmit antennas is transmitted as $\mathbf{X}_i = [X_i^{(0)}, X_i^{(1)}, \dots, X_i^{(k-1)}]$. The spatial multiplex is used in the MIMO system with N_T transmitted antenna and N_R received antennas. In the MIMO-OFDM system, the baseband equivalent model on the k -th subcarrier can be described in Eq. (1).

$$\mathbf{Y}^{(k)} = \mathbf{H}^{(k)} \cdot \mathbf{X}^{(k)} + \mathbf{N}^{(k)}. \quad (1)$$

A vector $\mathbf{X}^{(k)} = [X_1^{(k)}, X_2^{(k)}, \dots, X_{N_T}^{(k)}]^T$ is transmit symbol vector. The superscript T denotes the matrix transpose. The received symbol vector $\mathbf{Y}^{(k)}$ denotes $\mathbf{Y}^{(k)} = [Y_1^{(k)}, Y_2^{(k)}, \dots, Y_{N_R}^{(k)}]^T$. The Rayleigh fading channel matrix $\mathbf{H}$ is the N_R by N_T matrix which the (i,j) -th element is $h_{i,j}$. The elements of matrix $\mathbf{H}$ are independent identically distributed (i.i.d.) complex Gaussian random variable with zero mean and unit variance. It is assumed that the channel matrix $\mathbf{H}$ is

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known at the receiver.

The $\mathbf{N}^{(k)}$ vector can be also expressed $\mathbf{N}^{(k)} = [N_1^{(k)}, N_2^{(k)}, \dots, N_{N_R}^{(k)}]^T$. It is assumed that the noise at each N_R antenna is an independent and identically distributed (i.i.d) complex Gaussian random variable (r.v.) with zero mean and variance σ_n^2 .

3. Proposed Adaptive Detection Scheme

The MLD is the optimal detection method for MIMO systems. However, the MLD scheme has high computational complexity. To further reduce the complexity and attain near MLD performance, QRD-M detector based on QR-decomposition has been proposed.

The DFE detector based on QR-decomposition has good performance and low complexity than other several detectors. Because the DFE detector is performed by using the QR-decomposition, both QRD-M and DFE detector can use the QR-decomposition to detect the symbol without additional calculation.

In this letter, as a low complexity MIMO detector, the adaptively combined DFE and QRD-M detector is proposed.

To know the channel state for each subcarrier, post-signal-to-noise ratio (Post SNR) which can be determined by the channel state is used. The post SNR value for k -th subcarrier (ρ_i) is represented as follows,

$$\rho_i = \frac{\|X(k)\|^2}{\sigma_n^2 \|\mathbf{G}_i(k)\|^2} \quad (2)$$

where $\|X(k)\|^2$ means transmit power of subcarrier, σ_n^2 denotes noise power and $\mathbf{G}_i(k)$ is the i -th row of the Moore-Penrose pseudo-inverse matrix. The noise is considered by the minimum mean square error (MMSE) method which can be expressed as

$$\mathbf{G}_{MMSE} = \mathbf{H}^H (\mathbf{H}\mathbf{H}^H + \sigma_n^2 / \sigma_x^2 \mathbf{I}_{N_R})^{-1} \quad (3)$$

where $\mathbf{I}$ is identity matrix and the σ_x^2 denotes the power for the transmit signal. In Eq. (2), because the transmit signal power is 1, transmit power little impacts on the post SNR. Most impact on the post SNR power value is obtained by a Moore-Penrose pseudo-inverse matrix.

If the $\|\mathbf{G}_i(k)\|^2$ value is large, the post SNR is to be small and the channel state is determined to poor state. And vice versa, if the $\|\mathbf{G}_i(k)\|^2$ value is small, the channel state is determined good state.

Consequently, $\|\mathbf{G}_i(k)\|^2$ on each i -th layer ($i = 1, 2, \dots, N_T$) in a subcarrier is calculated. From a large value to a small value, $\|\mathbf{G}_i(k)\|^2$ is sorted. The sorted layer index can be expressed as the following equation

$$\mathbf{L} = [L_1, L_2, \dots, L_{N_T}]. \quad (4)$$

According to the order of $\mathbf{L}$, the columns of the channel matrix $\mathbf{H}$ is sorted.

This letter proposed an adaptive detector considering the channel state. By using Post SNR, the channel state

Fig. 1 The schematic diagram ($\hat{X}$ is ordering (descend) X).

can be found out. As shown in Eq. (2), if the norm of the Moore-Penrose pseudo-inverse matrix $\mathbf{G}(k) \|\mathbf{G}(k)\|^2$ has small value, the channel state is judged in good state. Thus, if $\|\mathbf{G}_i(k)\|^2$ value is less than any criterion, the i -th layer is judged in good condition. In other words, The channel state criterion is decided by an average of $\|\mathbf{G}(k)\|^2$ in this letter. Because the $\|\mathbf{G}_i(k)\|^2$ means the one row of the matrix $\|\mathbf{G}(k)\|^2$.

Thus, the number of the i -th layer which has smaller value than average value is counted. And then the number of i becomes the D value. According to the D value, the layers are detected by the DFE detector or QRD-M detector. So, the D value which equals the number of layer for low-complexity DFE detector is determined. According to the counted number D , the received low SNR layers for QRD-M detector are determined and the remainder high SNR layers for DFE detector are detected. If the transmitted signal to detect is $\hat{X}$, the transmitted signal is rewritten as

$$\hat{X}^{(k)} = [\hat{X}_1^{(k)}, \hat{X}_2^{(k)}, \dots, \hat{X}_D^{(k)}, \dots, \hat{X}_{N_T}^{(k)}]^T. \quad (5)$$

Approximate schematic diagram is shown in the Fig. 1. Thus, the symbols to detect for DFE can be written as

$$\hat{X}_{DFE} = [\hat{X}_1^{(k)}, \hat{X}_2^{(k)}, \dots, \hat{X}_D^{(k)}]^T. \quad (6)$$

To detect the remaining symbols as

$$\hat{X}_{QRD-M} = [\hat{X}_{D+1}^{(k)}, \hat{X}_{D+2}^{(k)}, \dots, \hat{X}_{N_T}^{(k)}]^T, \quad (7)$$

the QRD-M detector is executed.

The proposed detection algorithm is shown in Fig. 2. Furthermore, the proposed detector by using the adaptive M values of QRD-M detector based on D value can reduce complexity. The M value of QRD-M is mostly used as a modulation order. However, considering the complexity, the M value of the proposed detector is determined as the smaller value than the modulation order. It means the M value which has similar performance in case of using a modulation order is determined. In other words, if the D value has small value, it means channel state is in not good state. So, the M value of QRD-M detector should have large value. On the other hand, if the D value has large value, M value of QRD-M detector has small value because the channel state is in good state. So, in 4×4 MIMO system, the M value of the proposed detector based on the D value has in Table 1.

Fig. 2 The proposed detection algorithm.

Table 1 The number of M value based on the D value.

QPSK		16 QAM	
D value	M value	D value	M value
D = 1	M = 3	D = 1	M = 13
D = 2	M = 2	D = 2	M = 10
D = 3	M = 1	D = 3	M = 7

4. Computational Complexity

For the computational complexity comparison, only the multiplications are considered. Therefore, if there is one complex multiplication, the total number of multiplications is counted as four. Each multiplication computational complexity is calculated as follows,

$$C_{G_power} = 4 \cdot N_T \cdot N_R \quad (8)$$

$$C_{DFE} = 8 \cdot N_T^3 + 4 \cdot N_T^3 + 4 \cdot N_T^2 + 4 + \sum_{k=2}^M 4 \cdot (k+1) \quad (9)$$

$$C_{QRD-M} = 8 \cdot N_T^3 + 4 \cdot N_T^3 + 4 \cdot N_T^2 + 4 \cdot L + \sum_{D=2}^{N_T} 4 \cdot M \cdot D \cdot L + 4 \cdot L + \sum_{D=2}^{N_T} 4 \cdot M \cdot L, \quad M = 1, 2, \dots, L. \quad (10)$$

In Eq. (10), the L value is the number of layer.

$$C_{proposed} = 8 \cdot N_T^3 + 4 \cdot N_T^3 + 4 \cdot N_T^2 + 4 + \sum_{k=2}^D 4 \cdot (k+1) + 4 \cdot L + \sum_{D=2}^{N_T} 4 \cdot M \cdot D \cdot L + 4 \cdot L + \sum_{D=2}^{N_T} 4 \cdot M \cdot L. \quad (11)$$

The D value depends on the channel state at the moment.

Table 2 Computational complexity comparison for $N_T=N_R=4$ MIMO with QPSK, 16 QAM modulation modes.

Detection scheme	Required number of multiplication	
	QPSK	16 QAM
Order DFE (D=4)	884	884
QRD-M (M=1,7)	1056	6336
QRD-M (M=2,10)	1248	8640
QRD-M (M=3,13)	1440	10976
QRD-M (D=4),(M=4,16)	1632	13248
DFE-QRD-M (D=1),(M=3,13)	1540	10948
DFE-QRD-M (D=2),(M=2,10)	1246	8656
DFE-QRD-M (D=3),(M=1,7)	1040	5024
MLD	40448	10354688
Proposed Adaptive DFE-QRD-M (Modulation order M)	1422.72	9720.96
Proposed Adaptive DFE-QRD-M (adaptive M)	1046.8864	8040.8345

The D value has a value from 0 to N_T . So, the average value of D is obtained by saving the D values of the moments based on the channel state. As the simulated value, the average value of D is about 2.77 in 4×4 MIMO-OFDM system. The computational complexity that is calculated as the average value is shown in the Table 2.

As shown in Table 2, the computational complexity of proposed detector has smaller than the other detector. Because combining detector is proposed by using the adaptive M values of QRD-M detector by D value, the computational complexity of proposed detector has more lower complexity.

5. Simulation Results

The performance of the proposed detector is evaluated by computer simulation in respect to the bit-error-rate (BER) of the detectors. It is supposed that the channel state information (CSI) is known to receiver and the proposed detection algorithm considers 4×4 MIMO-OFDM system, with QPSK and 16 QAM modulation. The channel model is a Rayleigh channel and the number of paths is 7.

The simulation results are compared with the DFE detector, QRD-M detector, MLD and the proposed detector (using adaptive M value and modulation order M value) in Fig. 3, Fig. 4. As shown in Fig. 3 and Fig. 4, the proposed detector which adaptively combines DFE and QRD-M detector based on channel state has good performance above 20 dB. The BER performance of the proposed detector has not better than other detector at low SNR. But considering the low complexity, the proposed detector has better performance than other detectors. Also, in Fig. 3, the BER performance of using adaptive M value has similar to the BER performance of using fixed M value. For a more accurate comparison, the Fig. 5 shows the BER performance of the proposed detector with proposed adaptive M value and modulation order M value based on a fixed D value. In addition, compared with the fixed combining DFE-QRD-M detector, the proposed adaptive detector has better performance.

The simulation results show that the performances are significantly improved by dividing the appropriate layer

Fig. 3 BER performance of proposed adaptive detector (using adaptive M value and modulation order M value in QRD-M detector) and conventional detectors (DFE, QRD-M and MLD) with QPSK modulation.

Fig. 4 BER performance of proposed fixed combining detector and proposed adaptive detector with 16 QAM modulation.

number (D) based on channel state. The most optimal D values is not a fixed value and can be determined according to the complexity and performance of system requirement. In Table 2 and Fig. 5, the performance and complexity based on the D value is shown. But, as you can see, the adaptive D value based on the channel state has good performance and low complexity. Thus, the optimize value of the D value is adaptively changed based on the channel state.

6. Conclusion

An improved MIMO-OFDM detector is proposed in this letter. Simulation results show that the proposed detector

Fig. 5 BER performance of proposed fixed combining detector and proposed adaptive detector with QPSK modulation.

achieves performance improvements with low complexity. The core idea of the proposed detector is that DFE and QRD-M detector are combined according to the adaptive D value, depending on the channel state. In other words, the transmitted layers of each subcarrier in good channel state are detected by only the DFE detector which has low complexity. And the remainder layers of each subcarrier in bad channel state are detected by QRD-M detector using adaptive M value which has good performance.

Because the detector of the layers of each subcarrier is selected based on the channel state, the proposed adaptive detector offers both low computational complexity and improved performance.

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