Regularized Block Diagonalization Precoding Transmission Scheme Using Relay in NOMA

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Abstract—**In Multiuser Multiple Input Multiple Output (MU-MIMO) system, Block Diagonalization (BD) and Regularized Block Diagonalization (RBD) are schemes which completely suppress Inter-User Interference (IUI). BD and RBD use the same number of RF chains and transmit antennas as the number of data streams in general. This paper proposes a RBD precoding transmission scheme using relay in Non-orthogonal Multiple Access (NOMA) system to reduce complexity of transmitter structure. The proposed scheme uses only half the number of RF chains and transmit antennas compared to the conventional RBD scheme. The number of Singular Value Decomposition (SVD) of the proposed scheme is also reduced compared to the conventional RBD, while Successive Interference Cancellation (SIC) is needed additionally. However, the proposed algorithm can achieve low computational complexity since SIC is simpler than SVD. However, the proposed scheme has poor BER performance compared to the conventional RBD. Therefore, further study is needed to increase the BER performance while the complexity is reduced.**

Index Terms—**multiuser MIMO, Regularized Block Diagonalization (RBD), relay, Non-orthogonal Multiple Access (NOMA), precoding**

I. Introduction

A number of schemes have been studied to meet the challenging requirements of 5G wireless communication, such as improved capacity and high spectral efficiency [1]. Especially, Multiuser Multiple Input Multiple Output (MU-MIMO) system can achieve high capacity when multiple data streams of multiple users are accommodated in single physical cannel. Therefore, if any other users' beam patterns are not suppressed, Inter User Interference (IUI) occurs inevitably for a certain user [2]. Block Diagonalization (BD) and Regularized Block Diagonalization (RBD) are known as techniques to achieve perfect IUI nulling. IUI can be mitigated by exploiting precoding vector which is belonged to null space of certain user's channel. Therefore, the MU-MIMO broadcast channel is decomposed into multiple parallel Single User Multiple Input Multiple Output (SU-MIMO) channel by employing BD and RBD precoding algorithms. RBD technique achieves better BER performance than the conventional BD by taking the noise term into account [3].

Non-orthogonal Multiple Access (NOMA) also can address some of these challenges for 5G. In 5G wireless system, NOMA algorithm provides high spectral efficiency. Unlike conventional orthogonal multiple access schemes, NOMA can accommodate much more users via non-orthogonal resource allocation. In the NOMA scheme via power domain multiplexing with a Successive Interference Cancelation (SIC) receiver in the downlink, signals for different users are linearly added up under certain power partitions [4]. Power allocation depends on the user's channel condition. At the receiver, SIC is needed for detection.

In this paper, complexity of transmitter's hardware is reduced by exploiting RBD and NOMA. Conventional RBD uses transmit antennas and RF chains which are equal to or greater than the number of data streams in general. The RBD precoding transmission scheme using relay in NOMA uses only half the number of RF chains and transmit antennas compared to the conventional RBD. The number of Singular Value Decomposition (SVD) of the proposed scheme is also reduced compared to the conventional RBD, while Successive Interference Cancellation (SIC) is needed additionally. But the proposed algorithm can achieve low computational complexity because SIC is simpler than SVD.

II. Proposed Scheme

A. System Model

Fig. 1 is a system model of the proposed scheme. In this paper, a downlink channel of the MU-MIMO system is considered. N_u users are connected to a base station and classified as a relay or destination shown as Fig. 1. Transmit signal vectors which are allocated certain power are superposed to reduce the number of data streams. Fig. 1 shows the process in which the superposed transmit signal vector is transmitted from the base station to the relay and from the relay to the destination.

The number of the k th user's receive antennas is N_k. The total number of receive antennas can be expressed as follows,

$$N_r = \sum_{k=1}^{N_u} N_k \tag{1}$$

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The transmit signal vector $x_k \in \mathbb{C}^{S_k \times 1}$ is defined for the k th user. S_k is the number of the k th user's data streams. The total number of data streams is expressed as follows,

$$S = \sum_{k=1}^{N_u} S_k \tag{2}$$

For the sake of simplicity, it is assumed that each of the users has one transmit antenna and the total number of data streams S is equal to the number of users N_u. Power allocation factor $\sqrt{P_k}$ is multiplied by the k th user's data x_k where $\sqrt{P_k}$ satisfies the condition expressed as follows,

$$\sum_{k=1}^{N_u} \left(\sqrt{P_k}\right)^2 = 1 \tag{3}$$

X_k which is transmitted from the base station to the relay can be expressed as linear addition of the $\sqrt{P_k}x_k$. After SIC at the relay, estimated data is transmitted from the relay to the destination.

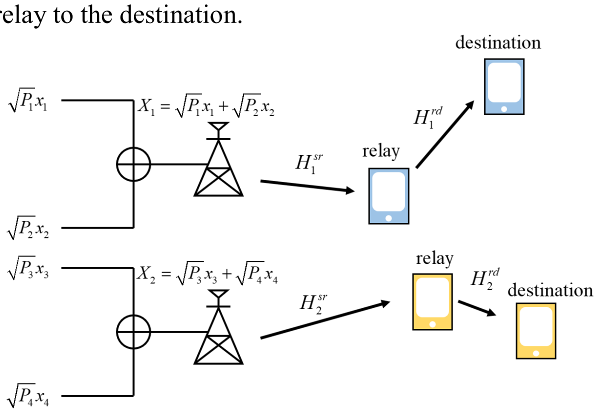

Figure 1. A system model of the multiuser MIMO downlink.

B. Proposed Scheme

First, all users are classified as a relay or a destination according to certain criteria. The criteria for classifying the relay and the destination is power of the channel $\mathbf{H} \in \mathbb{C}^{N_u \times S}$ between the base station and all users. A large power of the channel indicates that the channel has the good condition. A channel with a small power indicates a bad channel condition. Users which have good channel condition become the relay. In contrast, users with bad channel condition become the destination. In this paper, for the sake of simplicity, the system model with 4 users is considered as in Fig. 1. Two users which have good channel condition relatively are chosen as the relay. The others which have bad channel condition become the destination. Then, a certain power which is related to the power of the channel $\mathbf{H}$ is allocated to transmit signal vector x_k by multiplying the power allocation factor. The power allocation factor can be expressed as follows,

$$\begin{aligned} P_{2k-1} &= \frac{\|\mathbf{H}_{2k}\|^2}{\|\mathbf{H}_{2k-1}\|^2 \|\mathbf{H}_{2k}\|^2} \frac{2}{N_u} \\ P_{2k} &= \frac{2}{N_u} - P_{2k-1} \end{aligned} \tag{4}$$

Small power is assigned to the relay with good channel condition and large power is assigned to the destination with bad channel condition. X_k which is a linear addition of the power allocated signal $\sqrt{P_k}x_k$ can be expressed as follows,

$$X_k = \sqrt{P_{2k-1}}x_{2k-1} + \sqrt{P_{2k}}x_{2k} \tag{5}$$

Note that the number of data streams S can be reduced to $\frac{S}{2}$ by exploiting power domain multiplexing. This indicates that the number of transmit antennas and RF chains is also reduced by half.

X_k is transmitted to the relay through the channel $\mathbf{H}^{sr} \in \mathbb{C}^{\frac{N_u}{2} \times \frac{S}{2}}$ between the base station and the relay. Here, the RBD precoding scheme is exploited to suppress IUI perfectly. Unlike the conventional BD, RBD scheme take the noise term into account to achieve better BER performance. In [5-6], the k th users' precoding matrix $\mathbf{F}_k$ is defined as follows,

$$\mathbf{F}_k = \tilde{\beta}\tilde{\mathbf{F}}_k\overline{\mathbf{F}}_k \tag{6}$$

where the scaling factor $\tilde{\beta}$ represents a real positive number. $\tilde{\mathbf{H}}_k^{sr}$ which is a combined channel matrix except the k th user's channel can be written as follows,

$$\tilde{\mathbf{H}}_k^{sr} = \left[\left(\mathbf{H}_1^{sr}\right)^T, \cdots, \left(\mathbf{H}_{k-1}^{sr}\right)^T, \left(\mathbf{H}_{k+1}^{sr}\right)^T, \cdots, \left(\mathbf{H}_{N_u/2}^{sr}\right)^T\right]^T. \tag{7}$$

If the SVD of $\tilde{\mathbf{H}}_k^{sr}$ is defined as $\tilde{\mathbf{H}}_k^{sr} = \tilde{\mathbf{U}}_k\tilde{\Lambda}_k\tilde{\mathbf{V}}_k^H$, $\tilde{\mathbf{F}}_k$ can be expressed as follows,

$$\tilde{\mathbf{F}}_k = \tilde{\mathbf{V}}_k\left(\tilde{\Lambda}_k^H\tilde{\Lambda}_k + \alpha\mathbf{I}\right)^{-1/2} \tag{8}$$

$$\alpha = \frac{N_r}{2}\frac{\sigma^2}{P_{total}} \tag{9}$$

where σ^2 and P_{total} are the noise power and the total transmit signal power, respectively. Also, from the SVD of the k th user's equivalent channel the equation is achieved as follows,

$$\mathbf{H}_k\tilde{\mathbf{F}}_k = \bar{\mathbf{U}}_k\left[\bar{\Lambda}_k \quad \mathbf{O}\right]\left[\bar{\mathbf{V}}_k^{(1)} \quad \bar{\mathbf{V}}_k^{(0)}\right] \tag{10}$$

where $\mathbf{O}$, $\bar{\mathbf{V}}_k^{(1)}$ and $\bar{\mathbf{V}}_k^{(0)}$ indicate a zero matrix, the set of right singular vectors corresponding to non-zero singular values and the set of right singular vectors corresponding to zero singular values, respectively. The matrix $\bar{\mathbf{F}}_k$ is obtained as $\bar{\mathbf{F}}_k = \bar{\mathbf{V}}_k^{(1)}$ where $\bar{\mathbf{V}}_k^{(1)}$ denotes the set of right singular vectors corresponding to non-zero singular values. Finally, the k th user's precoding matrix of the RBD can be written as follows,

$$\mathbf{F}_k = \tilde{\mathbf{V}}_k\left(\tilde{\Lambda}_k^H\tilde{\Lambda}_k + \alpha\mathbf{I}\right)^{-1/2}\bar{\mathbf{V}}_k^{(1)} \tag{11}$$

After RBD precoding, y_k which is the received signal at the relay is expressed as follows,

$$y_k = \mathbf{H}_k^{sr}\mathbf{F}_k X_k + n_k \tag{12}$$

where n_k is the noise vector composed of complex Gaussian noise. IUI of the k th user is mitigated by precoding. However, y_k contains relay and destination signals simultaneously. Therefore, relay and destination signal should be separated by SIC [7] at the relay. The relay transmits the estimated signal to the destination through the channel $\mathbf{H}^{rd} \in \mathbb{C}^{1\times\frac{N_u}{2}}$ between the relay and the destination.

III. Simulation Results

Table I shows the simulation parameters used in this paper. Fig. 2 shows the BER performances of the proposed scheme. BER performance of BD using relay in NOMA, conventional RBD, and conventional BD are represented in Fig. 2. The BER performance of the relay and the destination are shown respectively in Fig. 2. The BER performance of the relay is poor compared to the destination because the allocated power is low. The BER performance of the proposed scheme is poor compared to conventional RBD.

It indicates that the number of transmit antennas and RF chains is reduced in the proposed system while the BER performance of the proposed scheme is sacrificed.

When the transmit power is low, the proposed scheme has slightly better performance compared to BD using relay in NOMA. However, there is no difference in BER performance between the proposed scheme and BD using relay in NOMA when the transmit power is high. Since the BER performance of the proposed scheme is improved by taking the noise term into account, when the effect of the noise is small, there is no performance improvement. The proposed scheme uses less SVD compared to conventional RBD while SIC is needed additionally. However, the proposed algorithm can achieve low computational complexity because SIC is simpler than SVD. In conclusion, the proposed scheme has lower complexity than the conventional RBD scheme.

TABLE I. Simulation Parameters

Modulation	BPSK
Number of data streams	4
Number of transmit antennas	2
Number of users	4
Number of each user's antennas	1
Total number of receive antennas	4

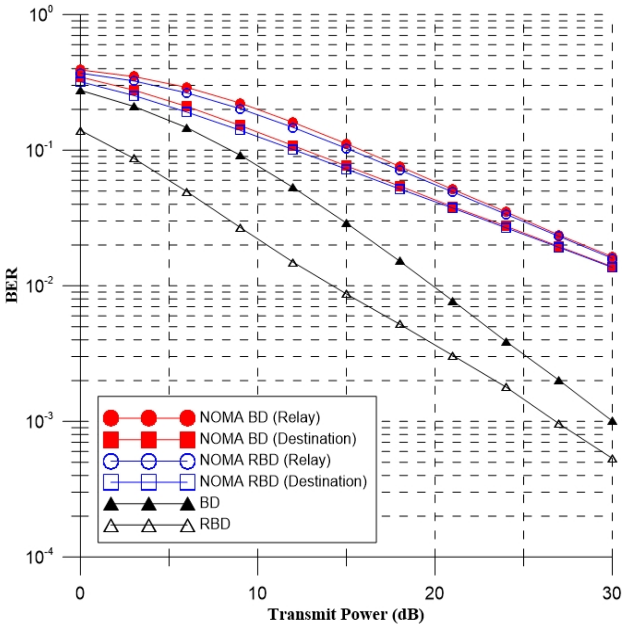

Figure 2. BER performance of the proposed scheme.

IV. Conclusion

In this paper, RBD precoding transmission scheme using relay in NOMA is proposed. The proposed scheme uses only half the number of RF chains and transmit antennas compared to conventional RBD scheme by using relay in NOMA system. The number of SVD is also reduced. However, as shown in simulation results, the reduction of the complexity leads to BER performance degradation. The proposed scheme has slight improvement in BER performance compared to BD using relay in NOMA system, only when the transmit power is low. Note that the proposed scheme has no performance improvement when the effect of the noise is small. Therefore, further study is needed to increase the BER performance while the complexity is reduced.

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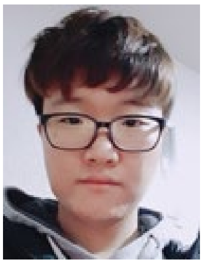

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