Hybrid MIMO-OFDM Detection Scheme for High Performance
Young-Min Ko, Dong-Hyun Ha, Chang-Bin Ha, Hyoung-Kyu Song

Abstract—In recent years, a multi-antenna system is actively used to improve the performance of the communication. A MIMO-OFDM system can provide multiplexing gain or diversity gain. These gains are obtained in proportion to the increase of the number of antennas. In order to provide the optimal gain of the MIMO-OFDM system, various transmission and reception schemes are presented. This paper aims to propose a hybrid scheme that base station provides both diversity gain and multiplexing gain at the same time.

Keywords—DFE, diversity gain, hybrid, MIMO, multiplexing gain.

I. INTRODUCTION

ORTHOGONAL frequency division multiplexing (OFDM) is an effective technique to combat multi-path fading in wireless channel. OFDM is a multi-carrier modulation technique where data symbols modulate a parallel collection of regularly spaced the sub-carrier. The sub-carrier has the minimum frequency separation to maintain orthogonality. OFDM is commonly used for high data rate in wireless communication and has been used in various wireless communication systems. Moreover, transmission systems based on OFDM can be extended to a multiple input multiple output (MIMO) system in order to obtain high performance. MIMO system has been studied to achieve the improved performance in wireless system. The MIMO system can achieve high reliability and high data rate without the use of additional bandwidth and energy consumption in wireless communication. Therefore, base station (BS) can achieve reliability and throughput with multiple antennas by using MIMO multiplexing schemes. One of the typical MIMO multiplexing schemes is vertical Bell laboratories layered space time (V-BLAST). The V-BLAST is an effective MIMO-OFDM system which provides spatial multiplexing gain and reception diversity gain. For this reason, a lot of detection algorithms compared with V-BLAST have been proposed for the MIMO-OFDM systems. Among those detection algorithms for V-BLAST, the linear detection schemes are popular way to detect the received signals with low complexity. However, the linear detection schemes have the worse performance among MIMO detection schemes for noise enhancement. The ordered successive interference cancellation (OSIC) and the decision feedback equalization (DFE) detection scheme has better performance than linear detection. Because the detection of the first signal determines the overall system performance, the accurate detection of the first signal is very important to obtain high performance in DFE scheme [1][5][6]. In this paper, an efficient DFE using a cyclic delay diversity (CDD) scheme is proposed in the MIMO-OFDM system [2]. The proposed scheme obtains high performance by the accurate detection of the first signal [4].

II. SYSTEM MODEL

Fig. 1 shows the 4x2 MIMO-OFDM system. The source is a base station and uses four transmission antennas. The destination is a mobile device and uses two antennas. Let $s = \begin{bmatrix} s_1 & s_2 & \cdots & s_M \end{bmatrix}^T$ denote the $M \times 1$ vector of transmit symbols, then the corresponding $N \times 1$ receive signal vector is given by

$$y = Hx + n$$

where $n$ is zero-mean Gaussian noise with variance $\sigma_n^2$ and $H = [h_1 \ h_2 \ \cdots \ h_N]^T$ is i.i.d. random complex vector of multi-path channel with each element of $h_n = [h_{n1} \ h_{n2} \ \cdots \ h_{nM}]^T$.

III. DFE SCHEME OF V-BLAST SYSTEM

V-BLAST is used to detect the multiple received signals in the MIMO-OFDM system. In V-BLAST with the
DFE scheme, the multiple received signals are detected by sequential detection scheme using QR decomposition. Detection method is as follows:

\[ G_{MMSE} = (H^H H + \sigma^2 I_M)^{-1} H^H. \]  

The minimum mean square error (MMSE) detector leads to the filter G matrix, where \( I_M \) is \( M \times M \) identity matrix. So, the channel matrix \( H \) is can be expressed as follows:

\[
H = \begin{bmatrix} H & \alpha I_M \end{bmatrix}.
\]  

The DFE scheme which is based on QR decomposition avoids the calculation of the pseudo-inverse matrix in every layer. In this QR decomposition, \( ||G||^2 \) is calculated and sorted from the smallest to the largest value. \( H_{sort} \) is also made by the way that the columns of channel coefficient \( H \) is sorted equally with \( ||G||^2 \). Sorted \( H_{sort} \) is decomposed to Q and R through QR decomposition.

\[ G_{MMSE} = (H^H H^{-1})H^H. \]

The matrix \( Q \) is an orthogonal matrix satisfied with \( Q^H Q = I \) and \( R \) is an upper triangular matrix. \( M \times 1 \) vector that \( Q \) ingredient is removed can be gained by using \( Q^H \).

\[
Z = Q^H Y = RX + \eta.
\]

where \( Z = [z_1 z_2 \ldots z_M]^T \) and \( \eta = Q^H W \). Based on such matrix, the first detected signal is expressed by removing channel ingredient of signal which would be first detected,

\[
\hat{X}_M = Q[Z_M/r_{M,M}] = Q[(r_{M,M}X_M + \eta_M)/r_{M,M}].
\]

After the first detection step, extra signals can be detected as follows:

\[
\hat{X}_{M-1} = Q[Z_{M-1} - r_{M-1,M} \cdot \hat{X}_M]/r_{M-1,M-1} \]
\[
\hat{X}_{M-2} = Q[(Z_{M-2} - (r_{M-2,M} \cdot \hat{X}_M + r_{M-2,M-1} \cdot \hat{X}_{M-1}))/r_{M-2,M-2}] \]
\[
\vdots \]
\[
\hat{X}_m = Q[(Z_m - \sum_{i=m+1}^M r_{m,i} \cdot \hat{X}_i)/r_{m,m}] \]
\[
\vdots \]
\[
\hat{X}_1 = Q[(Z_1 - \sum_{i=1}^M r_{1,i} \cdot \hat{X}_i)/r_{1,1}].
\]  

The DFE scheme sequentially detects signals. The first detected signal affects generally from next detected signal to the final detected signal. Also, the DFE scheme is not necessary to calculate the inverse matrix of the channel repeatedly. Therefore, the DFE scheme based on the QR decomposition has characteristic that complexity is very low.

**IV. PROPOSED HYBRID DETECTION SCHEME**

In this paper, the configuration of transmission signals which use the CDD scheme is proposed for the improved diversity gain and multiplexing gain at once. The accurate detection of the first signal can be obtained by the proposed configuration of transmission signal. In Fig. 1, the proposed scheme transmits the cyclically delayed signals on three antennas in order to obtain the diversity gain. Also, the proposed scheme transmits the other signals on one antenna in order to obtain the multiplexing gain. The proposed configuration of transmission signals applying the CDD scheme is presented in Table I. In each time slot, the four signals are transmitted from the base station by antennas. These signals are estimated in the mobile by the DFE scheme. In the CDD scheme, the cyclically delayed symbols give only an effect on the mobile as multi-path. \( \delta_i \) is defined as the cyclic delay length of the \( l \)-th antenna in the base station. The optimal cyclic delay \( \delta_i \) is defined as follows:

\[
\delta_l = |\delta_1 - \delta_2| = \frac{M}{l},
\]
where $A$ is the modulation order and $M$ is the number of carriers. In Fig. 1, base station transmits $S_{2^{n-3},\delta_1}$, $S_{2^{n-3},\delta_1}$ at $T_{X_1}$ and $T_{X_2}$. Therefore, those two antennas provide a diversity gain to the mobile as a diversity node. $S_{2n-3}$ and $S_{2n-2}$ are retransmitted from the $T_{X_3}$ and $T_{X_4}$. Therefore, the two antennas provide a multiplexing gain to the mobile as a multiplexing node [3].

In the mobile, the received signals are expressed in Table II. $H_{1i}$, $H_{2i}$, $H_{3i}$ and $G_{1i}$ are the channels that connect the signals from base station to the mobile at the $i$-th antenna of the mobile. The noise at the $i$-th antenna of the mobile at time $n$ is represented by $N_{ni}$. Therefore, the received symbols at the $i$-th antenna of the mobile at time $n$ are expressed as follows:

$$Y_{ni} = S_{2n-5,\delta_1}H_{1i} + S_{2n-5,\delta_1}H_{2i} + S_{2n-5}H_{3i} + S_{2n-4}G_{1i} + N_{ni},$$ (10)

The non-delayed signal and the CDD signal are expressed as follows:

$$s(n) = \frac{1}{M} \sum_{k=0}^{M-1} S(k) \cdot e^{j\frac{2\pi}{M}kn},$$ (11)

$$s_{\delta_1}(n) = \frac{1}{M} \sum_{k=0}^{M-1} e^{-j\frac{2\pi}{M}k\delta_1} \cdot S(k) \cdot e^{j\frac{2\pi}{M}kn},$$ (12)

where $M$ denotes the number of carriers. Therefore, Eq. (10) can be expressed as follows:

$$Y_{ni} = S_{2n-5}(H_{1i} + H_{2i}) \cdot e^{-j\frac{2\pi}{M}k\delta_1} + H_{3i} \cdot e^{-j\frac{2\pi}{M}k\delta_2} + S_{2n-4}G_{1i} + N_{ni}.$$ (13)

The received symbols in the frequency domain are expressed again as follows:

$$Y_{ni} = S_{2n-5}H_{1i} + S_{2n-4}G_{1i} + N_{ni},$$ (14)

where $H_1$ and $H_2$ are channel applying CDD through the three paths. The proposed scheme obtains diversity gain and multiplexing gain at the same time. Also, $H_1$ and $H_2$ are the largest columns of channel coefficient $H$. Therefore, $S_{2n-5}$ is detected as the first detected signal. And next time, $S_{2n-4}$ is detected. As a result, the proposed scheme provides the improved performance compared with the conventional DFE scheme.

### Table II: The received signals at the mobile

<table>
<thead>
<tr>
<th>Time slot</th>
<th>$Y_{x_1}$</th>
<th>$Y_{x_2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T = 1$</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$T = 2$</td>
<td>$Y_{2,1} = S_{1,\delta_1}H_{1,1} + S_{1,\delta_2}H_{1,2} + S_{2,\delta_1}G_{1,1} + N$</td>
<td>$Y_{2,2} = S_{1,\delta_1}H_{1,2} + S_{1,\delta_2}H_{2,2} + S_{2,\delta_1}G_{1,2} + N$</td>
</tr>
<tr>
<td>$T = 3$</td>
<td>$Y_{3,1} = S_{2n-5,\delta_1}H_{1,1} + S_{2n-5,\delta_1}H_{1,2} + S_{2n-5,\delta_1}H_{2,1} + S_{2n-4,\delta_1}H_{3,1} + S_{2n-4,\delta_1}H_{3,2} + S_{2n-4,\delta_1}H_{2,2} + S_{2n-4,\delta_1}H_{2,2} + S_{2n-4,\delta_1}H_{3,2} + N$</td>
<td>$Y_{3,2} = S_{2n-5,\delta_1}H_{1,2} + S_{2n-5,\delta_1}H_{2,2} + S_{2n-5,\delta_1}H_{3,2} + S_{2n-4,\delta_1}H_{3,2} + S_{2n-4,\delta_1}H_{3,2} + N$</td>
</tr>
<tr>
<td>$T = \infty$</td>
<td>!</td>
<td>!</td>
</tr>
</tbody>
</table>

### Table III: The configurations of transmission signals

<table>
<thead>
<tr>
<th>Antenna Configuration</th>
<th>$TX_1$</th>
<th>$TX_2$</th>
<th>$TX_3$</th>
<th>$TX_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 – 2</td>
<td>$S_{2n-3}$</td>
<td>$S_{2n-3,\delta_1}$</td>
<td>$S_{2n-2}$</td>
<td>$S_{2n-2,\delta_1}$</td>
</tr>
<tr>
<td>3 – 1</td>
<td>$S_{2n-3,\delta_1}$</td>
<td>$S_{2n-3,\delta_2}$</td>
<td>$S_{2n-3}$</td>
<td>$S_{2n-2}$</td>
</tr>
</tbody>
</table>
than the conventional DFE scheme in the 2x2 MIMO-OFDM system using two antennas. The proposed scheme has a higher BER performance than the 4x2 MIMO-OFDM system which applies the configuration of 2 − 2 transmission signals using four antennas. According to the simulation results, the proposed scheme can obtain the improved BER performance effectively.

VI. Conclusion

In this paper, the hybrid detection scheme is proposed in the MIMO-OFDM system. The proposed configuration of transmission signals provides the multiplexing gain and the diversity gain. Three antennas use the CDD scheme in order to provide the diversity gain. The other antenna transmits the different signals in order to provide the multiplexing gain. Therefore, the proposed scheme can obtain the diversity and multiplexing gain at same time.

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REFERENCES


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