Improvement of transmission performance by variable precoding in MIMO transmission

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Abstract: Conventional methods using precoding in MIMO transmission generally need channel state information (CSI) at the transmitter. In this paper we consider a method where precoding weights are temporally varied. The method does not require the transmitter to obtain CSI. By combining the method with FEC and a block interleaver, it outperforms the existing MIMO transmission schemes without precoding. We evaluate the performance of the proposed system by computer simulations and clarify the effectiveness of the system quantitatively. Since the method does not require CSI at the transmitter, it is particularly effective where MIMO transmission is applied to broadcast-type wireless communication systems.

Keywords: MIMO transmission, precoding, temporal variation, FEC, interleave

Classification: Wireless Communication Technologies

References


1 Introduction

Recently, with the dissemination of highly-functional devices, as demonstrated by smart-phones, and the expansion of services with high quality transmission, reliable and stable transmission of mass data is required. However, there is a limit on realistic high-capacity transmission in the limited frequency band. In order to make more expansion of capacity possible, Multiple Input-Multiple Output (MIMO) systems have been used [1, 2, 3].

In a MIMO system multiple signals are transmitted at the same time from multiple transmitting antennas. These signals interfere with each other at the receiver. Thus, it is necessary to separate the received signals. The signal separation methods are classified into two types: one where Channel State Information (CSI) is known at both the transmitter and receiver, and another where CSI is known only at the receiver. A representative example of the former is eigen-mode transmission method (E-SDM) [4], where the transmitted weights matching to CSI are multiplied by the transmitted signals. These weights are called precoding. The latter includes spatial filtering and Maximum Likelihood Detection (MLD). Since these methods require CSI only at the receiver, they are suitable in environments where channel state fluctuation is rapid [5]. Furthermore, signal detection by MLD provides generally higher quality than the other methods. The precoding is not usually applied in the spatial filtering and MLD. However, when it is used in such systems, the transmission performance varies according to the channel characteristics and precoding weights. If precoding is adopted in the spatial filtering and MLD to improve the transmission performance, it is necessary to use appropriate weights matching to CSI [6, 7]. Therefore, when channel is fluctuating by fading, it is necessary to change the precoding weights to follow the fading. On the other hand, if precoding weights are adjusted to follow the fading, E-SDM provides higher channel capacity than the others. Hence, if we can obtain CSI at the transmitter and use precoding, there is no merit to use methods like the spatial filtering and MLD.

In this paper we consider a method where precoding weights are temporally varied in a MIMO-MLD transmission system. The proposed system provides higher quality without requiring CSI at the transmitter by combining the method with FEC and a block interleaver. By computer simulations, we show that the proposed system outperforms the existing MIMO transmission schemes without the precoding. In the method, we assume the
temporally-changing precoding weights are pre-determined and repeated for transmission. Since the information of precoding weights is required at the receiver for demodulation, the weights must be pre-determined. However, it is not necessary in the method that the weights are matched to CSI. Only variation of the weights is required. Therefore, in the proposed method the precoding weights are pre-determined and they are repeatedly used synchronously between the transmitter and receiver.

Moreover, in recent years MIMO application is studied in broadcasting sector [8]. Since this method does not require CSI at the transmitter, it is particularly effective where MIMO transmission is applied to broadcast-type wireless communication systems. As an application example of the proposed method, we present the performance in a broadcast-type communication situation at the end of the paper.

2 Precoding at MIMO-MLD transmission

Generally, CSI is not considered at the transmitter and precoding is not used in MIMO-MLD transmission. On the other hand, if CSI is known and the most suitable precoding weights are configured to follow the fading, it is possible to improve the transmission performance such as the average BER over fading. The representative method is the optimal minimum distance-based precoding. This method improves the transmission performance of MLD via multiplying signals by transmitting weights at the transmitter that maximize the smallest Euclidean distance between possible replicas at the receiver [7, 8]. However, since the method needs CSI at the transmitter, the complexity of the system increases comparing to the existing MLD. In contrast, the proposed method is characterized by not requiring CSI at the transmitter because the method uses pre-determined precoding weights and they are repeated.

In this paper we assume $2 \times 2$ MIMO-MLD system with precoding. We express the information symbols by $s_1$ and $s_2$ and the precoding weight by $P_r$. The transmitting signals $x_1$ and $x_2$ are represented by the following expression.

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = P_r \begin{bmatrix} s_1 \\ s_2 \end{bmatrix}$$

(1)

Additionally, we express the channel matrix between the transmitter and the receiver by $H$ and noise vector by $z$. Then, the received signals at the two antennas $y_1$ and $y_2$ are represented as:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = H \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + z = H P_r \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + z$$

(2)

MLD is applied to $y_1$ and $y_2$ on the basis that precoding $P_r$ is known at the receiver.

Here, we describe the method to construct the precoding $P_r$. Generally, in order to obtain the optimum reception performance, we need the orthogonal condition where the two transmitting signals $x_1$ and $x_2$ are orthogonal to each
other. We express the weight matrix of the precoding $P_r$ as:

$$
P_r = \begin{bmatrix}
p_{11} & p_{12} \\
p_{21} & p_{22}
\end{bmatrix} \quad (3)
$$

The orthogonal condition can be expressed as follows:

$$
p_{11}p_{21}^* + p_{12}p_{22}^* = 0 \quad (4)
$$

Where $^*$ indicates the complex conjugate.

Moreover, we impose another constraint where the total transmission power is constant all the time and expressed as:

$$
|p_{11}|^2 + |p_{12}|^2 + |p_{21}|^2 + |p_{22}|^2 = 2 \quad (5)
$$

The precoding weights used in this paper are generated randomly under the constraint of two conditions given by Eqs. (4) and (5). Since we have four variables while the number of the constraints is two, we have two degrees of freedom and the elements of the precoding matrix cannot be deterministically decided. Here, as one way to decide the value, we use complex random numbers where the phases are random and the amplitudes are unity. In other words, we express two of the four elements of Eq. (3) by $e^{i\theta_1}$ and $e^{i\theta_2}$. $\theta_1$ and $\theta_2$ are chosen randomly from range of $0–2\pi$ (rad) independently each other. The remaining two elements are calculated using the conditions of Eqs. (4) and (5), $e^{i\theta_1}$ and $e^{i\theta_2}$.

The proposed method switches multiple precodings temporally satisfying the orthogonal conditions. The transmission performance varies by switching the precoding weights. We combine this method with FEC and a block interleaver. The block size of the interleaver is set larger than the switching period of the precoding weights. As a result of this setting, the transmission performance varies by precodings within one interleaver block. The burst errors generated at the bad precoding moments are expected to be removed by interleaver and FEC, since the transmission performance at the other moments using other precoding weights is expected better.

### 3 Performance evaluation by simulations

#### 3.1 Simulation system

We evaluated the performance of the proposed method by computer simulations. Fig. 1(a) shows the system model for single user environment. Simulation parameters are summarized in Table I. The numbers of the transmitting and the receiving antennas are 2 and 2, respectively. The modulation is single carrier QPSK. Each element of the channel matrix is generated according to i.i.d. quasi-static Rayleigh fading. We use convolutional coding and hard decision Viterbi decoding as the FEC system. In the evaluation the number $N$ of the precoding switching within an interleaving block is varied. Here, the interleave size is assumed 2000 bits. For example, for $N = 5$, the precoding weights are switched at every 400 bits. In this paper, the fading fluctuation is assumed static during the interleave block. If the channel varies during the block due to the fading, FEC and the interleaver effectively correct.
the error and the merit of the proposed system decreases. Therefore, we can say the improvement of the proposed system compared to the conventional system is large in slow fading environments.

Fig. 1(b) shows the system model of broadcast-type communication with one transmitter and multiple receivers. Channel matrix $H$ is different for each user in this environment. $K$ is the number of the receiving users.

### Table I. Simulation parameters.

| Number of transmitter and receiver antennas | $2 	imes 2$ |
| Modulation                     | QPSK         |
| Channel                         | Quasi-static i.i.d. Rayleigh fading |
| FEC                             | Convolutional encoding ($R = 1/2$, $L = 7$) + Viterbi decoding (Hard decision) |
| Interleave block size          | 100 bit × 20 bit |

the error and the merit of the proposed system decreases. Therefore, we can say the improvement of the proposed system compared to the conventional system is large in slow fading environments.

Fig. 1(b) shows the system model of broadcast-type communication with one transmitter and multiple receivers. Channel matrix $H$ is different for each user in this environment. $K$ is the number of the receiving users.

#### 3.2 BER performance of proposed method in single user environment

Fig. 2(a) shows the BER performance when the proposed method is used in the single user environment. The BER values are averaged over the fading variation. In the figure, $N$ is changed between 1–20. As a reference, the figure also shows the BER performance of MLD system without precoding. When $N = 1$, the performance is the same as that without precoding. It also can be seen from the figure that the improvement of the performance increases with increasing $N$, and the upper limit of the improvement is obtained at $N = 10$. The amount of the maximum improvement versus conventional method without the precoding is 2.7 dB.
3.3 Application to broadcast-type communication

Recently, an application of MIMO is considered in broadcast-type communication. In such case the proposed method is particularly effective for improvement of the transmission performance. Since in broadcast-type communication multiple users receive the same signals but the channels are different for each user, even if CSI is known at the transmitter, the best precoding weights cannot be configured for all users simultaneously. Therefore, the proposed method, where the transmitter does not need CSI and the precoding weights are not matched to CSI optimally, is effective in such situation.

Fig. 2(b) shows Average BER and Maximum BER (max BER) for the case $N = 10$ and $K = 10$ assuming the system model presented in Fig. 1(b). Average BER is the averaged BER value of all users over the fading fluctuation. Max BER is the averaged BER of the worst BER among 10 users and averaged over the fading. The figure shows that max BER of the proposed method is improved by 4.5 dB compared to the conventional method without

Fig. 2. BER characteristics of proposed system
precoding. It shows that the proposed method is more effective in improvement of the worst case. In broadcast-type communication systems, system design tuned to the lowest quality user is required. The proposed method is particularly effective in such system.

4 Conclusion

In this paper we proposed a new MIMO precoding system where the precoding weights are temporally varied in MIMO-MLD transmission system. By combining it with FEC and a block interleaver, the proposed method effectively improves the transmission performance. We evaluated the performance of the proposed method by simulations. As a result, we show the transmission performance improves with the increasing number of the precoding switching. The upper limit of the improvement is obtained when the number of switching is around 10. Additionally, we show that the proposed method is particularly effective for MIMO in broadcast communication systems where the ideal precoding weights matched to CSI cannot be configured for all users simultaneously.