LETTER

Channel-Adaptive Detection Scheme Based on Threshold in MIMO-OFDM Systems*

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SUMMARY In this letter, an improved channel-adaptive detection scheme based on condition number combined with a QRD-M and CLLL algorithms is presented for MIMO-OFDM systems. The proposed scheme estimates the channel state by using the condition number and then the number of layers for the QRD-M is changed according to the condition number of channel. After the number of layers is determined, the proposed scheme performs the combined QRD-M and CLLL. Simulation results show that the BER curves of the proposed scheme and QRD-M using CLLL have similar performance. However, the complexity of the proposed scheme is about 27% less than QRD-M detection using CLLL.

key words: *V-BLAST, QRD-M, MIMO-OFDM, condition number*

1. Introduction

Multiple input multiple output (MIMO)-orthogonal frequency division multiplexing (OFDM) systems are considered to be a promising solution to enhance the performance in rich scattering wireless channel. MIMO-OFDM systems can offer increased spectral efficiency. One of the main challenges in the practical realization of MIMO systems lies in the efficient implementation of the detector, which needs to separate the spatially multiplexed data streams [1], [2]. For this reason, efficient detection schemes for MIMO system have attracted much interest in recent years.

V-BLAST is commonly used in MIMO system since it has relatively low complexity. The low complexity detection schemes such as zero forcing (ZF) and minimum mean square error (MMSE) detection are commonly used. The maximum likelihood detection (MLD) algorithm provides the best bit error rate (BER) performance for MIMO system. However, the computational complexity of ML detection algorithm grows exponentially with the number of transmit antennas, which make it impractical for use in a real system [3]. To reduce the MLD complexity, the QR decomposition M algorithm (QRD-M) scheme which has comparable performance to the QRD-M reduces the complexity by selecting the M candidate branches with the smallest accumulated metrics at each layer of the tree search. Parameter M is the number of candidate symbols. Because the number of antennas and the size of modulation set are large, QRD-M still has high computational complexity [4].

To alleviate the complexity of QRD-M, the combined QRD-M and complex Lenstra-Lenstra-Lovasz (CLLL) was proposed [5]. The BER performance of MIMO detection schemes using CLLL reduced-basis is the same as those that use real LLL (RLLL)-reduced basis [6]. The QRD-M using CLLL employs a new parameter T to reduce detection complexity. The QRD-M is executed for T layers ($T \leq N_T$), and then the CLLL is executed from the next $T+1$ layer. However, a fixed T may not be the best choice under time-varying channels. For this reason, a more improved channel-adaptive detection scheme based on condition number than the conventional QRD-M using CLLL is proposed for MIMO-OFDM systems. First, the proposed detection scheme calculates the condition number of channel. Second, parameter T is determined in accordance with the previous condition number value of channel.

It is shown that the BER performance of the proposed detection scheme is similar to that of QRD-M. In addition, to confirm in practical wireless channel, the performance of two channel states for known perfect channel state and known imperfect channel state is compared. Finally, the complexity of the proposed detection scheme is approximately 60% of the QRD-M and 73% of the QRD-M using CLLL.

2. System Model

Figure 1 shows MIMO-OFDM system model. An $N_T \times N_R$ MIMO system with N_T transmit and N_R receive antennas is considered. After a data stream is divided into N_T substreams, OFDM symbols are transmitted over N_T transmit antennas simultaneously.

$$\mathbf{Y} = \sum_{i=1}^{N_R} \sum_{j=1}^{N_T} \mathbf{h_{i,j}} \cdot \mathbf{x_j} + \mathbf{n_i} = \mathbf{H} \cdot \mathbf{X} + \mathbf{N}, \tag{1}$$

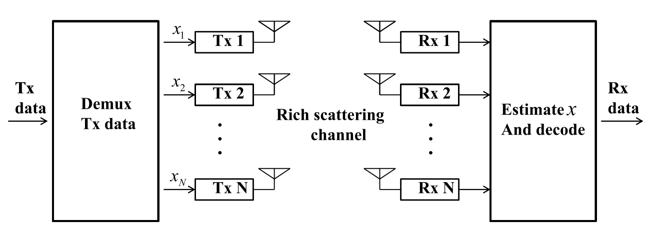

Fig. 1 MIMO-OFDM system model.

Manuscript received November 5, 2013.
Manuscript revised February 21, 2014.

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*This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No. 2012-000902.

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DOI: 10.1587/transinf.E97.D.1644

where i and j are receive and transmit antenna index, $\mathbf{X}$ and $\mathbf{Y}$ denote the $N_T \times 1$ transmit symbol vector and $N_R \times 1$ receive symbol vector respectively. $\mathbf{N}$ denotes the $N_R \times 1$ complex Gaussian additive noise vector. Finally, $\mathbf{H}$ is an $N_R \times N_T$ independent and identically distributed (i.i.d.) random complex matrix of multipath channel.

3. Channel-Adaptive Detection Scheme

3.1 Conventional QRD-M Using CLLL Algorithm

The conventional QRD-M using CLLL algorithm uses the parameter T due to reduction of complexity. The parameter T determines the number of layers for the QRD-M scheme ($T \le N_T$). Thus, QRD-M is executed until the T layers. And then, the complex lattice reduction (LR) -aided detection is executed at the rest layers ($N_T - T$). Among the decoded sequences, the most probable stream is chosen by likelihood test [5]. The whole algorithm is described as follows.

Step 1 : To improve the performance of the detection, $\|\mathbf{g_i}\|^2$ is calculated and ordered from large to small value and then, a index of the value is saved. $\mathbf{g_i}$ is the i-th row of the $\mathbf{G}$ matrix. The $\mathbf{G}$ matrix is determined as $\mathbf{G} = (\mathbf{H}^H\mathbf{H})^{-1}\mathbf{H}^H$. The columns of the channel matrix $\mathbf{H}$ are arrayed from well-condition channels to ill-condition channels according to the sorted index.

Step 2 : The QRD-M is executed from the first layer to T layer.

Step 3 : The LR-aided detection scheme using CLLL algorithm is executed from $T+1$ to N_T layer [5]. Table 1 shows the CLLL reduction algorithm. The LR-aided detection scheme using CLLL algorithm is executed for the M times. The parameter M represents surviving candidate streams. The CLLL algorithm is based on QR-decomposition of channel matrix. A new channel matrix $\tilde{\mathbf{H}}$ with QR-decomposition is described as $\tilde{\mathbf{H}} = \tilde{\mathbf{Q}}\tilde{\mathbf{R}} = \mathbf{HT}$, where $\mathbf{T}$ with determinant ± 1 is unimodular matrix. By using the this relation in Eq. (1), it is rewritten as follows,

$$\mathbf{Y} = \mathbf{HTT}^{-1}\mathbf{X} + \mathbf{N} = \tilde{\mathbf{H}}\mathbf{T}^{-1}\mathbf{X} + \mathbf{N} = \tilde{\mathbf{H}}\mathbf{Z} + \mathbf{N}. \quad (2)$$

The Moore-Penrose pseudo-inverse of the channel matrix $\tilde{\mathbf{H}}^{+}$ of the reduced channel matrix $\tilde{\mathbf{H}}$ is multiplied by the vector $\mathbf{Y}$.

$$\overline{\mathbf{Z}} = \tilde{\mathbf{H}}^{+}\mathbf{Y} = \mathbf{T}^{-1}\mathbf{X} + \overline{\mathbf{N}} = \mathbf{Z} + \overline{\mathbf{N}} \quad (3)$$

The estimated symbols $\hat{\mathbf{Z}}$ are as follows,

$$\hat{\mathbf{Z}} = Q(\overline{\mathbf{Z}}) = Q(\tilde{\mathbf{H}}^{+}\mathbf{Y}). \quad (4)$$

Here, the quantization $Q(\cdot)$ corresponds to a rounding operation. The estimated symbols are finally transformed from the original basis as $\hat{\mathbf{X}} = \mathbf{T}\hat{\mathbf{Z}} = \mathbf{TT}^{-1}\mathbf{X}$ [7].

Step 4 : The last stream maximizing the likelihood is selected among M streams, where M streams are as follows,

$$\begin{aligned} \hat{\mathbf{X}} &= [\hat{\mathbf{X}}^1, \cdots, \hat{\mathbf{X}}^m, \cdots, \hat{\mathbf{X}}^M], \\ \hat{\mathbf{X}}^M &= \{x_1^M, x_2^M, \cdots, x_{N_T}^M\}. \end{aligned} \quad (5)$$

Hence, the final decision value can be gotten as

$$\overline{\mathbf{X}} = \arg\min_{\hat{\mathbf{X}}^m} \left\|\mathbf{Y} - \mathbf{H}\cdot\hat{\mathbf{X}}^{\mathbf{m}}\right\|^2. \quad (6)$$

3.2 Proposed Detection Scheme

In this section, an improved channel-adaptive detection scheme based on condition number is proposed. Figure 2 shows the proposed detection scheme algorithm. First, the

Table 1 CLLL reduction algorithm.

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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
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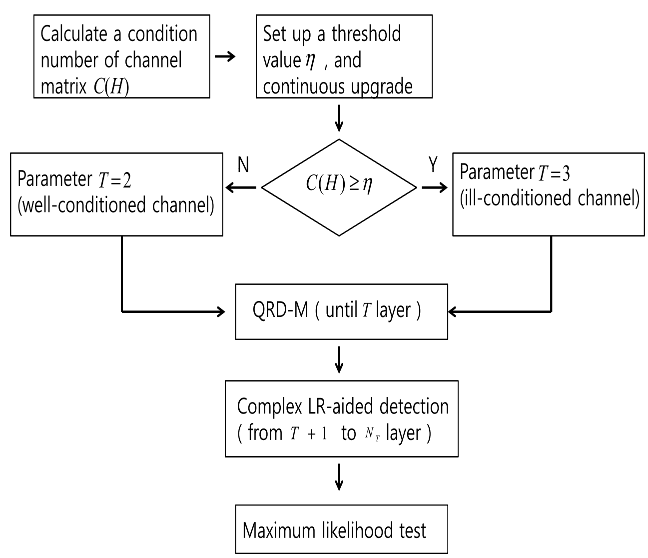

Fig. 2 The flowchart of channel-adaptive QRD-M + CLLL algorithm in 4×4 MIMO system.

proposed detection scheme calculates the condition number of channel. Condition number of channel $C_p(H)$ is as follows,

$$C_p(H) = \|H\|_p \cdot \|H\|_p\,, \tag{7}$$

$$\|H\|_1 = \sum_{i=1}^{n} |h_i|,\ \|H\|_2 = \left(\sum_{i=1}^{n} h_i^2\right)^{\frac{1}{2}},\ \|H\|_p = \left(\sum_{i=1}^{n} h_i^p\right)^{\frac{1}{p}}. \tag{8}$$

The condition number of channel $C_p(H)$ is determined according to the parameter p. The parameter p is matrix norm. The proposed scheme is set to 1-norm because of complexity. If the condition number value $C(H)$ is small, channel matrix H is said to be well-conditioned. On the other hand, $C(H)$ is said to be ill-conditioned. Therefore, the condition number value of channel matrix $C(H)$ describes an significant influence on the performance. The proposed detection scheme decides channel state based on condition number value. To choose the suitable parameter T, a threshold value η is cofigured. $C^i(H)$ is accumulated to calculate the threshold value η when signals are received from the transmit antennas, where $C^i(H)$ is the i-th condition number value of channel. And then, the arithmetic mean value is calculated. Thus, the threshold value η can be expressed as

$$\eta = \frac{1}{2}\left(\eta_{th}^0 + \frac{1}{n}\sum_{j=1}^{n} \eta^i(H)\right), \tag{9}$$

where η_{th}^0 is initial condition number of channel and $\eta^j(H)$ is j-th condition number of channel. When transmitted symbol is received, the threshold value η is upgraded since the channel state of received symbol is changed consistently in wireless communication environment. After choosing the η, the receiver applies to the parameter $T = \lfloor 3N_T/4 \rfloor$ of combined QRD-M and CLLL for poorly conditioned channels and the parameter $T = \lfloor N_T/2 \rfloor$ of combined QRD-M and CLLL for well-condition channels. Although the performance of $T = \lfloor 3N_T/4 \rfloor$ is better than $T = \lfloor N_T/2 \rfloor$, the complexity of $T = \lfloor 3N_T/4 \rfloor$ is reduced about 37.8% of the complexity of $T = \lfloor 3N_T/4 \rfloor$ for 4×4 MIMO-OFDM system. And then the QRD-M is executed for the first T layer. After T layer, the complex LR-aided detection is executed from $T + 1$ to N_T layer. Finally, the maximum likelihood test is performed among M streams.

4. Simulation Results

In this section, the BER performance of the proposed detection scheme and other detection schemes is illustrated by simulation. The simulation considers a MIMO-OFDM system which the number of subcarriers is 64. The MIMO-OFDM system with $N_T = N_R = 4$ in the Rayleigh fading channel model is investigated. The simulation is conducted with assumption of perfect channel state information at the receiver.

Figure 3 shows the BER performance of the proposed detection scheme based on condition number of channel with 16QAM. The proposed detection scheme has better BER performance than linear detections such as ZF and MMSE. The linear detections can't be estimated exactly at the first layer. However, the proposed detection scheme is accurately estimated by using QRD-M. Compared with the QRD-M using CLLL, the proposed detection scheme is more efficient than $T = 1$ and $T = 2$ about $2 \sim 6$ dB. BER performance of the proposed detection scheme has almost the same performance in case of the $T = 3$. However, the complexity of proposed detection scheme is reduced about 27% in comparison with the complexity of the QRD-M using CLLL ($T = 3$). And, BER performances of the proposed detection scheme and conventional QRD-M are compared. The performance decrease of the proposed detection scheme is roughly 3 dB. But, the complexity of the proposed scheme is reduced about average 40% in comparison with the complexity of QRD-M.

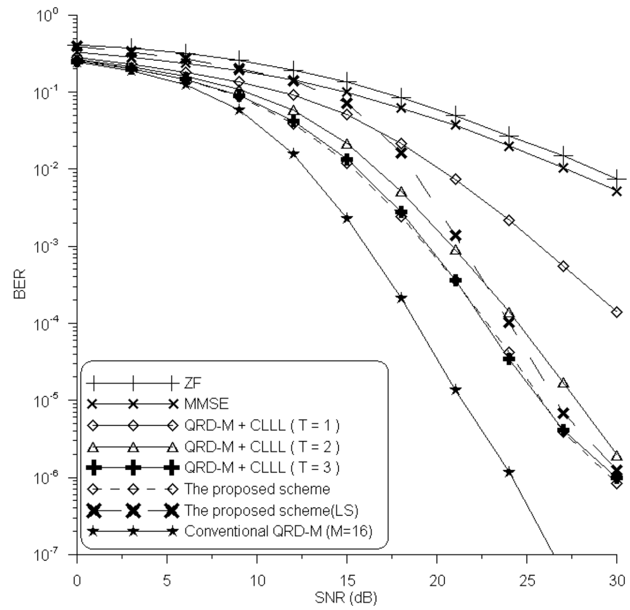

Fig. 3 BER performance of the proposed detection scheme and other detection schemes for 4×4 MIMO system with 16QAM.

In case of imperfect channel state, the result for proposed scheme using least square (LS) channel estimation algorithm is shown in Fig. 3. If the SNR is low, the BER performance is considerably worse because of imperfect channel state. However, the BER curve of the proposed scheme using LS channel estimation algorithm can be predicted similarly by comparing proposed scheme of perfect channel state when SNR is increased. Therefore, the proposed scheme can satisfy outstanding performance in actual wireless environment.

Figure 4 shows the BER performance of the proposed detection scheme based on condition number of channel with QPSK. The proposed detection scheme has better BER performance than linear detections and QRD-M using CLLL ($T = 1, 2$). Compared with the QRD-M using

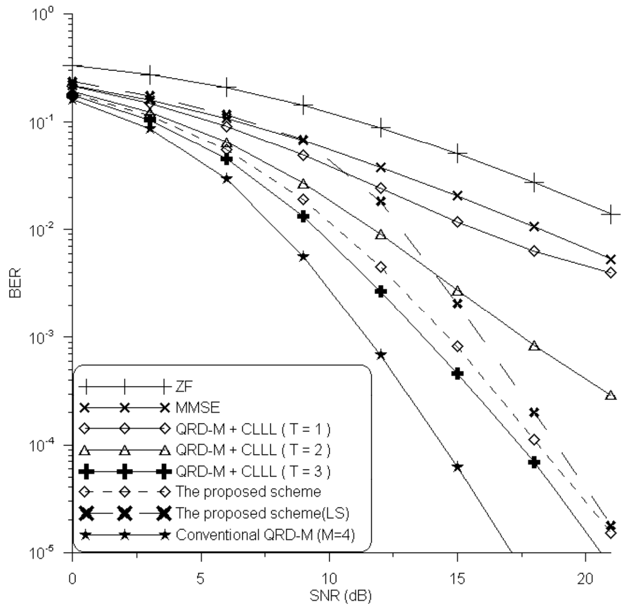

Fig. 4 BER performance of the proposed detection scheme and other detection schemes for 4×4 MIMO system with QPSK.

CLLL ($T = 3$) and QRD-M, the performance degradation of the proposed detection is about $1 \sim 5$ dB. But complexity of proposed detection scheme can be reduced less than one thirds.

5. Conclusion

In this letter, a novel channel-adaptive detection scheme using the condition number is proposed. Because a parameter, T, changes according to channel state, the performance of proposed detection scheme is better than that of the conventional QRD-M. Moreover, the proposed detection scheme has lower complexity than the conventional QRD-M.

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