A Regenerative Relay Transmission in Linearly Precoded MU-MIMO Downlink

Yasunori Iwanami
Dept. of Computer Science and Engineering
Nagoya Institute of Technology
Nagoya, Japan
E-mail: iwanami@nitech.ac.jp

Kentaro Iida
Dept. of Computer Science and Engineering
Nagoya Institute of Technology
Nagoya, Japan
E-mail: cke17506@stn.nitech.ac.jp

Abstract—**Recently, Muti-User MIMO (MU-MIMO) downlink system which uses multiple antennas at base station and accommodates multiple users with multiple receive antennas attracts much attention. In MU-MIMO downlink system, by knowing the Channel State Information (CSI) at the base station, Inter User Interferences (IUI's) among users are pre-excluded at the base station. By increasing the number of transmit antennas assigned to each user, the transmission quality of each user is improved. In MU-MIMO, there exists linear precoding or nonlinear precoding method, but linear precoding is considered more easily implemented and adjusted than nonlinear precoding. In this paper, we aim the coverage extension and the transmission quality improvement by using a regenerative Detect & Forward (DF) relay in MU-MIMO downlink system. We use Block Diagonalization (BD) + Eigen mode transmission (E-SDM) for linear MU-MIMO scheme. By sharing the BD matrix at both base station and relay, the relay can demodulate the receive signal only with receive CSI and can forward the signal to each user. With this system configuration, we have shown the effectiveness of regenerative relay through simulations.**

Keywords-MU-MIMO; Block Diagonalization; Eigen mode transmission; Regenerative relay; Detect & Forward.

I. INTRODUCTION

Recently, Multi-User MIMO down link communication systems in which base station can transmit spatially multiplexed signals to multiple users without Inter-User Interference (IUI) are well investigated [1]-[7]. In MU-MIMO downlink system, in order to remove the IUI at base station, the channel state information (CSI) of downlink has to be known at the base station. By increasing the number of transmit antennas at base station, the channel quality to each user can be arbitrary improved. As representative methods, there exist BD (Block Diagonalization) [2] and Channel Inversion (CI) [3] categorized as linear methods, and DPC (Dirty Paper Coding) [4], THP (Tomlinson-Harashima Precoding) [5] and Vector Perturbation (VP) [6][7] as nonlinear methods. Although nonlinear methods can achieve greater channel capacity than linear methods, its complexity is higher and the design method is more difficult. As for the linear methods, the CI method has the problems of increasing transmit power and limited sum-rate. The BD method consumes a lot of degree of freedom to make the nulls, but it can remove the IUI completely. Also, the BD method matches the Eigen mode transmission (E-SDM; Eigenbeam -Space Division Multiplexing) [8] well and is considered a practical design method. On the other hand, concerning the use of relay in MU-MIMO downlink, increasing the channel capacity by using the relay has been discussed [9][10]. On the relay transmission in MU-MIMO downlink system, the BD methods are used to remove the IUI at base station [11]-[15]. In [11], during the 1st time slot transmission from base station to relay, MU-MIMO is not employed, but during the 2nd time slot from relay to each user, it is used. In [12]-[15], the transmission from base station to relay is done during the 1st time slot, but the direct link from base station to each user during the 1st time slot is not considered.

In this paper, on the DF relay in MU-MIMO downlink system, we employed the BD+E-SDM method for the transmission from base station to each user during the 1st time slot. We assume that the DF relay which locates between base station and each user already knows the precoding matrix of the base station. By knowing the precoding matrix, the relay can demodulate the receive signal only by using receive CSI. Accordingly, the base station does not need to assign the transmit antennas to the relay and the transmission from base station to relay becomes SU (Single-User)-MIMO. During the 2nd time slot, the DF relay transmits the signals to each user also using the BD+E-SDM method. At each user, the received signals during the 1st and the 2nd time slots are combined using the symbol LLR (Log Likelihood Ratio) addition and the combined signal is demodulated. We show the effectiveness of the proposed novel DF relaying system in MU-MIMO downlink through computer simulations.

The paper is organized as follows. In Section II, the DF relay model in MU-MIMO downlink is introduced. In Section III, we design the downlink transmission during the 1st time slot. In Section IV, we design the downlink during the 2nd time slot. In Section V, we present the symbol LLR combining method of received signals at each user terminal. In Section VI, we clarify the BER characteristics through computer simulations. The paper is concluded with Section VII with the most important results and future work.

II. DF RELAY MODEL IN MU-MIMO DOWNLINK

The proposed DF relaying model in MU-MIMO downlink system is shown in Figure1. The base station is equipped with N_s transmit antennas. There exist total N_u users and the user $i\,(=1,\cdots,N_u)$ has m_i receive antennas. Thus, there are total $N_d = \sum_{i=1}^{N_u} m_i$ receive antennas at users.

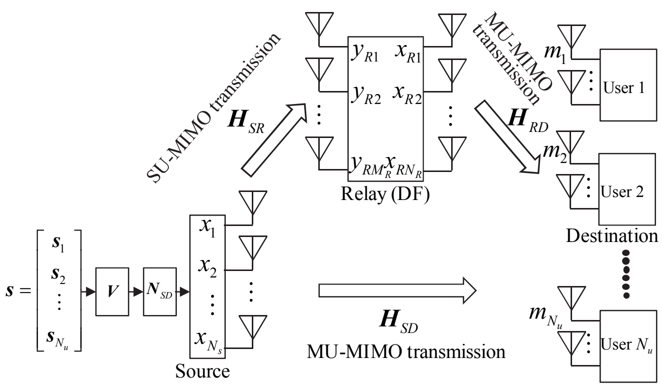

Figure 1. DF relay model in MU-MIMO downlink system

The DF relay, which locates between base station and user terminals, has M_R receive and N_R transmit antennas. At base station, the transmit signal $\boldsymbol{s} = [\boldsymbol{s}_1 \ \cdots \ \boldsymbol{s}_i \ \cdots \ \boldsymbol{s}_{N_u}]^T$ to each user is firstly multiplied by the precoding matrix $\boldsymbol{V}$ for making the multiple stream transmission using E-SDM. The transmit signal to user i is expressed as $\boldsymbol{s}_i = [s_i^{(1)} \ \cdots \ s_i^{(S_i)}]$ where S_i is the number of signal streams of user i. The matrix $\boldsymbol{V}$ is expressed as

$$\boldsymbol{V} = \begin{bmatrix} \boldsymbol{V}_1 & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \ddots & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{V}_{N_u} \end{bmatrix} \quad (1)$$

where the diagonal element matrix of $\boldsymbol{V}$ is the precoding matrix of E-SDM for each user. Secondary, the precoding matrix $\boldsymbol{N}_{SD}$ for BD is multiplied by $\boldsymbol{Vs}$. The transmit signal from the base station antenna is then given by $\boldsymbol{x} = \boldsymbol{N}_{SD}\boldsymbol{Vs} = [x_1 \ \ x_2 \ \ \cdots \ \ x_{N_s}]^T$. During the 1st time slot, the transmit signal $\boldsymbol{x}$ is broadcasted both to user terminals and the DF relay. The precoding matrix $\boldsymbol{N}_{SD}$ makes the channel matrix $\boldsymbol{H}_{SD}$ from base station to each user block diagonal. The receive signal vector $\boldsymbol{y}_{SD}$ at destination (users) is expressed as

$$\begin{cases} \boldsymbol{y}_{SD} = \boldsymbol{H}_{SD}\boldsymbol{N}_{SD}\boldsymbol{Vs} + \boldsymbol{n}_{SD} = \boldsymbol{B}_{SD}\boldsymbol{Vs} + \boldsymbol{n}_{SD} = \boldsymbol{H}_{SD}\boldsymbol{x} + \boldsymbol{n}_{SD} \\ \boldsymbol{B}_{SD} = \boldsymbol{H}_{SD}\boldsymbol{N}_{SD}, \quad \boldsymbol{x} = \boldsymbol{N}_{SD}\boldsymbol{Vs} \end{cases} \quad (2)$$

$\boldsymbol{B}_{SD}$ in (2) is the block diagonalized channel matrix and is expressed as

$$\boldsymbol{B}_{SD} = \begin{bmatrix} \boldsymbol{B}_{sd1} & \boldsymbol{0} & \cdots & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{B}_{sd2} & \cdots & \vdots \\ \vdots & \cdots & \ddots & \boldsymbol{0} \\ \boldsymbol{0} & \cdots & \boldsymbol{0} & \boldsymbol{B}_{sdN_u} \end{bmatrix} \quad (3)$$

where $\boldsymbol{B}_{sdi}, i = 1, \cdots, N_u$ is the block channel matrix for user i and $\boldsymbol{n}_{SD} = [\boldsymbol{n}_{sd1} \ \ \boldsymbol{n}_{sd2} \ \ \cdots \ \ \boldsymbol{n}_{sdN_u}]$ in (2) is the receive noise vector for each user. The size of block channel matrix $\boldsymbol{B}_{sdi}$ for user i in (3) is given by $m_i \times n\ell_i$, $i = 1, \cdots, N_u$, where $n\ell_i$ is the nullity of matrix $\tilde{\boldsymbol{H}}_{sdi}$ $(N_d - m_i \times N_s)$ [16] with $\tilde{\boldsymbol{H}}_{sdi}$ being the matrix in which the channel matrix $\boldsymbol{H}_{sdi}$ $(m_i \times N_s)$ for user i is subtracted from the entire channel matrix $\boldsymbol{H}_{SD}$ $(N_d \times N_s)$. The nullity $n\ell_i$ of the matrix $\tilde{\boldsymbol{H}}_{sdi}$ is defined by

$$n\ell_i = nullity(\tilde{\boldsymbol{H}}_{sdi}) = N_s - rank(\tilde{\boldsymbol{H}}_{sdi}) \quad (4)$$

As the rank of $\tilde{\boldsymbol{H}}_{sdi}$ is given by

$$rank(\tilde{\boldsymbol{H}}_{sdi}) = \min(N_D - m_i, N_s) \quad (5)$$

the nullity $n\ell_i$ is expressed as

$$n\ell_i = N_s - rank(\tilde{\boldsymbol{H}}_{sdi}) = N_s - N_d + m_i > 0 \quad (6)$$

We assume that the DF relay knows the precoding matrix $\boldsymbol{N}_{SD}\boldsymbol{V}$ of the base station. Therefore, the base station has to inform $\boldsymbol{N}_{SD}\boldsymbol{V}$ to the relay before the data transmission starts. The transmission from base station to relay during the 1st time slot is done by Single User-MIMO (SU-MIMO). The receive signal $\boldsymbol{y}_{SR} = [y_{r1} \ \ y_{r2} \ \ \cdots \ \ y_{rM_R}]$ at relay is expressed as

$$\boldsymbol{y}_{SR} = \boldsymbol{H}_{SR}\boldsymbol{x} + \boldsymbol{n}_{SR} = (\boldsymbol{H}_{SR}\boldsymbol{N}_{SD}\boldsymbol{V})\boldsymbol{s} + \boldsymbol{n}_{SR} \quad (7)$$

where $\boldsymbol{n}_{SR}$ $(M_R \times 1)$ is the receive noise vector at relay. The effective channel matrix $(\boldsymbol{H}_{SR}\boldsymbol{N}_{SD}\boldsymbol{V})$ in (7) is assumed to be known at the relay and the demodulation of transmit signal $\boldsymbol{s}$ is done by MMSE nulling or MLD (Maximum Likelihood Detection). This means that the base station does not need to inform the channel matrix $\boldsymbol{H}_{SR}$ between base station and relay to the relay. The demodulated signal $\hat{\boldsymbol{s}}$ at relay is transmitted to each user during the 2nd time slot using MU-MIMO with BD which is the same transmission scheme as in Source-Relay (SR) link. As in the Source-Destination (SD) link in the 1st time slot, the E-SDM is employed for the multiple stream transmission from relay to each user. At each user terminal, the received multiple stream signals during the 1st and the 2nd time slots are combined using symbol LLR addition and demodulated. When the errors are detected at relay through the CRC (Cyclic Redundancy Check) code for example, the transmission from relay to each user during the 2nd time slot may not be utilized. Because it causes the error propagation. That is, only when errors are not detected at relay, the demodulated signals at relay can be transmitted to the users. In this case, the 2nd time slot is not utilized between relay and each user, thus the vacant time slot can be used as the repeated transmission from base station to each user with BD+E-SDM as in the 1st time slot.

III. DESIGN OF DOWNLINK TRANSMISSION

A. Transmission during the 1st time slot

1) Design of SD Link

The SD transmission during the 1st time slot is done by using BD+E-SDM. The size of block channel matrix $\boldsymbol{B}_{sdi}$ is given by $m_{N_i} \times n\ell_i$ and the number of streams of eigen mode becomes $\min(m_{N_i} \times n\ell_i)$. When the number of streams is one, BD+E-SDM is referred to as BD+MRT (Maximum Ratio Transmission) [17]. From (6), the nullity $n\ell_i$ of user i can be arbitrary chosen by increasing or decreasing the number of transmit antennas N_s at base station. If the elements of channel matrix $\boldsymbol{H}_{SD}$ follow the i.i.d. complex Gaussian random variables, i.e., $\boldsymbol{H}_{SD}$ is the MIMO channel matrix of quasi-static flat Rayleigh fading, the diversity order of the first eigen mode stream in E-SDM for the block channel matrix $\boldsymbol{B}_{sdi}$ is given by $m_i \cdot n\ell_i$ [18]. When the minimum number of receive antennas among users is $m_{\min}$, from (6) the nullity $n\ell_{\min}$ of minimum antenna user is given by

$$n\ell_{\min} = N_s - N_d + m_{\min} > 0 \quad (8)$$

Hence, the number N_s of transmit antennas at base station is expressed as

$$N_s = n\ell_{\min} + N_d - m_{\min} \quad (9)$$

When the number of transmit antenna is N_s, the nullity $n\ell_i$ of user i other than the minimum antenna user becomes

$$n\ell_i = N_s - N_d + m_i > n\ell_{\min} \quad (10)$$

The size of block channel matrix $\boldsymbol{B}_{sdi}$ of user i is determined as $m_i \times n\ell_i$. In this design method, firstly the nullity $n\ell_{\min}$ of the user which has the minimum number of receive antennas $m_{\min}$ is determined and secondary the nullity $n\ell_i$ of the other user i is derived. The diversity orders of the first eigen mode stream of minimum antenna user and other user i are given by $m_{\min} \cdot n\ell_{\min}$ and $m_i \cdot n\ell_i \geq m_{\min} \cdot n\ell_{\min}$ respectively.

For example, we consider the case where the number of total users is $N_u = 3$, the numbers of receive antennas of users are $m_1 = 3$, $m_2 = 2$, $m_3 = 1$, and the total number of receive antennas is $N_d = m_1 + m_2 + m_3 = 6$. In this case, $m_3 = 1$ is minimum and it holds $m_{min} = m_3 = 1$. If the expected diversity order of the first eigen mode stream of user 3 is set to 3 for example, then we obtain $n\ell_{min} = 3/m_{min} = 3/1 = 3$. With those parameters, the total number of transmit antennas at base station N_s is determined as $N_s = n\ell_{min} + N_d - m_{min} = 3 + 6 - 1 = 8$ and the size of block matrix $\boldsymbol{D}_3$ of user 3 becomes $m_{min} \times n\ell_{min} = 1 \times 3$. Thus, the nullity of user 2 is determined as $n\ell_2 = N_s - N_d + m_2 = 8 - 6 + 2 = 4$, the size of $\boldsymbol{D}_2$ becomes $m_2 \times n\ell_2 = 2 \times 4$, and the diversity order of the first eigen mode stream of user 2 is given as $m_2 \cdot n\ell_2 = 2 \cdot 4 = 8$. Likewise, the nullity $n\ell_1$ of user 1 is given by $n\ell_1 = = N_s - N_d + m_1 = 8 - 6 + 3 = 5$, $\boldsymbol{D}_1$ becomes $m_1 \times n\ell_1 = 3 \times 5$, the diversity order of the first eigen mode stream of user 1 is determined as $m_1 \cdot n\ell_1 = 3 \cdot 5 = 15$.

2) *Design of SR Link*

For the SD link from base station to DF relay, the precoding at base station is not used. This means no degree of freedom of transmit antennas (number of transmit antennas) at base station is consumed for the SR link. This is because if the transmit antennas at base station are assigned to the DF relay also for BD, in the absence of relay the assigned transmit antennas to relay are of no use. Therefore the extra transmit antennas are then used for the users to enhance the SD link quality. In this case, the effect of using relay becomes not obvious compared with the enhanced SD link. That is, the DF relay should be employed when the SD link quality is poor and the additional relay brings great effect to the overall performance. As the demodulation at DF relay is done by only using receive CSI, the precoding matrix $\boldsymbol{N}_{SD}\boldsymbol{V}$ at base station needs to be informed to the relay in advance before the data transmission starts. The DF relay demodulates the receive signal with MMSE nulling or MLD by using equivalent channel matrix of $\boldsymbol{H}_{SR}\boldsymbol{N}_{SD}\boldsymbol{V}$. So, the SR link transmission is done by SU-MIMO and not by MU-MIMO. As the SR link quality directly affects the subsequent Relay-Destination (RD) link quality, we must raise the SR link quality as much as we can. Because the poor SR link quality causes error propagation to the RD link. To solve this problem, increasing the number of receive antennas at relay is considered. Also at relay, MLD with better BER characteristic than MMSE nulling is considered. But when the number of transmit streams of $\boldsymbol{s}$ from base station is large, the exponential increase of complexity in MLD becomes a problem. In such case, we can resort the problem to employ the Sphere Decoding (SD) with less complexity or to use the MMSE nulling with far less complexity for demodulating SU-MIMO signals. Even though the elements of $\boldsymbol{H}_{SR}$ are i.i.d. complex Gaussian random variables, the row elements of equivalent SR link channel matrix $\boldsymbol{H}_{SR}\boldsymbol{N}_{SD}\boldsymbol{V}$ do not always become i.i.d. complex Gaussian random variables. This channel element correlation deteriorates the BER characteristic of MMSE nulling, MLD or SD compared with i.i.d. random variable case. Also if errors are detected at the DF relay by using CRC code etc., we can consider the protocol in which the demodulated data at relay are not forwarded to users in the 2nd time slot. In this case, as the RD link in the 2nd time slot becomes vacant, in order to utilize the vacant time slot effectively, we can repeat the SD link transmission from the base station again in the 2nd time slot.

B. *Transmission during the 2nd time slot*

For the RD link transmission during the 2nd time slot, we use BD+MRT or BD+E-SDM the same as in the 1st time slot. In this case, the number of streams to each user of SD link should coincide with the one of RD link. This is because the symbol LLR combining for each user stream is done at each user. We can design the RD link quality like the SD link. Thus, we can improve the RD link quality by increasing the number of transmit antennas at relay N_R. In order to prevent the error propagation in the RD link, we adopt the protocol in which the data from relay are only forwarded to each user in case of no error detected at the DF relay. When the error is detected at the relay and the RD link is not used during the 2nd time slot, in order to prevent the degradation of receive signal quality, we repeat the SD transmission using the vacant 2nd time slot. The signals received in the 1st and the 2nd time slots are symbol LLR combined and demodulated at each user.

At each user terminal, each stream of MRT or E-SDM is equivalently represented as the AWGN channel with the

 ISBN: 978-1-61208-473-2

complex gain h. When the received signal in each stream is denoted as r and the corresponding transmitted signal $s_l, l=0,\cdots,Q-1$ has Q modulation levels, the equivalent AWGN channel of each stream is expressed as

$$r = hs_l + n,\ l=0,1,\cdots,Q-1 \tag{11}$$

The symbol LLR is the extension of bit LLR and defined as

$$LLR_l = \log_e \frac{p(r \mid s_l)}{p(r \mid s_0)} \tag{12}$$

where the transition probability density function $p(r \mid s_l)$ is expressed as

$$p(r \mid s_l) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(r-s_l)^2}{2\sigma^2}\right] \tag{13}$$

and $\sigma^2 = (1/2)E\{|n|^2\}$. From (12) and (13), it holds

$$LLR_l = \frac{2r(s_l - s_0) - (s_l^{\,2} - s_0^{\,2})}{2\sigma^2} \tag{14}$$

When the modulation level is $Q=2$, the symbol LLR coincides with the bit LLR. The symbol LLR combining (or addition) of two independent LLR's is equivalent to the MRC (Maximum Ratio Combining) and they give the same BER characteristics.

IV. Investigation of BER Characteristics through Computer Simulations

We have checked the BER characteristics of the proposed MU-MIMO downlink transmission using DF relay. The abscissa of BER characteristic is taken as the transmit SNR [19], which is defined as the ratio of total transmit power P from the base station to the receive noise power σ^2 at each user receive antenna and is given as

$$\left(\frac{S}{N}\right)_{\text{transmit}} = \frac{P}{\sigma^2} \tag{15}$$

The channel from base station to each user, the channel from base station to relay and the channel from relay to each user are all assumed to be quasi-static Rayleigh fading channel. That is, the element h_{ij} of channel matrix $\boldsymbol{H}$ $(\boldsymbol{H}_{SD}, \boldsymbol{H}_{SR}, \boldsymbol{H}_{RD})$ is an i.i.d. complex Gaussian random variable with the variance of $E\{|h_{ij}|^2\}=1$. We consider the distance from base station to each user is equal among users and the DF relay locates at the middle point between the base station and users. We also set the power decaying exponent as $\alpha = 3.5$ on the different distances from the base station to relay and users.

First, we investigate the case where the number of transmit antennas of base station is $N_s = 2$, the number of user terminal $N_u = 2$, the number of receive antennas of each user $m_1 = m_2 = 1$, the number of receive antennas of relay $M_R = 4$, and the number of transmit antennas of relay $N_R = 2$. We call this as $2\times(4,2)\times(1,1)$ model. In this model, for the SD link during the 1st time slot, BD+MRT scheme is used as the MU-MIMO transmission. QPSK modulation is used for each user stream. The BER characteristic is shown in Figure2. In Figure2, "SD link 2 times w/o relay" means the scheme in which the MU-MIMO transmission on SD link is repeated twice without using the relay. "$2\times(4,2)\times(1,1)$ MMSE" and "$2\times(4,2)\times(1,1)$ MLD" mean the schemes in which the receive signal at DF relay is demodulated using MMSE nulling and the one in which the receive signal at DF relay is demodulated using MLD, respectively.

We see from Figure2 that, by using the DF relay and combining the symbol LLR's of SD link and SRD link signals, the BER characteristic with using relay is very much improved compared with 2 times transmission on SD link without using relay. The SD link transmission without relay shows the diversity order of 1 $(\text{BER}=10^{-1}/10\text{ dB})$. As stated in III.B, as the row elements of channel matrix $\boldsymbol{H}_{SR}\boldsymbol{N}_{SD}\boldsymbol{V}$ on the SR link do not always become independent, the SR link quality is degraded. Accordingly, the diversity order of 2 at each user is not achieved especially when the MMSE nulling is used at relay. However, by using the MLD at relay, the SR link quality is improved and we can get the diversity order of almost 2.

Next, we consider the case where the number of transmit antenna at base station is $N_T = 4$, the number of users $N_u = 2$ and the numbers of receive antennas of each user are $m_1 = m_2 = 1$. Compared with the previous case of $N_T = 2$, more transmit antennas are assigned to each user. The numbers of receive antenna and transmit antenna at relay are $M_R = 4$ and $N_R = 4$ respectively. We call this as $4\times(4,4)\times(1,1)$ model. The transmission protocols of SD, SR and RD links are the same as the previous $2\times(4,2)\times(1,1)$ model. The modulation format is QPSK. We show the simulation results in Figure3. In Figure3, the channel matrix $\boldsymbol{H}_{SD}$ on SD link is 2×4 and the channel matrix $\tilde{\boldsymbol{H}}_{sdi}$ in which the channel matrix for user i is excluded from $\boldsymbol{H}_{SD}$ becomes 1×4.

From (10), the nullity of $\tilde{\boldsymbol{H}}_{sdi}$ is calculated as $n\ell_i = 4-2+1=3, (i=1,2)$. The size of block matrix $\boldsymbol{D}_i$ of each user becomes $m_i \times n\ell_i = 1\times3, (i=1,2)$ and the diversity

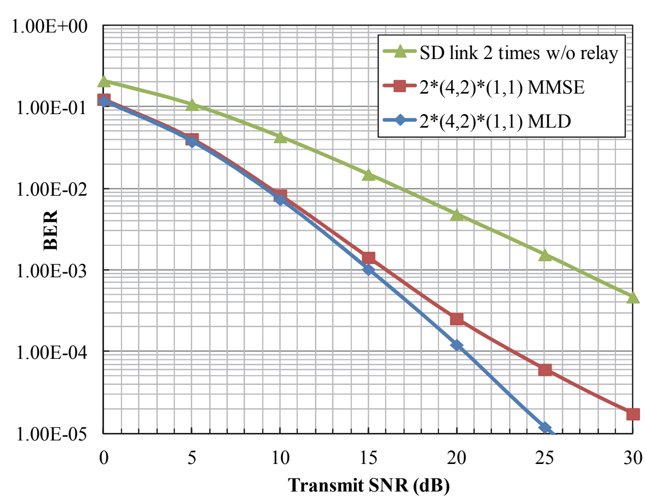

Figure 2. BER characteristics of $2\times(4,2)\times(1,1)$ model (Transmission rate to each user is 2(bps/Hz).)

order of each user stream is given by $m_i \cdot n\ell_i = 3, (i = 1, 2)$. From Figure3, “SD link 2 times w/o relay” shows the BER slope of about $10^{-3}/10\,(\text{dB})$ for the transmit SNR=5~15(dB) and we see that the diversity order of 3 is almost obtained. When using relay, we can also expect the diversity order of 3 on the RD link as in the SD link. Thus, if there is no error on the SR link, then we can say the diversity order of 6 is obtained on the BER after the symbol LLR addition at each user. As the transmit SNR becomes higher, the errors on SR link decrease and the diversity order of 6 is more easily achievable at high SNR region. But in Figure3, we see the BER falls by $10^{-1}/2\,(\text{dB})$ for SNR=7~9(dB) and we know the diversity order of 5 is achieved in this SNR region.

Next, we consider the case where the number of transmit antenna at base station is $N_T = 4$, the number of users $N_u = 2$ and the numbers of receive antennas of each user are $m_1 = m_2 = 2$. The numbers of receive and transmit antennas at relay are $N_R = 4$ respectively. We call this as $4 \times (4,4) \times (2,2)$ model. In this case, the optimum modulation formats which minimize the BER characteristics are selected under the constant transmission rate of 4(bps/Hz) on the SD link. This means one stream transmission with BD+MRT+16QAM or two stream transmission with BD+E-SDM+QPSK is adaptively selected for given $\boldsymbol{H}_{SD}$ [8]. Also in case of two stream transmission using two QPSK’s, the optimum power assignment to the 1st and 2nd eigen mode channels which minimizes the BER is made [8]. In this two stream transmission, the DF relay needs to know in advance the precoding matrix $\boldsymbol{N}_{SD}$ for BD, the matrix $\boldsymbol{V}$ for the eigen mode transmission in E-SDM and the power allocation factor to the 1st and 2nd eigen mode channels. Also in order to make the symbol LLR addition at each user, the number of streams on the RD link must coincide with the one on the SR link. Hence, the BD+E-SDM transmission on RD link adopts the same number of streams as in the SD link. The simulation results are shown in Figure4. In Figure4, BD+E-SDM scheme is employed on the SD link and the size of block channel matrix for each user becomes $\boldsymbol{D}_i = 2 \times 2\ (i = 1, 2)$. The transmission to each user is done by one stream transmission with the maximum eigen value using 16QAM or two stream transmission with two different eigen values using two QPSK’s. Figure4 shows the average BER characteristics. In this $4 \times (4,4) \times (2,2)$ model, like in Figure2 and Figure3, the use of DF relay and the symbol LLR addition at each user during the 1st and 2nd time slots improve the diversity order and the BER characteristic when compared with the 2 times transmission on the SD link without using relay.

Next, we consider the case where the number of transmit antenna at base station is $N_T = 8$, the number of users $N_u = 4$ and numbers of receive antennas of each user are $m_1 = m_2 = m_3 = m_4 = 2$. The numbers of receive and transmit antennas at relay is $M_R = 8$ and $N_R = 8$ respectively. We call this as $8 \times (8,8) \times (2,2,2,2)$ model. This model is the extension of previous $4 \times (4,4) \times (2,2)$ model to $N_u = 4$ users. The transmission protocols are the same as the previous $4 \times (4,4) \times (2,2)$ model. On the SD link, the size of

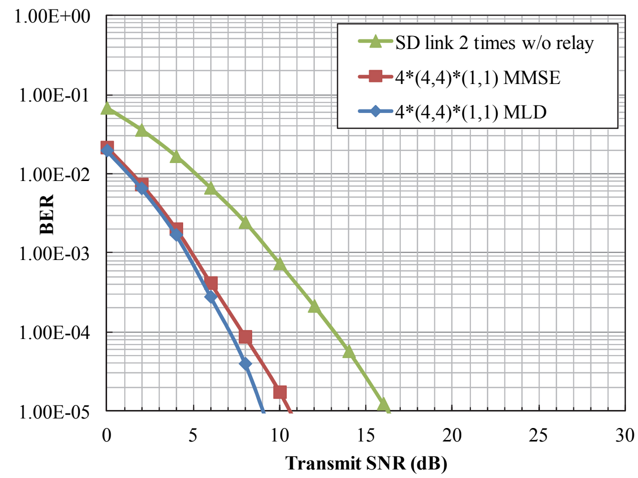

Figure 3. BER characteristics of $4 \times (4,4) \times (1,1)$ model (Transmission rate to each user is 2(bps/Hz).)

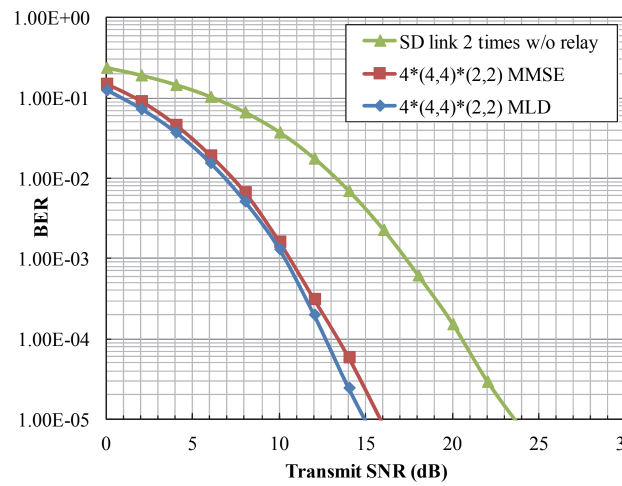

Figure 4. BER characteristics of $4 \times (4,4) \times (2,2)$ model (Transmission rate to each user is 4(bps/Hz) and 16QAM or QPSK is optimally selected to minimize the BER.)

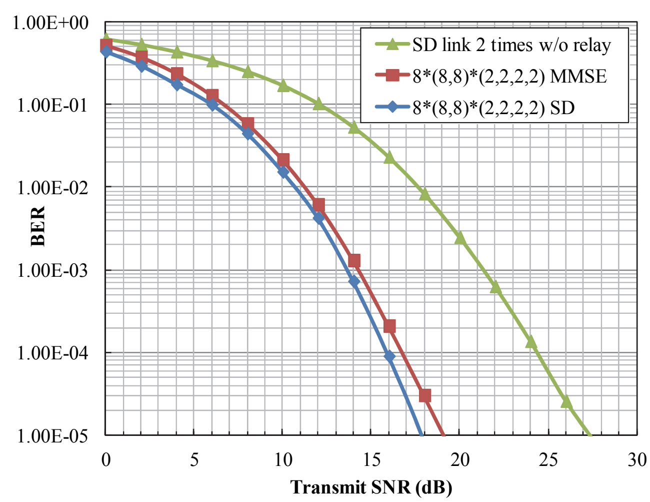

Figure 5. BER characteristics of $8 \times (8,8) \times (2,2,2,2)$ model (Transmission rate to each user is 4(bps/Hz) and 16QAM or QPSK is optimally selected to minimize the BER.)

 ISBN: 978-1-61208-473-2

block channel matrix for each user becomes $\boldsymbol{D}_i = 2 \times 2 \ (i = 1,2,3,4)$. For each user, one stream transmission with BD+MRT using 16QAM or two stream transmission with BD+E-SDM using two QPSK's is adaptively selected for $\boldsymbol{H}_{SD}$ under the constant transmission rate of 4(bps/Hz). The RD link transmission uses the same number of streams as in the SD link. We show the simulation results in Figure5. In this $8 \times (8,8) \times (2,2,2,2)$ model, the demodulation using MLD at relay becomes difficult because the number of searches in MLD becomes $4^8 = 65536$ for the total 8 streams from the base station. So instead of the MLD, we used the Sphere Decoding SE algorithm [20][21] that can obtain the same ML solution as the MLD with far less computational complexity. Like in Figure2, Figure3 and Figure4, the use of DF relay and the symbol LLR addition at each user during the 1st and 2nd time slots improve the diversity order and the BER characteristic compared with the 2 times transmission on SD link without using relay. We also see in Figure3~Figure5 that the BER difference between MMSE nulling and MLD (or Sphere Decoding) at relay is not so large. This is mainly because the BER of relay by MMSE nulling or MLD (or Sphere Decoding) is far better than the one of SD link, and the combined BER at destination is not so affected by the BER difference between MMSE nulling and MLD (or Sphere Decoding).

V. Conclusion and Future Work

In this paper, we discussed the improvement of transmission quality when the DF relay is applied to the MU-MIMO down link system with the linear block diagonalization plus MRT or E-SDM scheme. By knowing the precoding matrix of base station at the DF relay, the DF relay can demodulate the transmit signals from base station only with the receive CSI. As the existence of relay does not affect the design of precoding matrix at the base station, we can add the DF relay only when the cannel quality between the base station and user terminals is insufficient. By adding the DF relay and utilizing the 2nd time slot, we can improve the receive quality of each user terminal. We made the design of SD, SR and RD links during the 1st and the 2nd time slots and verified the effectiveness of using DF relay. Although the SR link quality affects the total BER performance very much, we can utilize the simple MMSE nulling by increasing the number of receive antenna at DF relay to improve the SR link quality.

As future studies, although we handled the case where the numbers of transmission streams on SR and RD link are equal, the case of different numbers will be considered.

Acknowledgement

This study is supported by the Japanese Grant-in-Aid for Scientific Research of 15K06059 and Sharp cooperation.

References

[1] H. S Quentin, B. P. Christian, and A. Lee Swindlehurst, M. Hardt, "An introduction to the multi-user MIMO downlink," IEEE communications Magazine, vol.42, Issue 10, pp.60-67, Oct. 2004.

[2] Q. H. Spencer, A. L. Swindlehurst, and M. Haardt, "Zero forcing methods for downlink spatial multiplexing in multiuser MIMO channels," IEEE Trans. Sig. Processing, vol.52, no.2, pp.461-471, Feb.2004.

[3] T.Haustein, C. von Helmolt, E.Jorswieck, V.Jungnickel, and V.Pohl, "Performance of MIMO systems with channel inversion," IEEE 55th VTC Spring, vol.1, pp. 35 – 39, 2002.

[4] S. Vishwanath, N. Jindal, and A. Goldsmith, "Duality, achievable rates, and sum-rate capacity of MIMO broadcast channels," IEEE Trans. Inform. Theory, vol. 49, no. 10, pp. 2658–2668, Oct. 2003.

[5] Veljko Stankovic and Martin Haardt, "Successive optimization Tomlinson-Harashima precoding (SO THP) for multi-user MIMO systems," IEEE International Conference on Acoustics, Speech, and Signal Processing, Proceedings (ICASSP '05), vol.3, pp.iii/1117-iii/1120, March 2005.

[6] C. B. Peel, B. M. Hochwald, and A. L. Swindlehurst, "A vector-perturbation technique for near-capacity multi antenna multiuser communication-part I: Channel inversion and regularization," IEEE Trans. Commun., vol. 53, pp.195-202, Jan. 2005.

[7] C. B. Peel, B. M. Hochwald, and A. L. Swindlehurst, "A Vector-Perturbation Technique for Near-Capacity Multi antenna Multiuser Communication—Part II: Perturbation," IEEE Trans. Commun., vol. 53, pp. 195–202, Jan. 2005.

[8] K. Miyashita, T. Nishimura, T. Ohgane, Y. Ogawa, Y. Takatori, and K. Cho, "Eigenbeam-Space Division Multiplexing (E-SDM) in a MIMO Channel," IEICE Technical Report, RCS2002−53, pp.13−18, May, 2002.

[9] H. Sun, S. Meng, Y. Wan, and X. You, "Sum-rate evaluation of multi-user MIMO-relay channel," IEICE Trans. Commun., vol.E-92-B, No.2, pp.683-686, Feb. 2009.

[10] K. Nishimori, N. Honma, M. Mizoguchi, "Effectiveness of relay MIMO transmission in an actual outdoor environment," IEICE Technical Report, RCS2008-228, pp.95-100, March 2009.

[11] K. Fujii and T. Fujii, "Adjacent Cell Interference Reduction Using Multiuser MIMO Relay Station," IEICE Technical Report, RCS2010-164, pp.31-36, Dec. 2010.

[12] W. Liu, C. Li, J.-D. Li, L. Hanzo, "Block diagonalization-based multiple input multiple output-aided downlink relaying," IET Commun, Vol.6, Iss.15, pp.2371-2377, 2012.

[13] L. Liang, W. Xu, X. Dong, "Limited feedback-based multi-antenna relay broadcast channels with block diagonalization," IEEE Trans. Wireless Commun., Vol.12, No.8, pp.4092-4101, Aug. 2013.

[14] Y. Tanahashi, Y. Iwanami, R. Yamada, N. Okamoto, "Study on VP Transmission Schemes for Multiuser MIMO Downlink using Non-Regenerative Relay," IEICE Technical Report, RCS2013-371, pp.395-400, March 2014.

[15] T. Taniguchi and Y. Karasawa, "An Elementary Study on Node Pair Selection in Relay-Aided Communication System Based on Stable Marriage Problem," IEICE Technical Report, RCS2014-50, pp.105-108, June 2014.

[16] G. Zhang and Y. Iwanami, "A design of communication quality in linearly precoded MU-MIMO downlink system," IEICE Technical Report, RCS2015, March 2016.

[17] T. K. Y. Lo,"Maximum Ratio Transmission," IEEE Trans. Commun.,vol.47, no.10, pp.1458-1461, Oct. 1999.

[18] Paulraj, R. Nabar and D. Gore, Introduction to Space Time wireless Communication, Cambridge University Press, 2008.

[19] J. K. Cavers, "Single-User and Multiuser Adaptive Maximum Ratio Transmission for Rayleigh Channel," IEEE Trans. On Vehicular Technology, Vol.49, No.6, pp.2043-2050, Nov. 2000.

[20] Z. Guo and P. Nilsson, "Reduced Complexity Schnorr-Euchner Decoding Algorithms for MIMO systems," IEEE communication letters, vol.8, no.5, pp286-288, May 2004.

[21] B. Shim and I. Kang, "Sphere Decoding with a probabilistic tree pruning," IEEE transactions on signal processing, vol.56, no.10, pp4867-4878, Oct. 2008.

