A Gain Matrix Design Method to Ensure Reciprocity in TDD MIMO Two-Hop Relay Systems

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***Abstract*-In two-hop relay systems, time division duplex (TDD) is usually adopted to support asymmetric traffic and offer channel reciprocity. When a relay is in the amplify-and-forward (AF) mode, the reciprocity is only provided within each hop. The equivalent channel between a base station (BS) and a mobile station (MS) cannot be reciprocal due to the operation at the relay. In some cases, the BS needs the whole downlink channel information to do pre-processing. However, the needed information could just be acquired through feedback in the conventional methods. In this paper, a gain matrix design method is proposed to maintain the whole link reciprocity and avoid large amount of feedback. Simulation results show that the mean square error (MSE) between whole downlink and uplink channel in proposed method is much smaller than that in the conventional gain matrix design schemes. Besides, the proposed method can maintain complete link reciprocity without performance loss.**

Keywords-relay; TDD; reciprocity; gain matrix design

I. INTRODUCTION

Relay technology has attracted much attention in recent years. It has the potential to overcome the shadow effect and realize high throughput as well as high data rate. With relay station (RS) between base station (BS) and mobile station (MS), the transmit power of the BS is saved while the interference to neighboring nodes is also mitigated.

Time division duplex (TDD) is usually adopted in relay systems to support asymmetric traffic and improve spectrum efficiency. Besides, one of the most important properties is that the downlink channel and uplink channel are reciprocal, i.e., the channel matrix of the downlink is the transpose of the one in uplink. In this case, the nodes can acquire the downlink channel information of the next hop from uplink channel estimation. Without channel reciprocity, the nodes can only acquire the needed information based on feedback, which induces delay. This delay can become overwhelming, especially, in the case of multiple hops. Thus, research in relay systems is often focused on TDD mode [1]-[3]. In order to simplify the implementation of the radio frequency hardware, half duplex TDD is usually considered [4]-[6].

There are two basic modes in relay systems, decode-and-forward (DF) mode and amplify-and-forward (AF) mode. In the DF mode, signal is decoded at the relay and re-encoded before transmission. In the AF mode, the relay just amplifies the signal and then retransmits it. The operation is linear and the whole link channel from the BS to the MS is similar to a simple MIMO channel. In some studies [7],[8], the whole link equivalent channel is identified by the BS to do pre-processing, such as precoding, beamforming, power allocation and so on. The utilization of the reciprocity to acquire the whole link channel information is one key problem.

In this paper, the processing matrix at the relay is defined as "relay matrix", while the part used for signal amplification is defined as "gain matrix". Study shows that the whole link channel in TDD AF relay systems loses its reciprocity when the same gain matrix design criterion is adopted in both downlink and uplink. That is because the amplification of the RS is not a symmetric function of the channel information of the first and second hops, which are interchanged in the downlink and uplink. Thus, the gain matrices of downlink and uplink are not reciprocal. A simple but effective gain matrix design method is proposed, which can be adopted in all TDD AF relay systems. Only small adjustment is needed at the relay and the whole link channel reciprocity can be acquired. Simulation results show that the mean square error (MSE) between whole downlink and uplink channel in the proposed method is much smaller than that in the conventional gain matrix design schemes.

The rest of paper is organized as follows. In Section II, the whole link reciprocity is described and some conventional relay matrix design methods are introduced. The proposed gain matrix design method is given in Section III and simulation results about the system performance are presented in Section IV. Conclusions are drawn in Section V.

Throughout this paper, the following conventions are used. $(\cdot)^T$, $(\cdot)^*$, $(\cdot)^H$, $\mathrm{tr}\{\}$ and $(\cdot)_{i,j}$ denote the transpose, conjugate, conjugate transpose , trace and (i,j)-th entry of the matrix, respectively. $P_{B,l}^A$ and $(\sigma_{B,l}^A)^2$ represent the transmit power and noise power of the antenna l of the terminal B, respectively. P_B^A represents the total transmit power at the terminal B. $\mathbf{H}_{BC}^A$ is the channel matrix of the link from terminal B to terminal C. The superscript A of them is "UL" or "DL", which represents the uplink or downlink.

II. THE WHOLE LINK RECIPROCITY

The basic system model for a dual-hop MIMO relay system is shown in Fig. 1. There is a BS with M antennas, a MS with

N antennas and a RS with L antennas. There is no direct path between the BS and the MS. The channel elements of the two hops are independent and identically distributed complex Gaussian random variables, which also implies that the channel matrices of the two hops are both full rank. The RS is a half-duplex relay and operates in a TDD mode. Each downlink (uplink) transmission period can be divided into two time slots. In the first time slot, the BS (MS) transmits signal to the RS. In the second time slot, the RS processes the signal and forwards it to the MS (BS).

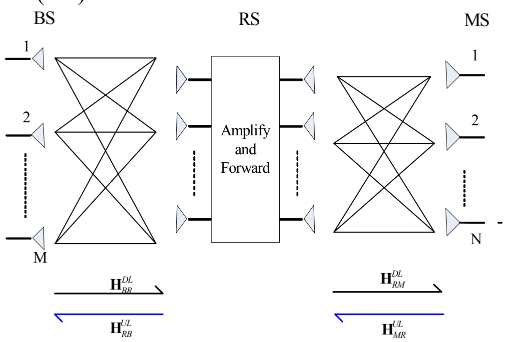

Fig. 1 The system model

In the downlink, the signal transmitted by BS is $\mathbf{x}$, the relay matrix and gain matrix of the RS is $\mathbf{R}^{DL}$ and $\mathbf{G}^{DL}$, respectively. Then the signal received at the MS is,

$$\mathbf{y} = \mathbf{H}_{RM}^{DL}\mathbf{R}^{DL}(\mathbf{H}_{BR}^{DL}\mathbf{x} + \mathbf{n}_1) + \mathbf{n}_2 \tag{1}$$

$\mathbf{n}_1$ and $\mathbf{n}_2$ are the noise received at the RS and MS. The whole downlink channel from BS to MS can be acquired as

$$\mathbf{H}_{eq}^{DL} = \mathbf{H}_{RM}^{DL}\mathbf{R}^{DL}\mathbf{H}_{BR}^{DL} \tag{2}$$

Similarly, the equivalent channel of the uplink is

$$\mathbf{H}_{eq}^{UL} = \mathbf{H}_{RB}^{UL}\mathbf{R}^{UL}\mathbf{H}_{MR}^{UL} \tag{3}$$

Lemma 1: Only when relay matrix of downlink and uplink are reciprocal, i.e., $\mathbf{G}^{UL} = (\mathbf{G}^{DL})^T$, could the two-hop AF relay system maintain the whole link reciprocity.

Proof: In the TDD mode, the channel matrix of downlink and uplink are reciprocal within each hop, i.e.,

$$\mathbf{H}_{RB}^{UL} = (\mathbf{H}_{BR}^{DL})^T \qquad \mathbf{H}_{MR}^{UL} = (\mathbf{H}_{RM}^{DL})^T \tag{4}$$

Utilizing the above results, (3) can be rewritten as,

$$\mathbf{H}_{eq}^{UL} = (\mathbf{H}_{BR}^{DL})^T\mathbf{R}^{UL}(\mathbf{H}_{RM}^{DL})^T = (\mathbf{H}_{RM}^{DL}(\mathbf{R}^{UL})^T\mathbf{H}_{BR}^{DL})^T \tag{5}$$

In order to maintain reciprocity between whole downlink equivalent channel and whole uplink equivalent channel, i.e., $\mathbf{H}_{eq}^{UL} = (\mathbf{H}_{eq}^{DL})^T$, the following equation should be satisfied,

$$(\mathbf{H}_{RM}^{DL}(\mathbf{R}^{UL})^T\mathbf{H}_{BR}^{DL})^T = (\mathbf{H}_{RM}^{DL}\mathbf{R}^{DL}\mathbf{H}_{BR}^{DL})^T \tag{6}$$

Because the channel matrices of the two hops are both full rank, it can be obtained that $\mathbf{R}^{UL} = (\mathbf{R}^{DL})^T$.

The downlink relay matrix can be expressed in a general form, $\mathbf{R}^{DL} = f_2(\mathbf{H}_{RM}^{DL})\mathbf{G}^{DL}f_1(\mathbf{H}_{BR}^{DL})$. f_1 and f_2 are functions about the channel information and they usually represent matrix transformations, decompositions or identity matrices. Actually, in some cases, f_1 and f_2 are same functions, since the operations for two hops are symmetrical at the relay. In [4], f_1 and f_2 are the transformations of the channel matrices, and they are adopted to accomplish the matched filter, zero-forcing filter and linear minimum mean-square error filter. In [5] and [10], above two functions come from the QR decomposition or singular value decomposition (SVD) of the channel matrices, respectively. These linear transformations can always make the following equations hold,

$$[f_1(\mathbf{H}_{BR}^{DL})]^T = f_2(\mathbf{H}_{RB}^{UL}) \quad [f_2(\mathbf{H}_{RM}^{DL})]^T = f_1(\mathbf{H}_{MR}^{UL}) \tag{7}$$

Finally, $\mathbf{G}^{UL} = (\mathbf{G}^{DL})^T$ can be derived from $\mathbf{R}^{UL} = (\mathbf{R}^{DL})^T$. ■

Thus, whole link reciprocity essentially depends on whether the gain matrix is reciprocal or not. In two-hop relay systems, gain matrix is diagonal and the diagonal elements are amplification coefficient (or gain factor) of each antenna of the relay. Therefore, the gain matrix is usually designed to implement power allocation at the relay. There are two universal gain matrix design methods in AF relay systems, uniform power allocation (UPA) scheme [1], [9] and naive amplify-and-forward (NAF) scheme [10]. The power allocation at the relay is not linear or symmetric function about the channel information of the first and second hops. If the channels of the two hops are interchanged, the gain factor of the relay will vary. However, in the uplink, the first (second) hop is just the link of the second (first) hop in the downlink. If the same criterion is used in both downlink and uplink, it is hard to make the downlink and uplink gain factors equal. Correspondingly, $\mathbf{G}^{UL} \neq (\mathbf{G}^{DL})^T$. According to *Lemma 1*, the whole link reciprocity is not held in general AF relay systems.

Then the following conclusion can be drawn for the AF relay systems. As the same criterion is adopted in both downlink and uplink gain matrix design, the whole link loses its reciprocity. To utilize reciprocity, the gain matrix of one side of the link (downlink or uplink) should be designed with the reciprocity specifically as a target. In next section, gain matrix design method which can keep reciprocity of the whole link will be elaborated under two different power constraints.

III. The Gain Matrix Design Method

In the downlink, $g_l^{DL}(l = 1, 2, \cdots, L)$ is the gain factor of the antenna l at the relay. It can be represented as [11]

$$g_l^{DL} = \sqrt{\frac{P_{RS.l}^{DL}}{\sum_{m=1}^{M} P_{BS.m}^{DL}\left|\left(\mathbf{H}_{BR}^{DL}\right)_{l,m}\right|^2 + \left(\sigma_{RS.l}^{DL}\right)^2}}\exp(j\phi_l^{DL}) \tag{8}$$

where ϕ_l^{DL} is the phase offset of the local oscillator at the antenna l of the relay relative to a given reference phase [11]. Here we assume all local oscillators are phase synchronized, ϕ_l^{DL} is equal to zero for all l . Similarly, the corresponding gain factor in the uplink is

$$g_l^{UL} = \sqrt{\frac{P_{RS.l}^{UL}}{\sum_{n=1}^{N} P_{MS.n}^{UL}\left|\left(\mathbf{H}_{MR}^{UL}\right)_{l,n}\right|^2 + \left(\sigma_{RS.l}^{UL}\right)^2}} \tag{9}$$

As discussed before, to guarantee reciprocity of the whole link, the gain matrices of the downlink and uplink are needed to be reciprocal. The gain matrix is usually the diagonal matrix, thus, the reciprocity condition can be rewritten as $g_l^{DL} = g_l^{UL}$ $(l = 1, 2, \cdots, L)$. This implies that

$$P_{RS.l}^{UL} = \frac{\sum_{n=1}^{N} P_{MS.n}^{UL} \left| \left(\mathbf{H}_{MR}^{UL}\right)_{l,n} \right|^2 + \left(\sigma_{RS.l}^{UL}\right)^2}{\sum_{m=1}^{M} P_{BS.m}^{DL} \left| \left(\mathbf{H}_{BR}^{DL}\right)_{l,m} \right|^2 + \left(\sigma_{RS.l}^{DL}\right)^2} P_{RS.l}^{DL} \tag{10-a}$$

$$P_{RS.l}^{DL} = \frac{\sum_{m=1}^{M} P_{BS.m}^{DL} \left| \left(\mathbf{H}_{BR}^{DL}\right)_{l,m} \right|^2 + \left(\sigma_{RS.l}^{DL}\right)^2}{\sum_{n=1}^{N} P_{MS.n}^{UL} \left| \left(\mathbf{H}_{MR}^{UL}\right)_{l,n} \right|^2 + \left(\sigma_{RS.l}^{UL}\right)^2} P_{RS.l}^{UL} \tag{10-b}$$

When the gain matrix of the downlink has been designed according to some certain optimization criteria, the transmit power of the relay in the uplink can be designed utilizing (10-a) to acquire the whole link reciprocity. Similarly, the transmit power of the relay in the downlink can be designed according to (10-b) if the gain matrix of the uplink is fixed. Hereafter, the analysis about the gain matrix design is only based on the downlink. Since the same conclusion can be got in the uplink design.

Besides (10-b), the transmit power of other terminals might be under certain constraint. Two kinds of power constraint are considered in the following analysis.

A. Individual Power Constraints

If both the RS and BS have individual power constraints, the power parameters of the uplink and the downlink can be determined separately from the downlink gain matrix design. Besides (10-b), the constraint conditions are:

$$\sum_{l=1}^{L} P_{RS.l}^{DL} \le P_{RS}^{DL} \tag{11}$$

$$P_{RS.l}^{DL} \ge 0, \quad l = 1, 2, \cdots, L \tag{12}$$

A slack variable δ is introduced to make the equality of (11) hold. Further two variables are defined to simplify the analysis,

$$\alpha_{l,m} = -\frac{P_{RS.l}^{UL} \left| \left(\mathbf{H}_{BR}^{DL}\right)_{l,m} \right|^2}{\sum_{n=1}^{N} P_{MS.n}^{UL} \left| \left(\mathbf{H}_{MR}^{UL}\right)_{l,n} \right|^2 + \left(\sigma_{RS.l}^{UL}\right)^2} \tag{13}$$

$$\beta_l = \frac{P_{RS.l}^{UL} \left(\sigma_{RS.l}^{DL}\right)^2}{\sum_{n=1}^{N} P_{MS.n}^{UL} \left| \left(\mathbf{H}_{MR}^{UL}\right)_{l,n} \right|^2 + \left(\sigma_{RS.l}^{UL}\right)^2} \tag{14}$$

Then the constraint conditions can be transformed into

$$\begin{cases} P_{RS.l}^{DL} + \sum_{m=1}^{M} P_{BS.m}^{DL} \alpha_{l,m} = \beta_l \\ \sum_{l=1}^{L} P_{RS.l}^{DL} + \delta = P_{RS}^{DL} \\ \delta, P_{RS.l}^{DL} \ge 0, \quad l = 1, 2, \cdots, L \end{cases} \tag{15}$$

The number of the unknowns and the number of the equations are both $L+1$. The equation group can be rewritten as

$$\begin{pmatrix} 1 & 0 & \cdots & 0 & 0 \\ 0 & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & & \vdots & \vdots \\ 0 & 0 & \cdots & 1 & 0 \\ 1 & 1 & \cdots & 1 & 1 \end{pmatrix} \begin{pmatrix} P_{RS.1}^{DL} \\ P_{RS.2}^{DL} \\ \vdots \\ P_{RS.L}^{DL} \\ \delta \end{pmatrix} = \begin{pmatrix} \beta_1 - \sum_{m=1}^{M} P_{BS.m}^{DL} \alpha_{1,m} \\ \beta_2 - \sum_{m=1}^{M} P_{BS.m}^{DL} \alpha_{2,m} \\ \vdots \\ \beta_L - \sum_{m=1}^{M} P_{BS.m}^{DL} \alpha_{L,m} \\ P_{RS}^{DL} \end{pmatrix} \tag{16}$$

It is assumed that the coefficient matrix of (16) is $\mathbf{A}$. Its determinant is $\det(\mathbf{A}) = 1$. It means that the problem of (16) has a unique solution. The solution can be expressed as,

$$P_{RS.l}^{DL} = \beta_l - \sum_{m=1}^{M} P_{BS.m}^{DL} \alpha_{l,m} \qquad \delta = P_{RS}^{DL} - \sum_{l=1}^{L} \left(\beta_l - \sum_{m=1}^{M} P_{BS.m}^{DL} \alpha_{l,m} \right) \tag{17}$$

It can be concluded from (10-b), when $P_{BS.m}^{DL} (m = 1, 2, \cdots M)$ is nonnegative, $P_{RS.l}^{DL}$ is also nonnegative. Therefore, the problem has solution only when δ is nonnegative, i.e.,

$$\delta = P_{RS}^{DL} - \sum_{l=1}^{L} \left(\frac{\sum_{m=1}^{M} P_{BS.m}^{DL} \left| \left(\mathbf{H}_{BR}^{DL}\right)_{l,m} \right|^2 + \left(\sigma_{RS.l}^{DL}\right)^2}{\sum_{n=1}^{N} P_{MS.n}^{UL} \left| \left(\mathbf{H}_{MR}^{UL}\right)_{l,n} \right|^2 + \left(\sigma_{RS.l}^{UL}\right)^2} \right) P_{RS.l}^{UL} \ge 0 \tag{18}$$

If δ is negative or equality of (11) needs to hold, we can make $\delta = 0$ and involve a normalized factor η to (10-b) or the first L equations of (15). Then the problem becomes

$$\begin{cases} P_{RS.l}^{DL} = \eta \left(\beta_l - \sum_{m=1}^{M} P_{BS.m}^{DL} \alpha_{l,m} \right) \\ \sum_{l=1}^{L} P_{RS.l}^{DL} = P_{RS}^{DL} \\ \eta, P_{RS.l}^{DL} \ge 0, \quad l = 1, 2, \cdots, L \end{cases} \tag{19}$$

The determinant of the coefficient matrix of (19) is L. Then the unique solution of η is $\eta = P_{RS}^{DL} \Big/ \sum_{l=1}^{L} \left(\beta_l - \sum_{m=1}^{M} P_{BS.m}^{DL} \alpha_{l,m} \right)$ which is always positive. In this case, however, η will destroy the reciprocity condition, and the equivalent downlink gain factor at antenna l is ηg_l^{UL}. Accordingly, the whole downlink channel can be expressed as $\mathbf{H}_{eq}^{DL} = \eta (\mathbf{H}_{eq}^{UL})^T$. Sometimes, the preprocessing methods adopted at the source (BS or MS) will not be affected by coefficient η, such as unitary precoding, then η can be selected freely. If the preprocessing at the source is sensitive to the channel coefficient, such as power allocation, η can be transmitted or fed back to the source for compensation. After all, the feedback quantity is much smaller than that feeding back the whole link channel information.

B. Sum Power Constraint

In some practical sensor networks, the total transmit power of the BS and RS is constrained [12]. In this case, besides (10-b), the constraint conditions are

$$\sum_{l=1}^{L} P_{RS.l}^{DL} + \sum_{m=1}^{M} P_{BS.n}^{DL} \le P^{DL} \tag{20}$$

$$P_{BS.m}^{DL} \ge 0, P_{RS.l}^{DL} \ge 0 \tag{21}$$

A slack variable μ is introduced to make the equality of (20) hold. At the same time, variables $\alpha_{l,m}$ and β_l defined in (13), (14) are still used. The constraint conditions can be written as

$$\begin{cases} P_{RS.l}^{DL} + \sum_{m=1}^{M} \left(P_{BS.m}^{DL} \alpha_{l,m} \right) = \beta_l \\ \sum_{l=1}^{L} P_{RS.l}^{DL} + \sum_{m=1}^{M} P_{BS.m}^{DL} + \mu = P^{DL} \\ \mu, P_{RS.l}^{DL} \ge 0, P_{BS.m}^{DL} \ge 0 \quad l = 1, \cdots, L; m = 1, \cdots, M \end{cases} \tag{22}$$

The number of the unknowns is $L + M + 1$ and the number of the equations is $L + 1$. It is assumed that the transmit power of each antenna of the BS is equal and $\mu = 0$. Then the number of the unknowns can decrease to $L + 1$. It is assumed that the coefficient matrix of (22) is $\mathbf{B}$. Its determinant is

$$\det(\mathbf{B}) = L + \sum_{l=1}^{L} \sum_{m=1}^{M} \frac{P_{RS.l}^{UL} \left| (\mathbf{H}_{BR}^{DL})_{l,m} \right|^2}{\sum_{n=1}^{N} P_{MS.n}^{UL} \left| (\mathbf{H}_{MR}^{UL})_{l,n} \right|^2 + (\sigma_{RS.l}^{UL})^2} > 0 \tag{23}$$

Thereby, the problem has the unique solution,

$$P_{RS.l}^{DL} = \beta_l - \frac{\left(P^{DL} - \sum_{l=1}^{L} \beta_l \right) \sum_{m=1}^{M} \alpha_{l,m}}{L - \sum_{l=1}^{L} \sum_{m=1}^{M} \alpha_{l,m}} \quad P_{BS.m}^{DL} = \frac{P^{DL} - \sum_{l=1}^{L} \beta_l}{L - \sum_{l=1}^{L} \sum_{m=1}^{M} \alpha_{l,m}} \tag{24}$$

It can be concluded from (10-b), if $P_{BS.m}^{DL} > 0$, then $P_{RS.l}^{DL} > 0$. Therefore, the equation group has solution only if $P_{BS.m}^{DL} > 0$, i.e.,

$$P^{DL} - \sum_{l=1}^{L} \frac{(\sigma_{RS.l}^{DL})^2}{\sum_{n=1}^{N} P_{MS.n}^{UL} \left| (\mathbf{H}_{MR}^{UL})_{l,n} \right|^2 + (\sigma_{RS.l}^{UL})^2} P_{RS.l}^{UL} > 0 \tag{25}$$

In TDD mode, the transmit power of the relay in downlink is usually equal to that in uplink, i.e., $\sum_{l=1}^{L} P_{RS.l}^{DL} = \sum_{l=1}^{L} P_{RS.l}^{UL}$. Thus, $P^{DL} > \sum_{l=1}^{L} P_{RS.l}^{DL} = \sum_{l=1}^{L} P_{RS.l}^{UL}$. At the antenna l of the relay, the downlink noise power is not larger than uplink total receive power, i.e., $(\sigma_{RS.l}^{DL})^2 \le \sum_{n=1}^{N} P_{MS.n}^{UL} \left| (\mathbf{H}_{MR}^{UL})_{l,n} \right|^2 + (\sigma_{RS.l}^{UL})^2$. Therefore, (25) will hold unless the receive noise at the relay in downlink is extremely large.

In this section, the gain matrix design method to maintain the whole link channel reciprocity is introduced under two different power constraint cases. The existing gain matrix design methods can be adopted in downlink (uplink) to meet different requirements, such as capacity or MSE optimization, while the proposed method is used in the uplink (downlink) to keep the whole link reciprocity.

IV. SIMULATION RESULTS

The MSE between the whole downlink and uplink channel in traditional and proposed gain matrix design methods are evaluated in this section. It is assumed that the whole uplink channel can be identified perfectly and the MSE is defined as,

$$\zeta = E\left(\sum_{n=1}^{N} \sum_{m=1}^{M} \left| (\mathbf{H}_{eq}^{DL})_{n,m} - (\mathbf{H}_{eq}^{UL})_{m,n} \right|^2 \right) \Big/ E\left(\sum_{n=1}^{N} \sum_{m=1}^{M} \left| (\mathbf{H}_{eq}^{UL})_{m,n} \right|^2 \right) \tag{26}$$

In the simulation, BS, RS and MS all have four antennas. The signal-to-noise ratio (SNR) between BS and RS link is equal to that between RS and MS link, and it varies from 0dB to 20dB. The maximum transmit power of the BS, MS and RS are all 1 watt. When the total transmit power of BS and RS is constrained jointly, the maximum power is 2 watt.

Fig. 2 shows the MSE between the whole downlink and uplink channel in conventional UPA and NAF schemes under ideal channel estimation case. The whole downlink and uplink channel have large deviation in UPA and NAF schemes, even in the ideal case. This is because the channel is not reciprocal in these two approaches. Moreover, the deviation in UPA scheme is much larger than that in NAF scheme. Thus, the whole downlink channel cannot be seen as the approximate uplink channel in conventional gain matrix design methods.

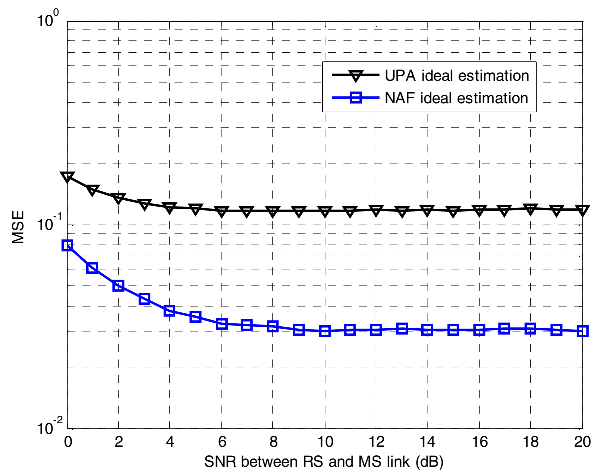

Fig. 2 Comparison of MSE in conventional UPA and NAF schemes under ideal channel estimation

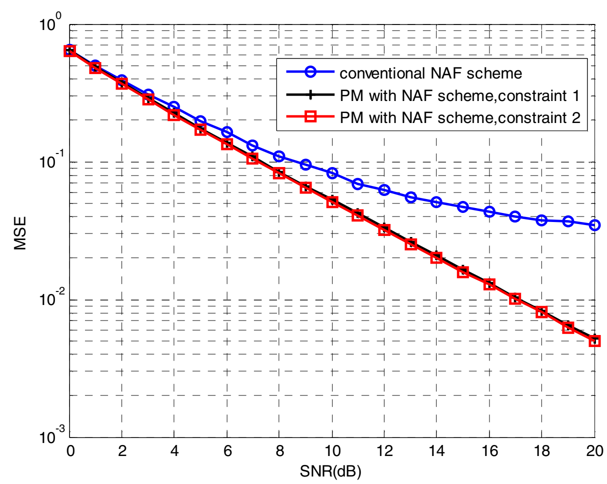

Fig. 3 Comparison of MSE in conventional NAF scheme and proposed method under non-ideal channel estimation

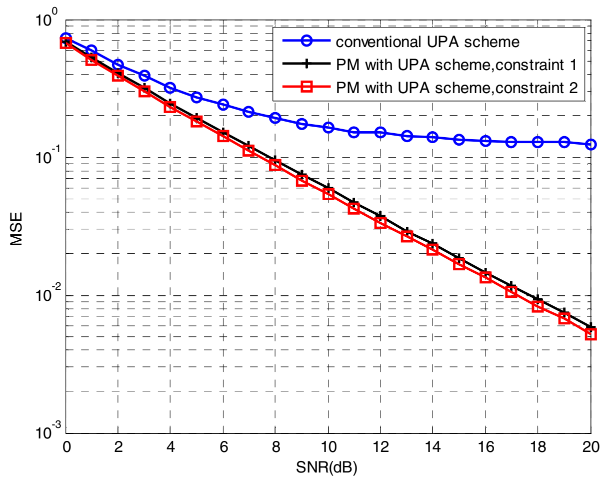

Fig. 4 Comparison of MSE in conventional UPA scheme and proposed method under non-ideal channel estimation

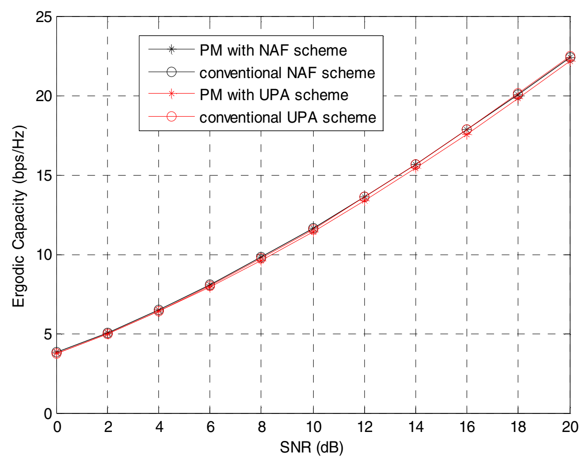

Fig. 5 Comparison of the downlink ergodic capacity performance

Fig. 3 and Fig. 4 show the comparison of the MSE between the conventional (NAF and UPA) schemes and the proposed method under non-ideal channel estimation. Least squares (LS) channel estimation is used. "PM" is the abbreviation of the "proposed method". "PM with UPA (or NAF) scheme" means that UPA (or NAF) scheme is adopted in the uplink, while the proposed gain matrix design criterion is used in the downlink. It is observed that the proposed method with different power constraint cases achieve similar performance. Compared with the conventional NAF scheme, the MSE of the proposed method is reduced by one order of magnitude at high SNR region. Moreover, nearly two orders of magnitude are reduced by the proposed method compared to the conventional UPA scheme.

Since the proposed method is performed in the downlink in the simulation, whether it degrades the downlink performance or not is an important concern. Fig. 5 shows the comparison of downlink ergodic capacity of the proposed method and the conventional methods. In the proposed method, "Constraint 1" is adopted and the transmit power of the relay is strict 1 watt to ensure the comparison reasonable. It is clear that the proposed method have the similar performance with the conventional schemes. The reason is that the gain matrix in propose method is η times of the one in the uplink which is designed by the same criterion with the conventional method. Thus, the proposed method can be seen as another realization of the conventional one. Simulation results also illustrate that, compared with the traditional methods, the proposed method doesn't degrade the system performance.

V. Conclusion

In this paper, we proposed a gain matrix design method in TDD AF relay systems to keep the whole link reciprocity. With the proposed method, the whole downlink (uplink) channel is the transpose of the one in uplink (downlink), and it can be acquired through uplink (downlink) channel estimation directly. Simulation results show that the proposed method can maintain the whole link reciprocity without a performance loss.

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