Relay Deployment for AF-MIMO Two-Way Relaying Networks with Antenna Selection

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Abstract —In this paper the outage-optimal relay deployment problem for amplify-and-forward (AF) multi-input multi-output (MIMO) two-way relaying network with antenna selection is studied. By utilizing an approximation of the outage probability, the outage-optimal relay location is shown feasible. On this basis a relay deployment scheme is developed by providing the near-optimal relay position in an approximate closed form. Theoretical analysis shows that the optimal relay position is affected by the number of antennas at sources but independent of the number of antennas at the relay. Simulations confirm the theoretical analysis and show the performance gain achieved by the developed relay deployment scheme.

Index Terms—AF-MIMO, two-way relaying, antenna selection, relay deployment

I. Introduction

In half-duplex wireless communication networks, two-way relaying has been well recognized to achieve high spectrum efficiency. In a two-way relaying network (TWRN), the system throughput can be twice as high as that in traditional one-way relay work [1]-[3]. With the utilization of Multi-input Multi-output (MIMO) technique, the spectrum efficiency can be further significantly improved [4]. However, the main drawback of any MIMO system is the increased system complexity due to the additional cost for enabling multiple transmit and receive radio frequency (RF) chains [5]. For example, the beam-forming or other pre-coding algorithms for MIMO TWRN are greatly challenged by increased complexity on computation, signaling overhead as well as the hardware cost on Radio Frequency chains[6]-[8]. To make the performance gain achieved by MIMO more affordable, antenna selection schemes have been proposed to reduce the complexity of the transmitter as well as hardware cost [9]-[10]. In [9], a max-min antenna selection scheme is proposed and it is proved that diversity gain is still achievable with antenna selection at the relay. In [10], two antenna selection schemes are studied for amplify-and-forward (AF) MIMO two-way relaying networks, both showing high performance gain in outage probability. Moreover, in [11]-[12] MMSE precoders are designed for cooperative two-way relaying networks with multiple single-antenna and multiple-antenna half-duplex amplify-and-forward relays.

In the meantime, relay location/placement/deployment has been recognized as a non-negligible factor in a two-way relaying network [13]-[16]. In [13], the analysis and tests in practical indoor Environments show that even a sub-optimal relay placement algorithm can improve the system performance. In [14], a joint power and location optimization solution for MIMO TWRN is proposed and shows that optimal relay location can bring more performance gain compared with optimal power allocation. In [15], relay location optimization problem is investigated to illustrate the effects on energy efficiency for two-way relaying. In [16], it is suggested that the relay is best positioned in the middle point of the two sources for energy consumption. All the studies in [13]-[16] reveal the importance of relay deployment optimization. However, the conclusions in the literature are made for specific scenarios thus not applied directly to the AF-MIMO two-way relaying network with antenna selection.

In this paper, utilizing an approximation of the outage probability for AF MIMO two-way relaying networks with antenna selection, we reveal the feasibility of the outage-optimal relay location and developed a near-optimal relay deployment scheme by approximately locating the stationary point of the outage probability as a function of the relay position. The near-optimal relay position is expressed in closed form so that an insightful discussion can be provided in this paper.

The remainder of the paper is organized as the following: Section II describes the system model. In Section III, the near-optimal relay deployment scheme is studied by the outage approximation. Section VI reports simulation results and Section VII concludes the paper.

II. System Model

We consider an AF-MIMO two-way relaying network with two source nodes and one relay, as shown in Fig. 1,

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where S_1, S_2 and R are equipped with N_1, N_2 and N_R antennas, respectively. During the transmission, all nodes are assumed working in half-duplex mode and channels are assumed reciprocal, semi-static and frequency-flat Rayleigh fading, *i.e.*, the channel state keeps constant within a transmission slot for both uplink and downlink while independent identical distributed among different time slots. In assumption, the channel states of the link between $S_i|_{i=1}^2$ and R and the link between R and $S_i|_{i=1}^2$ can be denoted by $\mathbf{H}_{S_iR}$ and $\mathbf{H}_{S_iR}^T$, respectively. $h_{S_iR}^{p,l}$, the (p,l)-th element of $\mathbf{H}_{S_iR}$, is assumed circularly-symmetric complex Gaussian, *i.e.*, $h_{S_iR}^{p,l} \sim \mathcal{CN}(0,\zeta_i)$. Here $\zeta_i|_{i=1}^2$ is the long-time path loss and assumed that $\zeta_i \sim (d_{S_iR})^{-\alpha}$, where $d_{S_iR}|_{i=1}^2$ is the distance between S_i and R, and $\alpha \in (2,6)$ denotes path loss exponent of $S_i \to R$ channel. No direct link is assumed between S_1 and S_2 due to heavy path-loss and shadowing, so that any communication between the two sources has to be implemented by relaying. In addition, we assume the additive noise at each receiver is modeled as complex zero mean white Gaussian noise.

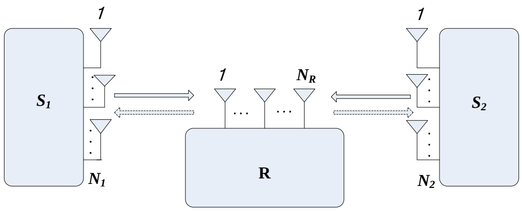

Fig. 1. System model of MIMO two-way relaying.

In the system model above, in each transmission time slot, the information symbols χ_1 and χ_2, where $\varepsilon\{|\chi_1|^2\}=1$ $\varepsilon\{|\chi_2|^2\}=1$, are exchanged between S_1 and S_2 via two phases. In Phase I, the j-th and l-th antenna are selected respectively by S_1 and S_2 to broadcast their corresponding message χ_1 and χ_2 over a multiple access channel. At relay R, the mixed signals in the air received by selecting the m-th antenna is

$$Y_R = \sqrt{P_{S_1}} h_{S_1R}^{m,j} \chi_1 + \sqrt{P_{S_2}} h_{S_2R}^{m,l} \chi_2 + n_R \quad (1)$$

where $\mathrm{P}_{S_i}|_{i=1}^2$ is the transmitting power at S_i, and n_R is the additive Gaussian noise (AWGN) at R with zero mean and variance σ_R^2. In Phase II, the relay R amplifies its received signal with amplifying gain G via its m-th antenna and then forward it to $S_i|_{i=1}^2$. In the meantime, this relayed signal is received with j-th antenna of S_1 and l-th antenna of S_2. The received signal can be expressed by

$$Y_{S_1} = G h_{S_1R}^{m,j} Y_R + n_1 \quad (2)$$

and

$$Y_{S_2} = G h_{S_2R}^{m,l} Y_R + n_2 \quad (3)$$

where P_R is the transmitting power at R, $G = \sqrt{P_R/(P_{S_1}|h_{S_1R}^{m,j}|^2 + P_{S_2}|h_{S_2R}^{m,l}|^2 + \sigma_R^2)}$ denotes the amplification gain, and $n_i|_{i=1}^2 \sim \mathcal{CN}(0,\sigma_i^2)$ is the additive Gaussian noise at S_i.

Once the signal is received by substituting (1) into (2) and (3) and canceling the so called "self-interference" before signal detection, the end-to-end signal-noise-ratio (SNR) at $S_i|_{i=1}^2$ can be derived. Without loss of generality, we take S_1 as example and express its SNR by

$$\gamma_{S_1}^{(j,l,m)} = \frac{(P_R|h_{S_1R}^{m,j}|^2/\sigma_1^2)(P_{S_2}|h_{S_2R}^{m,l}|^2/\sigma_R^2)}{(P_R/\sigma_1^2 + P_{S_1}/\sigma_R^2)|h_{S_1R}^{m,j}|^2 + P_{S_2}|h_{S_2R}^{m,l}|^2/\sigma_R^2 + 1} \quad (4)$$

As is known in [10], when the optimal relay location is determined, the best combination of antenna at S_1, R and S_2, *i.e.*, (J,L,M), can be selected by the maximization of the system sum rate. The instantaneous sum-rate of S_1 and S_2 can be expressed as

$$\begin{aligned}\Re^{(j,l,m)} &= \frac{1}{2}\log(1+\gamma_{S_1}^{(j,l,m)}) + \frac{1}{2}\log(1+\gamma_{S_2}^{(j,l,m)}) \\ &= \frac{1}{2}\log\left((1+\gamma_{S_1}^{(j,l,m)})(1+\gamma_{S_2}^{(j,l,m)})\right)\end{aligned} \quad (5)$$

Then the best (J,L,M) can be obtained by

$$\{J,L,M\} = \underset{\substack{1\le j\le N_1, 1\le l\le N_2 \\ 1\le m\le N_R}}{\arg\max}\left[\left(1+\gamma_{S_1}^{(j,l,m)}\right)\left(1+\gamma_{S_2}^{(j,l,m)}\right)\right] \quad (6)$$

III. Relay Deployment

In this section, we first derive the closed-form approximate outage probability by the antenna selection strategy in (6), then use the closed-form outage probability approximation to study the best position of the relay that achieves globally minimum outage probability. As will be shown in this section and simulations, although our study is based on an approximation of outage probability due to the lack of the accurate closed-form expression, the performance can still be significantly improved by the developed relay deployment scheme.

The outage probability can be defined as the probability that the instantaneous sum-rate falls below a target rate R_{th} which is given by

$$P_{out} = P\left[\underset{\substack{1\le j\le N_1, 1\le l\le N_2 \\ 1\le m\le N_R}}{\arg\max} \Re^{\{j,l,m\}} \le R_{th}\right] = P[W \le 2^{2R_{th}} - 1] \quad (7)$$

where W is given by

$$W = \max_{\substack{1\le j\le N_1, 1\le l\le N_2 \\ 1\le m\le N_R}}\left[\gamma_{S_1}^{(j,l,m)} + \gamma_{S_2}^{(j,l,m)} + \gamma_{S_1}^{(j,l,m)}\gamma_{S_2}^{(j,l,m)}\right]$$

Therefore the outage probability can be derived through the CDF of W, which will be expressed below in detail.

When SNR is sufficiently large, the instantaneous sum-rate of MIMO AF TWRNs can be approximated as follows:

$$\Re^{(j,l,m)} \approx \frac{1}{2}\log\left(\gamma_{S_1}^{(j,l,m)}\gamma_{S_2}^{(j,l,m)}\right) \quad (8)$$

Hence the CDF of approximated effective SNR can be derived as

$$\begin{aligned} F_{W'}(\omega) &= \Pr\left[W' = \max_{\substack{1\le j\le N_1, 1\le l\le N_2 \\ 1\le m\le N_R}} \{\gamma_{S_1}^{(j,l,m)}\gamma_{S_2}^{(j,l,m)}\} \le \omega \right] \\ &= \Pr\left[\max_{1\le m\le N_R} \{\gamma_{S_1}^{(J,L,m)}\gamma_{S_2}^{(J,L,m)}\} \le z \right] \end{aligned} \quad (9)$$

where

$$\gamma_{S_1}^{(J,L,m)} = \max_{1\le j\le N_1, 1\le l\le N_2} (\gamma_{S_1}^{(j,l,m)})$$

$$\gamma_{S_2}^{(J,L,m)} = \max_{1\le j\le N_1, 1\le l\le N_2} (\gamma_{S_2}^{(j,l,m)})$$

Next we define $W_m{}'$ and then expand it as follows:

$$\begin{aligned} W_m{}' &= \gamma_{S_1}^{(J,L,m)}\gamma_{S_2}^{(J,L,m)} \\ &= \frac{\beta_0^{-2} X_m^2 Y_m^2}{(u_1 X_m + Y_m + 1/\bar{\gamma}_{S_2})(X_m + u_2 Y_m + 1/\bar{\gamma}_{S_1})} \end{aligned} \quad (10)$$

where

$$X_m = \left|h_{S_1R}^{(m,J)}\right|^2 = \max_{1\le j\le N_1}(\left|h_{S_1R}^{(m,j)}\right|^2)$$

$$Y_m = \left|h_{S_2R}^{(m,J)}\right|^2 = \max_{1\le l\le N_2}(\left|h_{S_2R}^{(m,l)}\right|^2)$$

$$\beta_0 = 1/\bar{\gamma}_R,\ u_1 = (\bar{\gamma}_R + \bar{\gamma}_{S_1})/\bar{\gamma}_{S_2}$$

$$u_2 = (\bar{\gamma}_R + \bar{\gamma}_{S_2})/\bar{\gamma}_{S_1}$$

In the further, the upper bound of $W_m{}'$ can be approximated as

$$\begin{aligned} W_m' &\le \frac{\beta_0^{-2} X_m^2 Y_m^2}{(u_1 X_m + Y_m)(X_m + u_2 Y_m)} \\ &\le \frac{1}{\beta_0{}^2}\frac{1}{u_1 u_2}\left(\frac{\sqrt{u_1}X_m\sqrt{u_2}Y_m}{\sqrt{u_1}X_m + \sqrt{u_2}Y_m}\right)^2 \frac{(\sqrt{u_1}X_m + \sqrt{u_2}Y_m)^2}{(\sqrt{u_1}X_m + \sqrt{u_2}Y_m)^2} \\ &= \frac{1}{\beta_0{}^2}\frac{1}{u_1 u_2}\left(\frac{\sqrt{u_1}X_m\sqrt{u_2}Y_m}{\sqrt{u_1}X_m + \sqrt{u_2}Y_m}\right)^2 \\ &\le \frac{1}{\beta_0{}^2}\frac{1}{u_1 u_2}(\min(\sqrt{u_1}X_m, \sqrt{u_2}Y_m))^2 = W_m^{ub} \end{aligned} \quad (11)$$

So the CDF of W_m^{ub} in (11) can be derived as follows:

$$\begin{aligned} F_{W_m}(\omega) &\ge F_{W_m{}^{ub}}(\omega) \\ &= \Pr\left(W_m^{ub} = \frac{(\min(\sqrt{u_1}X_m, \sqrt{u_2}Y_m))^2}{\beta_0{}^2 u_1 u_2} \le \omega \right) \\ &= \left[1 - (1 - F_{X_m}(\beta_0\sqrt{u_2\omega}))(1 - F_{Y_m}(\beta_0\sqrt{u_1\omega})\right] \end{aligned} \quad (12)$$

where $F_{X_m}(x)$ and $F_{Y_m}(x)$ are the CDFs of X_m and Y_m which are defined as $F_{X_m}(x) = (1 - e^{-x/\zeta_1})^{N_1}$ and $F_{Y_m}(x) = (1 - e^{-x/\zeta_2})^{N_2}$, respectively. Further, the CDF of $W^{ub} = \max_{1\le m\le N_R}\{W_m^{ub}\}$ can be derived as follows:

$$\begin{aligned} F_{W^{ub}}(\omega) &= \Big[1 - (1 - F_{X_m}(\beta_0\sqrt{u_2\omega}))\times \\ &\quad (1 - F_{Y_m}(\beta_0\sqrt{u_1\omega})\Big]^{N_R} \\ &= \left[1 - \left(1 - \left(1 - \exp\left(-\frac{\beta_0\sqrt{u_2\omega}}{\zeta_1}\right)\right)^{N_1}\right)\times\right. \\ &\quad \left.\left(1 - \left(1 - \exp\left(-\frac{\beta_0\sqrt{u_1\omega}}{\zeta_2}\right)\right)^{N_2}\right)\right]^{N_R} \end{aligned} \quad (13)$$

Thus the corresponding outage probability is

$$\begin{aligned} P_{out} &= F_{W^{ub}}(\omega) \\ &= \left[1 - \left(1 - \left[1 - \exp\left(-\frac{\beta_0\sqrt{u_2\omega}}{\zeta_1}\right)\right]^{N_1}\right)\times\right. \\ &\quad \left.\left(1 - \left[1 - \exp\left(-\frac{\beta_0\sqrt{u_1\omega}}{\zeta_2}\right)\right]^{N_2}\right)\right]^{N_R} \end{aligned} \quad (14)$$

As can be observed from (14), the outage probability is clearly a function of the distance between the sources and the relay. In the following, the best position of the relay to achieve globally minimum outage probability is analyzed by using the closed-form outage probability approximation in (14).

Letting $\beta := \beta_0\sqrt{\omega}$, we can obtain

$$\begin{aligned} P_{out}(w) &= \left[1 - \left(1 - \left(1 - \exp\left[\frac{-\beta\sqrt{u_2}}{\zeta_1}\right]\right)^{N_1}\right)\times\right. \\ &\quad \left.\left(1 - \left(1 - \exp\left[\frac{-\beta\sqrt{u_1}}{\zeta_2}\right]\right)^{N_2}\right)\right]^{N_R} \end{aligned} \quad (15)$$

It can be concluded from (15) that the optimal relay location is irrelevant to the number of antennas at the relay. Further, the minimization of (15) is equivalent to minimizing

$$\begin{aligned} g(d_{S_1R}) &= \left[1 - \exp\left(\frac{-\beta\sqrt{u_2}}{\zeta_1}\right)\right]^{N_1} + \left[1 - \exp\left(\frac{-\beta\sqrt{u_1}}{\zeta_2}\right)\right]^{N_2} - \\ &\quad \left[1 - \exp\left(\frac{-\beta\sqrt{u_2}}{\zeta_1}\right)\right]^{N_1}\left[1 - \exp\left(\frac{-\beta\sqrt{u_1}}{\zeta_2}\right)\right]^{N_2} \end{aligned} \quad (16)$$

A numerical method can be readily developed to get the minimum point and its corresponding distance by exhaust search. However, this search is at the price of the high complexity, which may not be affordable in practice. To reduce the complexity and offer a deeper insight into the relationship between outage performance and the location of the relay, in the following the analytical expression of d_{S_1R} is developed.

Since $\beta := \beta_0\sqrt{\omega}$ is sufficiently small when SNR is sufficiently large, the last term on the right side of (16) can be treated as negligible thus can be removed away. Applying $\beta := \beta_0\sqrt{\omega}$ and considering the optimal position must fall in the line between the two sources, the new optimization problem can be formulated as

$$\text{(P1):}\quad \text{minimize}\quad f(d_{S_1R}) = \left(1-e^{-\beta\sqrt{u_2}d_{S_1R}^{\alpha}}\right)^{N_1} + \left(1-e^{-\beta\sqrt{u_1}(1-d_{S_1R})^{\alpha}}\right)^{N_2}$$

$$\text{subject to}\quad 0 < d_{S_1R} < 1 \tag{17}$$

It can be proved that (P1) is a quasi-convex problem thus has a unique globally optimal solution. But still, the problem (P1) is not trivial since the complexity of numerical method is usually not affordable in practical two-way relaying networks with multiple potential relays.

To reveal the analytical solution for (P1), we first convert this optimization into solving the equation in the following by finding the stationary point of $f(d_{S_1R})$. So we can take derivation in two sides of $f(d_{S_1R})$, and then make it equal to zero to find the stationary point.

$$\begin{aligned} & N_1\left(1-e^{-\beta\sqrt{u_2}d_{S_1R}^{\alpha}}\right)^{N_1-1} e^{-\beta\sqrt{u_2}d_{S_1R}^{\alpha}}\sqrt{u_2}\,d_{S_1R}^{\alpha-1} \\ & = N_2\left(1-e^{-\beta\sqrt{u_1}(1-d_{S_1R})^{\alpha}}\right)^{N_2-1} \times \\ & e^{-\beta\sqrt{u_1}(1-d_{S_1R})^{\alpha}}\sqrt{u_1}(1-d_{S_1R})^{\alpha-1} \end{aligned} \tag{18}$$

When SNR is sufficiently large, we obtain $\beta \to 0$, then it is readily known that $1-e^{-\beta\sqrt{u_2}d_{S_1R}^{\alpha}} \sim \beta\sqrt{u_2}d_{S_1R}^{\alpha}$, $1-e^{-\beta\sqrt{u_1}(1-d_{S_1R})^{\alpha}} \sim \beta\sqrt{u_1}(1-d_{S_1R})^{\alpha}$.

For simplicity, letting $t = \dfrac{N_1(u_2)^{N_1/2}}{N_2(u_1)^{N_2/2}}\beta^{N_1-N_2}$ yields

$$\begin{aligned} & t d_{S_1R}^{\alpha N_1-1}\left(1-\beta\sqrt{u_2}d_{S_1R}^{\alpha}\right) \\ & = \left(1-d_{S_1R}\right)^{\alpha N_2-1}\left[1-\beta\sqrt{u_1}(1-d_{S_1R})^{\alpha}\right] \end{aligned} \tag{19}$$

A further approximation can be performed by removing all terms related to β since β approaches to 0 asymptotically. Utilizing the polynomial approximation of (19), we can obtain

$$t d_{S_1R}^{\alpha N_1-1} = (1-d_{S_1R})^{\alpha N_2-1} \tag{20}$$

which seems quite a simple expression at first sight. Unfortunately, it has been well-known that there is no mathematical general solution for (20) for arbitrary N_1 and N_2. Nevertheless, it is clear that definitely there exists a solution for (20) since $f'(d_{S_1R})$ is continuous and $f'(0) > 0$, $f'(1) < 0$. To approximate the solution, we rewrite (20) into an equivalent form, which is

$$\ln t + (\alpha N_1 - 1)\ln d_{S_1R} = (\alpha N_2 - 1)\ln(1-d_{S_1R}) \tag{21}$$

and fit $\ln d_{S_1R}$ and $\ln(1-d_{S_1R})$ into polynomial forms by using $\ln(1+x) = ax + bx^2 + O(x^3)$ for $-1 \le x \le 1$. It is tested that for $-1/2 \le x \le 0$, $a = 1$, $b = -0.32$ is an acceptable pair of fitting factor; for $-1 < x < -1/2$, the fitting factors a, b can be found in a similar way. So when $N_1 = N_2 = N$, the optimal d_{S_1R} can be approximated by

$$d_{S_1R} = 1/2 - \ln t / 2(a-b)(\alpha N - 1) \tag{22a}$$

while when $N_1 < N_2$, the optimal d_{S_1R} will be less than $1/2$, which coincides with the simulation results in [10].

So when $N_1 \ne N_2$, the optimal d_{S_1R} can be approximated by

$$d_{S_1R} = \frac{-\tau + \sqrt{\tau^2 - 4\eta[\ln t - 4\eta(a-b)\alpha N_1 + (a-b)]}}{2\eta} \tag{22b}$$

where

$$\eta = \alpha b(N_1 - N_2)$$

$$\tau = a\alpha(N_1 + N_2) - 2b\alpha N_1 - 2(a-b)$$

As a result of (22), the optimal distance between the relay R and the source S_1 is a function of transmitting power and the number of antennas at sources, but irrelevant to the number of antennas at the relay, which implies that, once the source nodes are paired for two-way relaying, the optimal location of the relay is pre-determined. On this basis, the relay can be deployed in this near-optimal position to achieve performance gain. Furthermore, in the scenarios with multiple potential relays, since a relay closer to this near-optimal relay position achieves better outage performance, the proposed near-optimal relay position can also help with quick relay selection.

IV. Simulation Results

In this section, numerical results and Monte-Carlo simulations are provided to reveal the performance gain brought by the developed relay deployment scheme. Without loss of generality, in the simulation the path loss exponent is set to $\alpha = 3.5$; the variances of the noise are equally allocated to the sources and the relay; the overall target rate of the system is set to $\omega = 2.5 bps/Hz$ (implying the target rate of the each source node is $1.25 bps/Hz$).

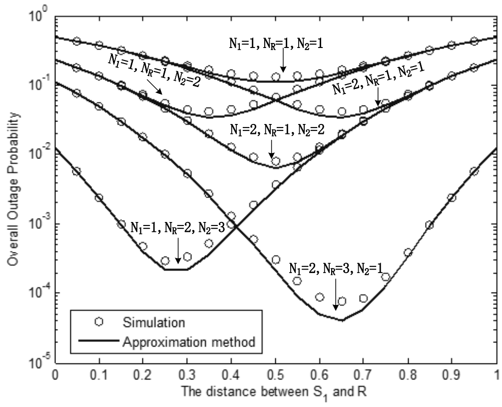

Fig. 2. Outage probability against the distance d_{S_1R} with various antenna equiment when SNR is 10.79dB and $P_{S_1} = P_{S_2} = P_R$.

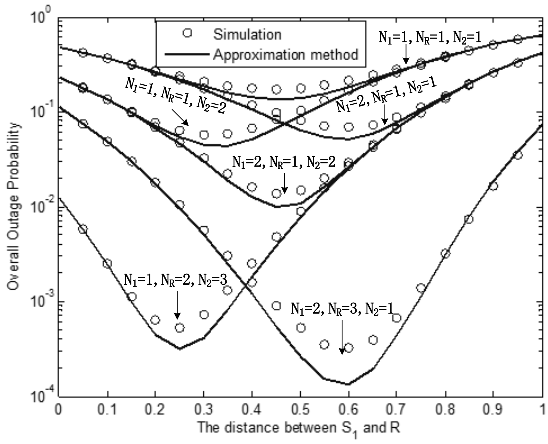

Fig. 3. Outage probability against the distance d_{S_1R} with various antenna equiment when SNR is 10.79dB, $P_{S_1} = P_R / 3$ and $P_{S_2} = 2P_R / 3$.

Fig. 2 and Fig. 3 show the overall outage probability against the distance d_{S_1R} with various antenna equipment, where both analytical approximations and Monte-Carlo simulations are presented when SNR is 10.79dB, the transmitting power is $P_{S_1} = P_{S_2} = P_R$ and $P_{S_1} = P_R / 3$, $P_{S_2} = 2P_R / 3$, respectively. As expected, Fig. 2 and Fig. 3 all confirm that, the optimal position of the relay is independent of the number of the relay since $(N_1, N_R, N_2) = (2,1,1)$ and $(2,3,1)$ share the same optimal position. Further observation from Fig. 2 finds that when the antenna configuration of the two sources is symmetric, *i.e.*, $N_1 = N_2$, the outage-optimal relay deployment solution is to put the relay in the half-way between the two sources; while when the antenna configuration of the two sources is asymmetric, *i.e.*, $N_1 \neq N_2$, the optimal relay location will be closer to the source with less antennas -- this coincides with the analytical results in (22). On the other hand, we can also observe from Fig. 3 that when the transmitting power of the two sources are in-equivalent, the optimal relay location will have a slight difference with the situation in Fig. 2, but which is consistent with each other. Again, the optimal relay location will also be closer to the source with less power in any antenna configuration of the two sources. Moreover, Fig. 2 and Fig. 3 show that the approximations of the outage probability is very close to the Monte-Carlo simulation results, which means although our study is based on the approximate expressions of outage probability, the derived near-optimal relay position is actually very close to the optimal one.

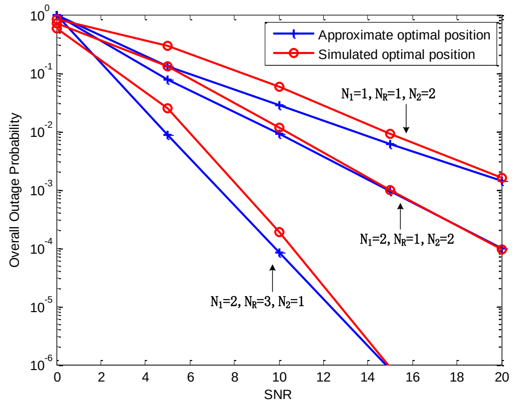

Fig. 4. Outage probability when the relay is deployed at the proposed position and the actual optimal position with $P_{S_1} = P_{S_2} = P_R$.

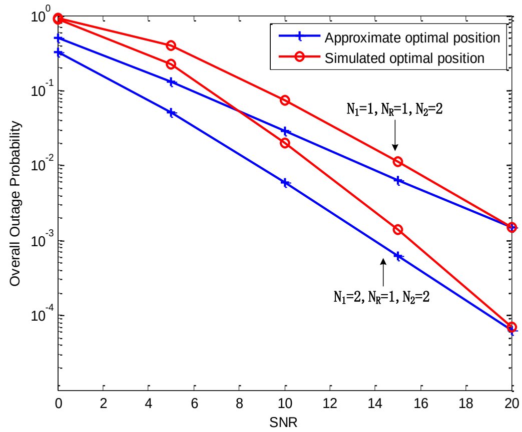

Fig. 5. Outage probability when the relay is deployed at the proposed position and the actual optimal position with $P_{S_1} = P_R/3$ and $P_{S_2} = 2P_R/3$.

In Fig. 4 and Fig. 5, the outage probability of the developed approximate relay position is presented compared with Monte-Carlo simulation with different SNR. Fig. 4 shows that the outage probability of the proposed relay deployment scheme is very close to the actual optimal one when the transmitting power of the two sources and relay are the same. For example, when the SNR is around 20dB, the approximate relay position is almost the same as the actual globally optimal one when the antenna configuration of the two sources and the relay is $N_1 = 1$, $N_2 = 2$ and $N_R = 1$, respectively. Moreover, the same conclusion also stands when the transmitting power is allocated unequally in Fig. 5, where the transmitting power of the two sources and relay are $P_{S_1} = P_R / 3$, $P_{S_2} = 2P_R / 3$, respectively. The observations above verify that the developed scheme only brings negligible performance loss thus is applicable in practice.

To further reveal the performance gain achieved by the proposed relay deployment scheme, Fig. 6 presents the outage probability for different relay positions when the transmitting power of the two sources and relay are $P_{S_1} = P_{S_2} = P_R$ for the antenna configuration of the two sources and the relay are $N_1 = 2$, $N_2 = 1$ and $N_R = 3$, respectively. It can be observed from Fig. 6 that the proposed relay deployment scheme significantly outperforms other relay deployment solutions in terms of outage behavior. For example, when the outage probability is 10^{-3}, the proposed relay deployment scheme achieves about 4dB and 7dB gain compared to the position randomly when $d_{S_1R} = 0.3$ and $d_{S_1R} = 0.1$, respectively. Therefore, Fig. 6 also indicates that even in a network with multiple potential relays, the proposed deployment scheme can also help with quick relay selection by choosing the relay closest to the developed approximate position.

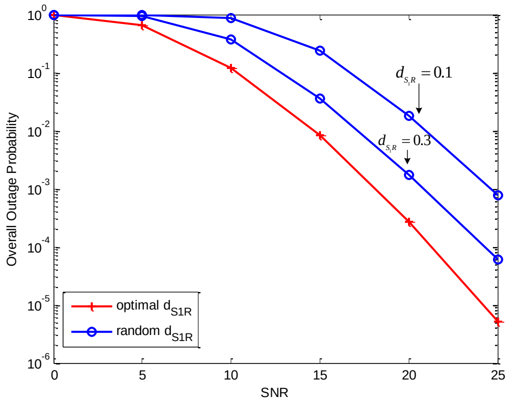

Fig. 6. Outage probability for the proposed and other relay postion when $P_{S_1} = P_{S_2} = P_R$.

V. Conclusions

In this paper the relay deployment for AF MIMO two-way relaying was studied. An approximation of the outage probability was utilized to reveal the existence of the outage-optimal relay location and developed a near-optimal relay deployment scheme. The near-optimal relay position was expressed in closed form, showing that the optimal relay position is affected by the number of antennas and the transmitting power at sources but independent of the number of antennas at the relay. Simulations confirmed theoretical analysis and showed the achieved performance gain.

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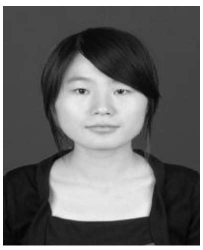

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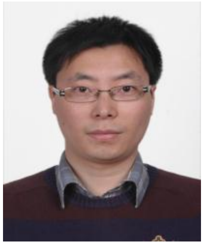

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