Joint Destination-Relay Selection and Antenna Mode Selection in Full-Duplex Relay Network

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Received November 18, 2016; revised March 14, 2017; accepted April 5, 2017; published June 30, 2017

Abstract

In this paper, a joint destination-relay selection and antenna mode selection scheme for full-duplex (FD) relay network is investigated, which consists of one source node, N FD amplify-and-forward (AF) relays and M destination nodes. Multiple antennas are configured at the source node, and beamforming technique is adopted. Two antennas are employed at each relay, one for receiving and the other for transmitting. Only one antenna is equipped at each destination node. In the proposed scheme, the best destination node is firstly selected according to the direct links between the source node and destination nodes. Then the transmit and receive mode of two antennas at each relay is adaptively selected based on the relaying link condition. Meanwhile, the best relay with the optimal Tx/Rx antenna configuration is selected to forward the signals. To characterize the performance of the proposed scheme, the closed-form expression of the outage probability is derived; meanwhile, the simple asymptotic expressions are also obtained. Our analysis shows that the proposed scheme obtains the benefits of multi-relay diversity and multi-destination diversity. Moreover, extra space diversity in the medium SNR region can be achieved due to the antenna selection at the relay. Finally, Monte-Carlo simulations are provided to consolidate the analytical results, and show the effectiveness of the proposed scheme.

Keywords: Beamforming, Full Duplex, High-SNR approximation, Multi-relay Multi-destination, Outage Probability.

This work is supported by the National Natural Science Foundation of China (No. 61671072 and 61401041), China's 863 Project (No. 2015AA01A706), the National S&T Major Project (2016ZX03001017), Science and Technology Program of Beijing (D161100001016002).

https://doi.org/10.3837/tiis.2017.06.002 **ISSN : 1976-7277**

1. Introduction

Full-duplex (FD) transmission has recently emerged as a promising technology to improve the spectral efficiency and capacity of the relay networks, thus being considered as an attractive technique for future wireless systems [1, 2]. In FD relay networks, the transmission and reception operated by the relay are performed simultaneously over the same frequency, rather than over two orthogonal channels in half-duplex (HD) relay network. FD relay can provide several benefits, such as increasing the throughput of the relay networks, and improving the performance of the cellular edge destination nodes [3, 4]. However, because of the strong signal leakage between the co-located transmit and the receive antennas, FD relaying mode suffers from a strong self-interference. As a result, powerful self-interference cancellation techniques are required to mitigate the influence of the self-interference. Many techniques on interference mitigation have been proposed in previous works, such as the antenna separation [5], and the time-domain interference cancellation [6]. However, due to imperfect cancellation process in practice, the self-interference cannot be completely removed, and the residual self-interference (RSI) still exists unavoidably. It is noted that the residual self-interference is generally modeled as a fading channel [6, 7], and can be further mitigated by applying optimal signal processing techniques. Thus the theoretical analysis with RSI for FD relay network can be improved with better signal processing.

In practical multi-destination multi-relay (MDMR) system, selection is a cost-effective way to exploit the inherent cooperative and multi-destination diversity and improves the communication reliability in the relay network [8, 9]. Meanwhile, signaling overhead and operation complexity can also be reduced. Joint destination-relay scheduling for the HD relay networks has been studied in [10], which simultaneously selects appropriate relays and destinations for communication, but neglects the direct links between the source and the destinations. Some works have already considered the direct links between the source nodes and the destination nodes as a potential path to forward the signals. In [11], the direct link is considered as a transmission path to overcome zero-diversity in FD relay network, but only a simple three nodes model is considered. In [12], the authors propose a joint source-relay selection scheme to harvest the cooperative and multi-user diversity, in which the channel state information (CSI) of all the links had to be estimated. Meanwhile, almost all the works assume that receive and transmit mode of antennas at the relay is unchanged. It is noted that when the channel link from the source node/ transmit antenna of relay to the receive antenna of relay/destination falls into deep fading, the performance of the relay network is impaired. In [7, 13], a transmit-receive antenna pair selection at the relay is proposed, which dynamically chooses FD or HD transmission mode according to the channel conditions, and the performance outperforms the traditional FD. Therefore, it is worth investigating the scenario that the Tx/Rx antenna configuration of the relay adaptively changes. Moreover, to improve the performance of the relay network, multiple-input multiple-output (MIMO) relay network has attracted a lot of attention due to its ability to enhance the transmission reliability and spectral efficiency. For a relay network with multi-antenna source, such as [14, 15], it shows that the transmit beamforming using maximal ratio transmission (MRT) can improve the system performance.

In this paper, we investigate a FD relay network which consists of one source node, N FD amplify-and-forward (AF) relays and M destination nodes. Multiple antennas are adopted and beamforming is employed by the source node to improve the performance of the system.

In addition, each relay is equipped with two antennas, one for receiving, and the other for transmitting. It is the simplest configuration for the considered problem. As the direct links can convey the signals, in order to combine the cooperative and multi-user diversity, and reduce the amount of channel estimation, a joint destination-relay selection and antenna mode selection (DRAS) scheme for FD relay network is proposed in this paper. Firstly, the best destination is selected according to the direct links between source nodes and destination nodes. Then the best relay with the optimal Tx/Rx mode of two antennas is selected according to the instantaneous channel conditions between the source node and the selected destination via the relays. The main contribution of this paper is summarized as follows: (1) a joint destination-relay selection and antenna mode selection scheme is proposed for the MDMR system. (2) the RSI is considered in this paper due to the practical imperfect self-interference mitigation. In addition, the cumulative distribution functions (CDFs) of the direct link signal-to-noise ratio (SNR) and the relaying link signal-to-interference-plus-noise (SINR) are derived. (3) based on the CDFs expression, the closed-form outage probability and the simple asymptotic expressions are derived. According to the analysis, the proposed scheme can achieve diversity gain as $2N+M$ in the medium SNR with small self-interference. In the high SNR region, the diversity gain of the proposed scheme will be M .

The remainder of the paper is organized as follows: Section 2 describes the system model and the proposed selection scheme. In Section 3, the outage performance analysis of the proposed joint destination and relay with optimal Tx/Rx configuration of two antennas is described in detail. Simulation results and performance analysis are presented in Section4. Finally, a brief conclusion is provided in Section5.

2. System Model and Selection Scheme

2.1 System Model

In this paper, we consider a MDMR system, as shown in **Fig. 1**, where one source node intends to communicate with one out of M destinations D_m ($m=1,2,\ldots,M$) with the help of one out of N FD AF relays R_n ($n=1,2,\ldots,N$). We assume that the direct link between the source node S and the destination node D_m is available to forward signals. In particular, there exist L antennas at the source node employing transmit beamforming while each destination is equipped with one antenna. Meanwhile, two antennas are configured at the relays, one for receiving and the other for transmitting. Specifically, the Tx/Rx mode of two antennas in each relay is adaptively determined based on the instantaneous SINR of the relaying links. The RSI remains unchanged despite of the Tx/Rx configuration of two antennas at each relay [16]. In the proposed DRAS, the best destination is selected based on the direct links between the source node and destination nodes firstly. Then the mode configuration of two antennas at each relay are adopted based on the instantaneous channel conditions via relaying link. Finally, the best link between direct links and relaying links is selected to convey the information.

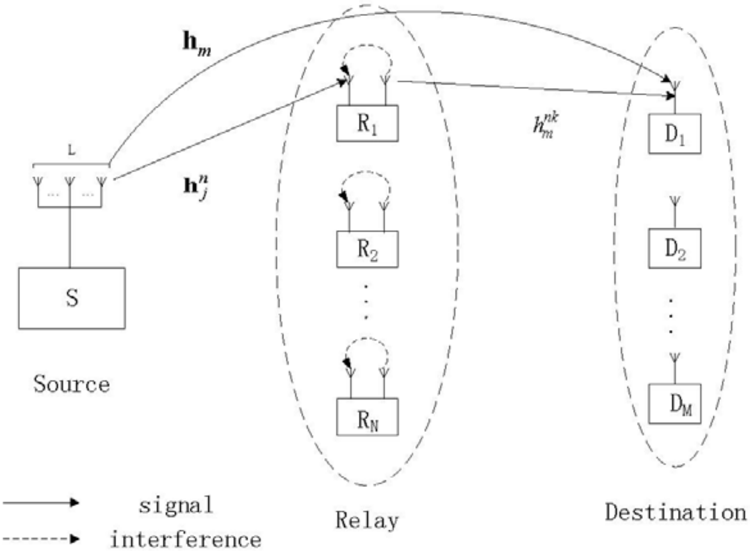

Fig. 1. System model for the MDMR system, where one L-antenna source node communicates with one out of M destination nodes via one out of N relays.

Transmit beamforming is employed at the source node to communicate with the destinations and the relays. At time-slot i, the source node transmits signals to the destinations using MRT firstly. The received signal at the destination over the direct link is given by

$$y_m(i) = \mathbf{h}_m^T \mathbf{w}_m \sqrt{P_s}\, x_s(i) + z_m(i), \tag{1}$$

where $x_s(i)$ denotes the transmitted signal from the source node S, and $\mathbb{E}\left[\left|x_s(i)\right|^2\right] = 1$. P_S represents the transmit power of the source node, and $z_m(i) \sim \mathcal{CN}(0, N_0)$. represents the additive white Gaussian noise (AWGN) at the destination node D_m. The $L \times 1$ vector $\mathbf{h}_m = \left[h_1^m; h_2^m; \ldots; h_L^m\right]$ denotes the channel between the source node and the destination D_m. Moreover, each fading component h_l^m follows independent and identical distributed (i.i.d.) complex Gaussian distribution, i.e., $h_l^m \sim \mathcal{CN}\left(0, \sigma_{SD}^2\right)$. According to the principle of MRT, the $L \times 1$ weight vector $\mathbf{w}_m$ at the source node S can be expressed as $\left(\mathbf{h}_m^\dagger / \left\|\mathbf{h}_m\right\|\right)^T$. Then the received SNR at the destination D_m over the direct link is written as

$$\gamma_m = \frac{\left\|\mathbf{h}_m\right\|^2 P_s}{N_0}. \tag{2}$$

At the n-th relay node R_n, we assume that the receive antenna is T_j, and T_k denotes the transmit antenna, $j, k \in \{1, 2\}$ and $j \neq k$.

The received signal by antenna T_j of the relay R_n at time-slot i is given by

$$y_j^n\left(i\right)=\left(\mathbf{h}_j^n\right)^T \mathbf{w}_j^n\sqrt{P_s}x_s\left(i\right)+I_n^{k\to j}\sqrt{P_r}x_n\left(i\right)+z_j^n\left(i\right), \tag{3}$$

where $x_n\left(i\right)$ is the transmitted signal of the relay R_n with a unit transmit power. P_r denotes the transmit power of the relay node. The $L\times 1$ vector $\mathbf{h}_j^n=\left[h_{j1}^n;h_{j2}^n;\ldots;h_{jL}^n\right]$ represents the channel between the source node and the antenna T_j of the relay R_n, and each fading component h_{jl}^n are complex Gaussian random variable with zero mean and variance σ_{SRj}^2. According to [17], the channel links between the source and two antennas of each relay satisfy independent and identical distribution, so we assume $\sigma_{SR1}^2=\sigma_{SR2}^2=\sigma_{SR}^2$. Then, the weight vector can be written as $\mathbf{w}_j^n=\left(\left(\mathbf{h}_j^n\right)^\dagger/\left\|\mathbf{h}_j^n\right\|\right)^T$. $I_n^{k\to j}$ is the residual self-interference channel between the transmit antenna T_k and the receive antenna T_j of the relay R_n, which is subjected to complex Gaussian distribution, i.e., $I_n^{k\to j}\sim\mathcal{CN}\left(0,\sigma_I^2\right)$. z_j^n is the AWGN with the power N_0

Then the previous signal $\beta_n^{k\to j}y_j^n\left(i-1\right)$ is amplified and retransmitted by the antenna T_k of the relay R_n to the selected destination. The retransmitted signal x_n of the relay R_n can be formulated as

$$x_n\left(i\right)=\beta_n^{k\to j}y_j^n\left(i-1\right), \tag{4}$$

where $\beta_n^{k\to j}$ denotes the power amplification factor at the relay R_n. Without loss of generality, we normalize the average power of the transmitted signal at the relay R_n as

$$\mathbb{E}\left[\left|x_n\left(i\right)\right|^2\right]=\left(\beta_n^{k\to j}\right)^2\left(\left\|\mathbf{h}_j^n\right\|^2P_s+\left|I_n^{k\to j}\right|^2P_r+N_0\right)=1. \tag{5}$$

Then the amplification factor $\beta_n^{k\to j}$ can be written as

$$\beta_n^{k\to j}=\sqrt{\frac{1}{\left\|\mathbf{h}_j^n\right\|^2P_s+\left|I_n^{k\to j}\right|^2P_r+N_0}}. \tag{6}$$

The received signal at the selected destination over the relay R_n can be expressed as

$$y_{m^*}^n\left(i\right)=h_{m^*}^{nk}\sqrt{P_r}x_n\left(i\right)+z_{m^*}^D\left(i\right), \tag{7}$$

where $h_{m^*}^{nk}$ denotes the channel between the antenna T_k of the relay R_n and the selected destination node D_{m^*}, and satisfies i.i.d. complex Gaussian distribution, i.e., $h_{m^*}^{nk}\sim\mathcal{CN}\left(0,\sigma_{RDk}^2\right)$. Furthermore, we assume the channel links between the destination and two antennas of each relay follow independent and identical distribution, i.e., $\sigma_{RD1}^2=\sigma_{RD2}^2=\sigma_{RD}^2$. z_{m^*} is the AWGN with power N_0.

Then by substituting (3), (6) and (4) into (7), the relaying link end-to-end SINR obtained at the best destination can be expressed as

$$\gamma_{nm^*}^{k\to j}=\frac{\left|h_{m^*}^{nk}\right|^2\frac{P_r}{N_0}\left\|\mathbf{h}_j^n\right\|^2\frac{P_s}{N_0}}{\left\|\mathbf{h}_j^n\right\|^2\frac{P_s}{N_0}+\left[\left|h_{m^*}^{nk}\right|^2\frac{P_r}{N_0}+1\right]\left[\left|I_n^{k\to j}\right|^2\frac{P_r}{N_0}+1\right]}\ . \tag{8}$$

2.2 Selection Scheme

In this section, the proposed DRAS is described in details for multi-relay multi-destination FD relay network.

At first, the best destination D_{m^*} is selected according to the direct link, i.e., the destination D_{m^*} is selected according to $m^*=\max\limits_{m\in\{1,2,\ldots,M\}}\gamma_m$. Secondly, the best relay with optimal Tx/Rx antenna configuration is chosen to forward the signals. Specifically, there are two possible relaying link pairs between one relay and the source node/destination. The best transmit/receive antenna configuration can be expressed as

$$O_n=\max\left\{\gamma_{nm^*}^{1\to 2},\gamma_{nm^*}^{2\to 1}\right\}, \tag{9}$$

where the mode $\gamma_{nm^*}^{k\to j}$ means the antenna T_k of the relay R_n forwards the signals to the selected destination, and the antenna T_j receives the signals, $k,j\in\{1,2\},k\neq j$.

After transmit/receive antenna configuration, the best relay is selected as

$$N^*=\max_{n\in\{1,2,\ldots,N\}}O_n\ . \tag{10}$$

Then the best link from the direct links and relaying links is chosen to forward the signals. The system end-to-end SINR γ can be expressed as

$$\gamma^{e2e}=\max\left[\max_{m\in\{1,2,\ldots,M\}}\gamma_m,\max_{n\in\{1,2,\ldots,N\}}\max\left(\gamma_{nm^*}^{1\to 2},\gamma_{nm^*}^{2\to 1}\right)\right]. \tag{11}$$

3. Outage Probability

In this section, the outage performance of the DRAS is investigated. A tight closed-form outage probability is derived, as well as simple asymptotic expressions.

3.1 Outage Probability

By definition, the system is in outage if the system SINR γ^{e2e} is smaller than a threshold γ_0. Then the outage probability of the FD relay network can be formulated as

$$\begin{aligned}P_{out}&=\Pr\left[\gamma^{e2e}<\gamma_0\right]\\&\overset{(a)}{=}\underbrace{\Pr\left[\max_{m\in\{1,2,\ldots,M\}}\gamma_m<\gamma_0\right]}_{\Phi}\\&\quad\times\underbrace{\Pr\left[\max_{n\in\{1,2,\ldots,N\}}\max\left(\gamma_{nm^*}^{1\to 2},\gamma_{nm^*}^{2\to 1}\right)<\gamma_0\right]}_{\Psi}\end{aligned}\ . \tag{12}$$

Because of the independence of the direct link and the relay link, the step (a) is established. The first term Φ can be calculated as

$$\Pr\left[\max_{m\in\{1,2,\ldots,M\}} \gamma_m < \gamma_0\right] = \prod_{m=1}^{M} F_m\left(\gamma_0\right), \tag{13}$$

where $F_m\left(\gamma_0\right)$ is the CDF of γ_m . According to [18], it can be written as $F_m\left(x\right) = 1 - e^{-\frac{x}{\bar{\gamma}_m}} \sum_{l=0}^{L-1} \frac{1}{l!}\left(\frac{x}{\bar{\gamma}_m}\right)^l$, and we have $\bar{\gamma}_m = \frac{\mathbb{E}\left\|\mathbf{h}_m\right\|^2 P_s}{N_0}$.

Based on the total probability , Ψ in (12) can be calculated as

$$\Psi = \sum_{m=1}^{M} \Pr\left(m^* = m\right) \prod_{n=1}^{N} \underbrace{\Pr\left[\max\left(\gamma_{nm}^{1\to 2}, \gamma_{nm}^{2\to 1}\right) < \gamma_0\right]}_{\Omega}, \tag{14}$$

where $\Pr\left(m^* = m\right)$ means the probability when the m -th destination is selected. According to [19], the term $\Pr\left(m^* = m\right)$ can be attained as

$$\Pr(m^* = m) = 1 + \sum_{k=1}^{M-1} \sum_{\substack{A_k \subseteq 1,\ldots,m-1,m+1,\ldots,M \\ |A_k| = k}} (-1)^k \times \frac{\lambda_m}{\lambda_m + \sum_{j\in A_k} \lambda_m}, \tag{15}$$

where $\lambda_m = 1/\bar{\gamma}_m$.

According to the including excluding principle, the term Ω in (14) can be attained as

$$\begin{aligned}\Omega &= \Pr\left[\max\left(\gamma_{nm}^{1\to 2}, \gamma_{nm}^{2\to 1}\right) < \gamma_0\right] \\ &= 1 - \Pr\left(\gamma_{nm}^{1\to 2} > \gamma_0\right) - \Pr\left(\gamma_{nm}^{2\to 1} > \gamma_0\right) \\ &\quad + \Pr\left(\gamma_{nm}^{1\to 2} > \gamma_0, \gamma_{nm}^{2\to 1} > \gamma_0\right)\end{aligned} \tag{16}$$

After further calculation and analysis, the relaying link SINR (8) can be formulated as

$$\gamma_{nm}^{k\to j} = \frac{X_j^n \left|h_m^{nk}\right|^2 \frac{P_r}{N_0}}{X_j^n + \left|h_m^{nk}\right|^2 \frac{P_r}{N_0} + 1}, \tag{17}$$

where $X_j^n = \frac{\left\|\mathbf{h}_j^n\right\|^2 \frac{P_s}{N_0}}{\left|I_n^{k\to j}\right|^2 \frac{P_r}{N_0} + 1}$. The distribution of X_j^n can be calculated as [16]

$$F_{X_j^n}\left(x\right) = 1 - \frac{1}{1 + \eta_n x} e^{-\lambda_{SR_n j} x}, \tag{18}$$

where $\eta_n = \frac{\lambda_{SR_n j}}{\lambda_I}$. Note that $\lambda_{SR_n j} = 1/\mathbb{E}\left(\left\|\mathbf{h}_j^n\right\|^2 \frac{p_s}{N_0}\right)$, $\lambda_I = \frac{N_0}{P_r \sigma_I^2}$. Furthermore, $\eta_n = \eta$ is established, as the channel link h_{jl}^{n} between the source antenna and each relay antenna follows independent and identical distribution, so we can omit the n index. Then the CDF of the relaying link SINR with the antenna configuration model $T_1 \to T_2$ can be expressed as

$$\Pr\left(\gamma_{nm}^{1\to 2} > \gamma_0\right) = \lambda_{R_n D_m 1} \int_{\gamma_0}^{\infty} \frac{1}{1+\eta\left(\gamma_0 + \frac{\gamma_0^2+\gamma_0}{V_1-\gamma_0}\right)} \times e^{-\lambda_{SR_n 2}\left(\gamma_0+\frac{\gamma_0^2+\gamma_0}{V_1-\gamma_0}\right)-\lambda_{R_n D_m 1} V_1} dV_1 . \tag{19}$$

Note that $V_1 = \left|h_m^{n1}\right|^2 \frac{P_r}{N_0}$. Meanwhile, $\lambda_{R_n D_m 1} = 1/\mathbb{E}\left(\left|h_m^{n1}\right|^2 \frac{P_r}{N_0}\right)$ means the reciprocal of the mean value of the channel between the relay R_n's antenna T_1 and the destination D_m. Meanwhile, the channel links between the destination and the relay antennas follow i.i.d. Thus we have $\lambda_{R_n D_m 1} = \lambda_{R_n D_m 2} = \lambda_{R_n D_m}$, where $\lambda_{R_n D_m 2}$ denotes the reciprocal of the mean value of the channel between the relay R_n's antenna T_2 and the destination D_m.

Unfortunately, there does not exist a closed-form solution in (19). Note that $\gamma_0 >> \frac{\gamma_0^2+\gamma_0}{V_1-\gamma_0}$ at high SNR. Similar to [19], with the help of this simplification, then we have

$$\Pr\left(\gamma_{nm}^{1\to 2} > \gamma_0\right) \approx \frac{1}{1+\eta\gamma_0} 2\sqrt{\left(\gamma_0^2+\gamma_0\right)\lambda_{R_n D_m}\lambda_{SR_n}} \times K_1\left(2\sqrt{\left(\gamma_0^2+\gamma_0\right)\lambda_{R_n D_m}\lambda_{SR_n 2}}\right) e^{-\left(\lambda_{R_n D_m}+\lambda_{SR_n}\right)\gamma_0}, \tag{20}$$

in which $K_1(\cdot)$ denotes the first-order modified Bessel function of the second kind, and we assume that the expectation of the instantaneous channel SNR is same.

According to the form of the received SINR $\gamma_{nm}^{2\to 1}$, the $\Pr\left(\gamma_{nm}^{2\to 1} > \gamma_0\right)$ can be calculated by the similar expression as (20).

Based on (9) and (17), the last term in (16) can be expressed.

$$\begin{aligned}\Pr\left(\gamma_{nm}^{1\to 2} > \gamma_0, \gamma_{nm}^{2\to 1} > \gamma_0\right) &= \int_{\gamma_0}^{\infty}\int_{\gamma_0}^{\infty} \frac{1}{1+\eta\left(\gamma_0+\frac{\gamma_0^2+\gamma_0}{V_1-\gamma_0}\right)+\eta\left(\gamma_0+\frac{\gamma_0^2+\gamma_0}{V_2-\gamma_0}\right)} \lambda_{R_n D_m} \\ &\quad \times e^{-\lambda_{SR_n}\left(\gamma_0+\frac{\gamma_0^2+\gamma_0}{V_1-\gamma_0}\right)-V_1\lambda_{R_n D_m}} e^{-\lambda_n\left(\gamma_0+\frac{\gamma_0^2+\gamma_0}{V_2-\gamma_0}\right)-V_2\lambda_{R_n D_m}} dV_1 dV_2 \\ &= \frac{\left(4\gamma_0^2+4\gamma_0\right)\lambda_{R_n D_m}\lambda_{SR_n}}{1+2\eta\gamma_0} K_1^2\left(2\sqrt{\left(\gamma_0^2+\gamma_0\right)\lambda_{R_n D_m}\lambda_{SR_n 2}}\right) e^{-2\gamma_0\left(\lambda_{R_n Dm}+\lambda_{SR_n}\right)}\end{aligned} , \tag{21}$$

where $V_2 = \left|h_m^{n2}\right|^2 \frac{P_r}{N_0}$.

The expression (16) can be get as

$$\Omega = 1 - \frac{2}{1+\eta\gamma_0} I\left(\gamma_0\right) + \frac{1}{1+2\eta\gamma_0} I^2\left(\gamma_0\right), \tag{22}$$

where $I\left(\gamma_0\right) = 2\sqrt{\left(\gamma_0^2+\gamma_0\right)\lambda_{R_nD_m}\lambda_{SR_n}}\, e^{-\left(\lambda_{R_nD_m}+\lambda_{SR_n}\right)\gamma_0} \times K_1\left(2\sqrt{\left(\gamma_0^2+\gamma_0\right)\lambda_{R_nD_m}\lambda_{SR_n}}\right)$.

Finally, substituting (23) and (15) into (14), the plugging (14) and (13) into (12). The outage probability of the relay network can be expressed as

$$\begin{aligned} P_{out} &= \prod_{m=1}^{M}\left[1 - e^{-\frac{\gamma_0}{\bar{\gamma}}}\sum_{l=0}^{L-1}\frac{1}{l!}\left(\frac{\gamma_0}{\bar{\gamma}}\right)^l\right]\sum_{m=1}^{M}\Pr\left(m^*=m\right) \\ &\times\prod_{n=1}^{N}\left[1-\frac{2}{1+\eta\gamma_0}I\left(\gamma_0\right)+\frac{1}{1+2\eta\gamma_0}I^2\left(\gamma_0\right)\right] \end{aligned}. \tag{23}$$

3.2 Asymptotic Analysis

Based on the previous results, the asymptotic analysis of the outage probability is formulated in this section.

In sufficiently high SNR region, i.e., SNR $\to\infty$, where $\text{SNR} = \frac{P}{N_0}$ denotes the system SNR, the term Φ can be calculated as $\Phi = \prod_{m=1}^{M}\frac{\gamma_0}{\mathbb{E}\left\|\mathbf{h}_m\right\|^2 \text{SNR}}$. According to [20], the term $2\sqrt{\left(\gamma_0^2+\gamma_0\right)\lambda_{R_nD_m}\lambda_{SR_n}} \times K_1\left(2\sqrt{\left(\gamma_0^2+\gamma_0\right)\lambda_{R_nD_m}\lambda_{SR_n}}\right) \to 1$ as SNR $\to\infty$, thus we can get $I\left(\gamma_0\right)\to 1$, then the formula (22) can be expressed as $\Omega = 1-\frac{2}{1+\eta\gamma_0}+\frac{1}{1+2\eta\gamma_0}$. Therefore, in the sufficiently high SNR region, the outage probability of the proposed scheme can be written as

$$\begin{aligned} P_{out}^{\infty} &\approx \prod_{m=1}^{M}\frac{\gamma_0}{\bar{\gamma}}\sum_{m=1}^{M}\Pr\left(m^*=m\right) \\ &\times\prod_{n=1}^{N}\left(1-\frac{2}{1+\eta\gamma_0}+\frac{1}{1+2\eta\gamma_0}\right)\propto\left(\frac{1}{\text{SNR}}\right)^M \end{aligned}. \tag{24}$$

Moreover, in the high SNR, we have the following approximation: $I\left(\gamma_0\right)\to e^{-\left(\lambda_{R_nU_m}+\lambda_{SR_n}\right)\gamma_0}$. When the RSI is small, the term Ω can be expressed as

$$\begin{aligned} \Omega \approx \prod_{n=1}^{N}&\left[\left(1-e^{-\left(\lambda_{R_nD_m}+\lambda_{SR_n}\right)\gamma_0}\right)^2\right. \\ &\left.+2\eta\left(e^{-\left(\lambda_{R_nU_m}+\lambda_{SR_n}\right)\gamma_0}-e^{-2\left(\lambda_{R_nD_m}+\lambda_{SR_n}\right)\gamma_0}\right)\right] \end{aligned}, \tag{25}$$

when $\eta\to 0$, $\left(1-e^{-\left(\lambda_{R_nD_m}+\lambda_{SR_n}\right)\gamma_0}\right)^2 >> 2\eta\left(e^{-\left(\lambda_{R_nD_m}+\lambda_{SR_n}\right)\gamma_0}-e^{-2\left(\lambda_{R_nD_m}+\lambda_{SR_n}\right)\gamma_0}\right)$ is established in the medium SNR. Then the outage probability can be written as

$$\begin{aligned} P_{out} &\approx \prod_{m=1}^{M} \frac{\gamma_0}{\bar{\gamma}} \sum_{m=1}^{M} \Pr\left(m^* = m\right) \\ &\times \prod_{n=1}^{N} \left(1 - e^{-\left(\lambda_{R_n D_m} + \lambda_{SR_n}\right)\gamma_0}\right)^2 \propto \left(\frac{1}{\mathrm{SNR}}\right)^{M+2N} . \end{aligned} \tag{26}$$

According to [21], the reduction speed in outage probability due to the increase of the SNR is called diversity order. The diversity order determines the slope of the outage probability versus SNR curve in a log-log scale at high SNR. It can be formulated as $P_{out}\left(SNR\right) \rightarrow SNR^d$ for $SNR \rightarrow \infty$, where d is the diversity order. From the asymptotic analysis, we can see that the total diversity order is M when the SNR is sufficiently large. In the medial SNR region, the total diversity will be $2N + M$ with small residual self-interference.

3.3 Complexity analysis

To further appreciate the proposed scheme, we compare our scheme with an optimal selection scheme: exhaustive search (ES). The complexities of the proposed scheme and the ES are briefly analyzed. In the ES scheme, local CSI is needed at each relay and destination. $M \times \left(1 + 2N\right)$ potential links have to be compared for selecting the best link with maximum SNR. Each relay needs to enumerate $2 * M$ relaying links. For each relaying link, the relay needs to perform signal processing, and the corresponding computational complexity can be treated as a constant. Thus the complexity at relay can be expressed as $O\left(M\right)$. The computational complexity is large when the relay network including large number of destinationes. Compared with ES, $M + 2N$ potential links are only required to be compared in the proposed selection scheme of this paper. Meanwhile, in the proposed scheme, as the optimal destination is firstly selected, thus each relay only needs to enumerate 2 relaying links, and the corresponding computational complexity is assumed to be constant. Thus the complexity at relay of the proposed scheme can be given as $O\left(1\right)$. Compared with the ES scheme, the proposed DRAS scheme is sub-optimal, However, the complexity decreases with a little performance loss.

4. Simulations

In this section, the simulation results are presented to verify the validity of the analysis. Without loss of generality, we assume that the transmit power of the source node and the relays is equal, $P_s = P_r = P$. The power of the noise at the relays and the destinations is assumed to be constant, i.e., $N_0 = 1$. In particular, we assume that the distance between the source node and the destinations is normalized to unity. Furthermore, the path loss factor is assumed to be 4. As a result, the values of $\sigma_{SD}^2, \sigma_{SR}^2, \sigma_{RD}^2$ equal to $1, d_1^{-4}, \left(1 - d_1\right)^{-4}$, where d_1 is the distance of between the source node and the relays.

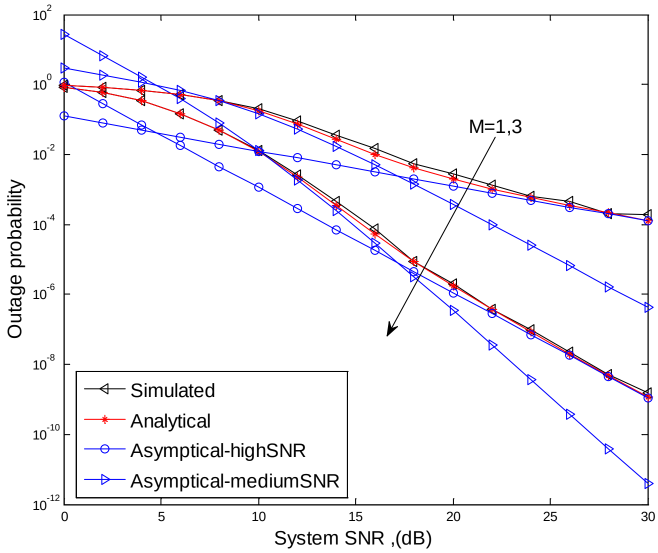

Fig. 2. Outage probability of proposed scheme with different destination, $L=1$, $N=2$.

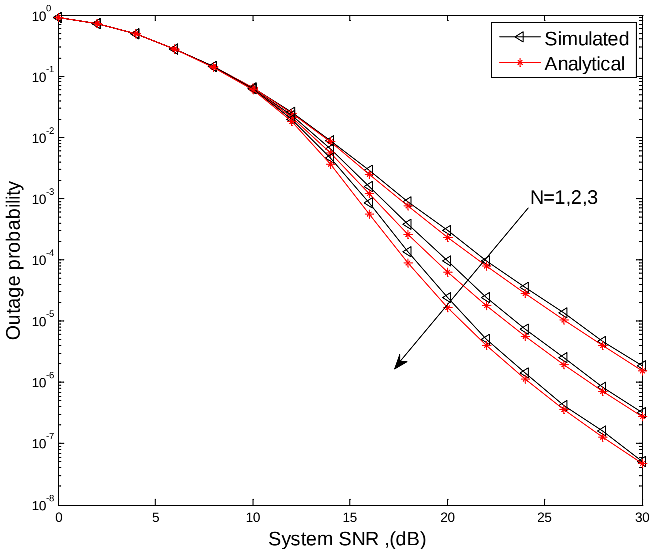

Fig. 3. Outage probability of the proposed scheme with different relay, $L=1$, $M=2$.

Fig. 2 and **Fig. 3** show the impact of the number of source M and the number of relay N on the outage performance of the proposed scheme in this paper. The target threshold γ_0 and the residual self-interference η_n stay the same, From the simulation results, we can see the exact outage probability curves tightly match with the analytical result in (23). In **Fig. 2**, the number of relay and antenna at the source node remain unchanged, but the number of the destination will be $M=1,3$. We can see that the outage performance ameliorates as the number of destination increases. In addition, we can see that the asymptotic outage probability curves match with the simulation results in the medium and high SNR respectively. As expected, the diversity order of the DRAS achieves M in the high SNR and $M+2N$ in the medium SNR as analysis in (24) and (26). In **Fig. 3**, the number of destination and antenna at the source node stay the same, but the number of relay will be $N=1,2,3$ orderly. The simulation result shows that the outage performance will be better as the number of relay increases. Meanwhile, we can see that the diversity order increases in the medium as the number of the relay increases.

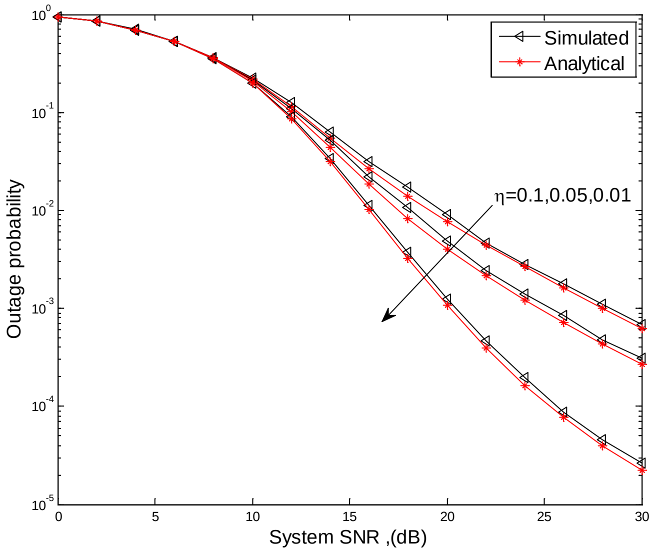

Fig. 4. The outage performance of the proposed scheme with different self-interference.

Fig. 4 shows the impact of the residual self-interference on the outage performance of the proposed scheme. When $\eta_n = 0.1, 0.05, 0.01$, we can see that the outage performance of the proposed scheme improves as the residual self-interference decreases.

In **Fig. 5**, we present the outage performance of the proposed schemes with different relay number when the relay nodes are distributed randomly. The source node is located at $(0,0)$, and the destination nodes are clustered together at $(1,0)$. Meanwhile, the relay nodes are also clusetered and distributed randomly in a circle which locates at $(0.5,0)$ and the radius is 0.3. Meanwhile, the distance between the source node and the destinations is normalized to unity. d_1 and d_2 denote the distance between the source node and the relay, the relay and the destinations, respectively. The values of $\sigma_{SD}^2, \sigma_{SR}^2, \sigma_{RD}^2$ equal to $1, d_1^{-4}, d_2^{-4}$. The relay number is $N=1,2,3$, and the outage performance improves as the relay number increases, which validates the effectiveness of the proposed scheme in practical scenarios.

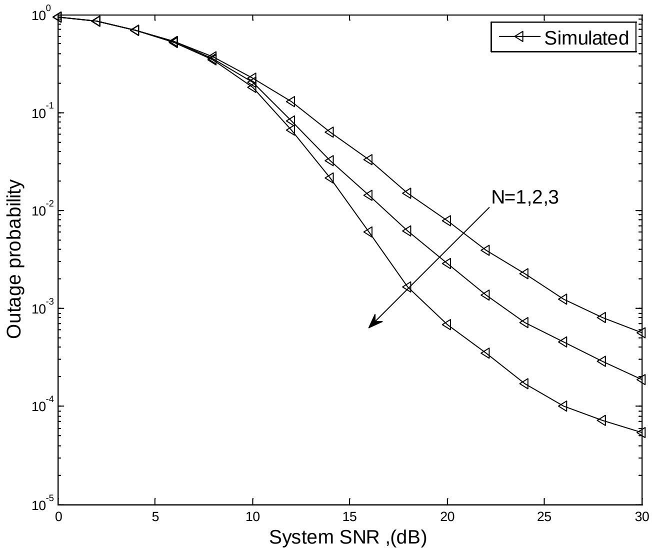

Fig. 5. The outage performance of the proposed scheme when the relay nodes distribute randomly.

In **Fig. 6**, we assume that the total transmit power of the source node and the relay node is P. The portion of the total transmit power αP is allocated to the source node, and the residual part is allocated to the relay node, where $\alpha\left(0 \le \alpha \le 1\right)$ denotes the power allocation coefficient. The power allocation coefficient is $\alpha = 0.25, 0.5, 0.75, 1$. We can see that the outage performance increases as $\alpha = 0.25, 0.5, 0.75$. When the $\alpha = 1$, the outage performance decreases compared with $\alpha = 0.5$, 0.75. Thus an optimal power allocation coefficient exists and it can minimize the outage probability.

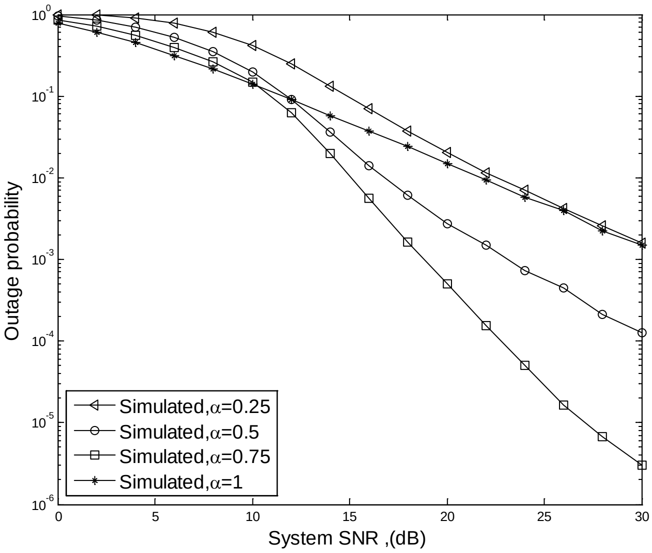

Fig. 6. The outage performance of the proposed scheme with different power allocation coefficients

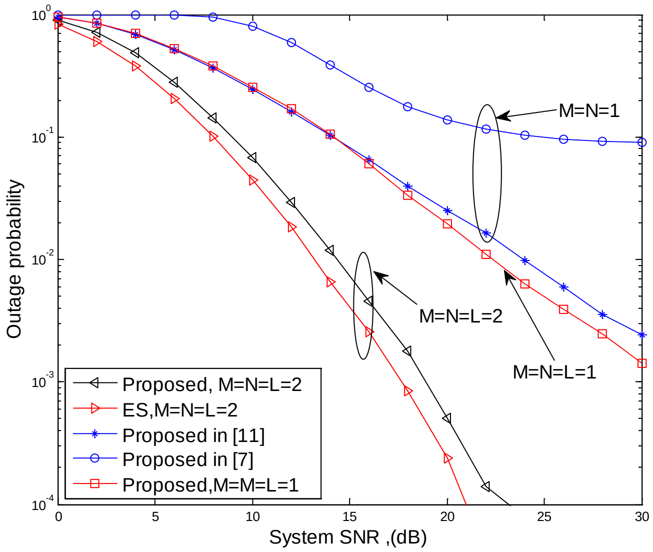

Fig. 7. The outage performance of the proposed scheme with different destination and antenna

In **Fig. 7**, we make a comparison between the proposed scheme for the FD relay network in this paper, the proposed schemes in [7, 11]. When $L = M = N = 1$, the target threshold $\gamma_0 = 3$, and the variance of residual self-interference $\sigma_I^2 = 0.1$, it can be seen that the proposed scheme in this paper outperforms the proposed scheme in [7] where one source node with one antenna, one relay with two adaptively switched antennas and one destination are configured in the system, only relaying links are exploited. More, the proposed scheme has a comparable performance with [11] where fixed antenna configuration is adopted at the relay, and maximal-ratio combining is employed at the destination. It can be seen that the proposed scheme improves the performance compared with conventional selection scheme. When $M = N = L = 2$,we can see that our proposed selection scheme has slight performance loss compared with the ES. In contrast with ES, our proposed selection scheme has lower complexity.

5. Conclusion

In this paper, we investigate the FD relay network which consists of one source node, N FD AF relays and M destinations. In the source node, multiple antennas are configured and beamforming technique is employed. Each relay is equipped with two antennas, one for receiving signals, and the other for transmitting signals. A joint destination-relay selection and antenna mode selection scheme for FD relay network is proposed. In this paper, closed-form expression and asymptotic analytical results are derived. Moreover, the analytical results are verified by Monte Carlo simulations. From the analytical results, we can see that the proposed scheme can achieve diversity gain $2N + M$ in the medium SNR with small residual interference. At high SNR region, the diversity gain will be M .

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