Int. J. Electron. Commun. (AEÜ) 86 (2018) 92–102

Contents lists available at ScienceDirect

Int. J. Electron. Commun. (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

Regular paper

Performance of antenna selection schemes in dual hop full-duplex decode-and-forward relaying over Nakagami-*m* fading channels

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ARTICLE INFO

Keywords:
Dual-hop networks
Full-duplex
Decode-and-forward
Antenna selection
Outage probability

ABSTRACT

In this paper, we investigate the outage performance of several antenna selection (AS) schemes in dual hop full-duplex (FD) multiple-input multiple-output (MIMO) relay networks in which the relay adopts decode-and-forward (DF) protocol over Nakagami-*m* fading channels. In the network, the source (S), destination (D) and relay (R) are assumed to be equipped with multiple antennas. We assume that the line-of-sight component between S and D cannot be established due to the poor fading environment conditions. For signal transmission-reception during the training period, only a single antenna at each node is selected according to selection techniques, and then with the help of an error-free feedback channel the selected antenna index is sent to the related node. Outage probability (OP) expressions related to AS schemes are obtained in closed forms and asymptotic OPs are also derived in order to get more meaningful insights into OP and diversity behaviour. The theoretical results are verified by Monte Carlo simulations. We show that performance of the FD relay can be significantly improved by using selection techniques compared to half-duplex (HD), especially at low signal-to-noise ratio (*SNR*) region. In addition, results show that the performance floor level meaning zero diversity at high *SNR* region, which is also confirmed by asymptotic analysis and is an inherent disadvantage of FD relay, can be decreased. Moreover, it is shown that the FD relay with AS schemes outperforms HD as the target rate increases for a certain value of *SNR* and residual self-interference power.

1. Introduction

Relay-assisted cooperative transmission technique has emerged as a promising solution for wireless communications due to its coverage area, increased capacity and capability in combating channel impairments [1,2]. While there are several relaying protocols, the most commonly preferred ones are amplify-and-forward (AF) and decode-and-forward (DF) protocols [3]. In addition to relaying protocols, according to its operation the relays can be classified in two modes: half-duplex (HD) and full-duplex (FD). HD relaying causes spectral inefficiency since it requires to allocate two orthogonal channels for signal transmission from source to destination. On the other hand, FD relaying, which maintains the data transmission and reception simultaneously by using the same time slot and frequency band, has ability to combat loss of the spectral efficiency in HD [4,5]. As a result of simultaneous transmission, an interference link named self-interference (SI) occurs at receiver antenna of the relay due to the signal leakage between relay transmit and receive antennas, and this causes performance degradation and zero diversity gain in the asymptotic regime. Therefore, mitigation and cancellation of the SI effect is still a hot topic on the FD technology [6–8]. However, even with recent advances in cancellation techniques, it has been shown that FD relay still suffers from a limited SI effect which is called residual self-interference (RSI) and can be taken into account as a mere Gaussian noise or fading effect with low power [7,9]. By considering the RSI effect existing at the relay receiver antenna, many studies on the performance of FD AF or DF relay have been conducted in the literature [9–14]. For example, in [9], the authors investigated bit error rate (BER) performance and diversity order of FD AF relay network in which the variance of the RSI is considered as proportional to the λ-th power of the transmitted power from the source. The authors demonstrated that an error floor occurs when λ is close to one (pessimistic state) and a significant performance can be achieved in case that λ is close to zero (optimistic state). From the results, for a BER value of $10^{-3}, \lambda = 0.3$ provides approximately 50 dB signal-to-noise (SNR) gain compared to $\lambda = 0.7$. Accordingly, the results reveal that the better quality of SI cancellation, the better performance gain is achieved.

Due to the fact that the RSI is a seriously important factor that

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https://doi.org/10.1016/j.aeue.2018.01.018
Received 13 July 2017; Accepted 19 January 2018

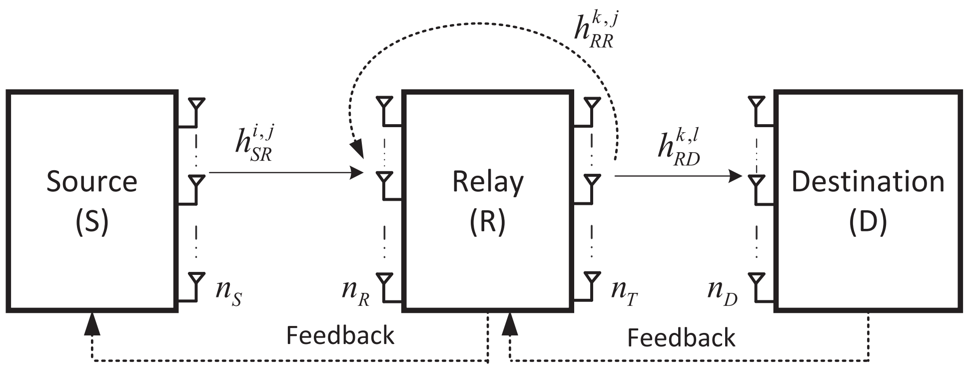

Fig. 1. System model of the FD MIMO relay network.

cannot be ignored, combination of multiple-input multiple-output (MIMO) and diversity techniques with FD relay has gained a great deal of interest. MIMO and diversity techniques increase system performance and provide diversity gain by combating multipath fading [15,16]. Accordingly, applying MIMO and diversity techniques to FD relay both improves system performance and decreases performance floor level which occurs as a result of the RSI effect [17,18]. In [17], MIMO FD relaying combined with maximal ratio combining (MRC) technique is investigated by using null space projection to mitigate the SI effect and closed form expressions related to outage probability (OP) and symbol error rate (SER) are derived. Their results demonstrated for an OP value of 10^{-5} that approximately 11 dB SNR gain can be achieved when the RSI power is 6 dB and the number of antennas is increased from 2 to 4 at all nodes. In addition, if the RSI power is increased to 12 dB, an additional SNR of 5 dB is needed to achieve the same OP value of 10^{-5}, which emphasizes the importance of the quality of SI cancellation. In [18], authors analyzed the OP performance of dual hop MIMO FD AF relaying with transmit antenna selection (TAS)/MRC over Rayleigh fading channels in case of fading and non-fading RSI, and they show that level of performance floor is determined by antenna numbers at the first hop while second hop provides performance gain in low SNR region. In addition, authors of [18] investigated the same relay network using three different approaches in the presence of co-channel interferences (CCIs) in [19]. They obtained OP expressions in single integral forms in case of the faded/non-fading RSI and in closed form in case of the noise neglected approach, and also conducted asymptotic OPs and effective diversity order analysis. The authors show that the RSI and CCIs cause a serious performance degradation. Accordingly, for the scenario that the variance of the RSI is set to 0.02 and the source and destination are equipped with 3 antennas, for an SNR value of 20 dB, if the number of CCIs is increased from 1 to 5, OP value of the system increases by 10 times. Their results reveal that a significant performance gain can be achieved by applying TAS at the source and MRC at the destination. In [20], OP performance of MIMO FD relaying system, which zero forcing/maximal-ratio transmission technique is applied at the relay, is investigated and closed form expressions are derived. Moreover, authors show that the system performance can be improved by choosing the precoding scheme. For example, in order to achieve superior system performance, receive ZF should be performed when the number of receive antennas at the relay node is greater than the number of transmit antennas. Similarly, transmit ZF should be performed when the number of transmit antennas is greater. In [21], in order to increase system performance, authors investigated antenna selection schemes for FD AF relaying over Rayleigh fading channels, and exact OP expressions and asymptotic approximations were provided. In [22], authors investigated OP of partial antenna selection (PAS) in the FD DF MIMO relay networks over Rayleigh fading channels and obtained closed form expression.

Motivated by the above studies on MIMO FD relaying systems, we investigate the OP of several antenna selection schemes in dual hop MIMO FD DF relay networks under Nakagami-m fading environment in order to overcome the RSI effect and improve system performance. In the network, the source and destination are assumed to be equipped with multiple antennas and the relay is equipped with two groups of multiple antennas so that one group is for receiving and the other one for transmitting. The direct link between the source and destination cannot be available due to the heavy fading conditions. Three antenna selection schemes; such as max-max antenna selection (MMAS), PAS and self-interference antenna selection (SIAS) are analyzed and closed form OP expressions are obtained. In addition, optimum antenna selection scheme is investigated only by Monte Carlo simulations. Moreover, asymptotic OP expressions are also derived in order to provide more meaningful insights into OP and diversity behaviour. Considered FD MIMO relay network with antenna selection techniques is also compared to the one with HD.

The reminder of this paper is as follows. In Section 2, detailed system model is introduced and channel statistics are presented. In Section 3, procedures of several antenna selection schemes are presented and OP expressions for the considered schemes are derived. Moreover, asymptotic analyses are also conducted. Analytical results verified by simulations and comparisons are given in Section 4. Conclusions are drawn in Section 5.

2. System model

We consider a dual hop MIMO FD DF relaying network given in Fig. 1 in which the source (S) and destination (D) equipped with n_S and n_D antennas, respectively. The relay (R) is equipped with n_R and n_T antennas for receiving from the source and transmitting to the destination, respectively. We assume that the direct link between the S and D is not available due to the heavy channel conditions such as path loss, high shadowing and deep fading. During the training period, at each node only one antenna is selected according to antenna selection techniques for signal transmission or reception, and then the selected antenna index is sent to the related node by using an error-free feedback channel. The envelopes of all channel gains denoted by $|h_X^A|$ are considered as independent and identically distributed (*i.i.d.*) Nakagami-m fading, which is a generalized fading model, where $X \in \{SR,RD,RR\}$ and $A \in \{(i,j),(k,l),(k,j)\}$. We assume the $S-R$ and $R-D$ channel gains have unit power, i.e., $\Omega_{SR} = E[|h_{SR}^{i,j}|^2] = 1$ and $\Omega_{RD} = E[|h_{RD}^{k,l}|^2] = 1$. On the other hand, we consider the squared mean of the $R-R$ channel gain as $\Omega_{RR} = E[|h_{RR}^{k,j}|^2] = \sigma_e^2$, where $E[\cdot]$ represents expectation operator.

By assuming any $\{i,j,k,l\}$ antenna indices are selected to transmit the information from the source to the destination, the received instantaneous signal-to-interference-plus-noise ratio (SINR) in the first hop and SNR in the second hop can be written as

$$\begin{aligned} \gamma_R^{i,j,k} &= \frac{\gamma_{SR}^{i,j}}{\gamma_{RR}^{k,j}+1} \\ \gamma_{RD}^{k,l} &= \frac{P_t}{\sigma^2}|h_{RD}^{k,l}|^2 \end{aligned} \tag{1}$$

where $\gamma_{SR}^{i,j} = \frac{P_t}{\sigma^2}|h_{SR}^{i,j}|^2$ and $\gamma_{RR}^{k,j} = \frac{P_t}{\sigma^2}|h_{RR}^{k,j}|^2$ are instantaneous SNR and