Performance analysis of full-duplex relaying over Rayleigh-Rician fading channels

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Abstract— **In this paper, a multiple full-duplex relaying network using partial relay selection operating is investigated over mixed Rayleigh-Rician asymmetric fading environment. The first hop (source-relay) and the second hop (relay-destination) are subjected to Rayleigh and Rician fading respectively. Simulation results are provided for outage probability (OP) and bit error rate (BER) to enable building strong foundations for cooperative relaying communications design and optimization.**

Keywords—Full-duplex relay, outage probability, bit error rate, amplify-and-forward, Rayleigh fading, Rician fading.

I. INTRODUCTION

Nowdays, in order to pursue the potential spectrum efficiency enhancement, full-duplex (FD) relaying has been identified as a promising technology for future communication systems to reduce the influence of multipath. Comparing with half duplex (HD) relaying, FD relaying allows the user to receive and transmit data in the same frequency band or at the same time slot [1]. FD relaying can be implemented into amplify-and-forward (AF) protocol [2]. In AF technique, the relay amplifies the received signal and forwards it to the destination without any further processing [2].

Several works have studied the performance of FD relay networks focus mainly on symmetric fading channels which means both of the two hops are subjected to the same fading conditions [3]. There are merely a few literatures considering asymmetric fading channels but also are limited to single HD relay system. To the best of our knowledge, with respect to the Nakagami-m and Rayleigh fading conditions, the Rician fading has been the least-studied fading environment in many literatures, which is mainly because of its heavy mathematics and intractability, hindering its practical applications.

In this paper, we investigate full-duplex system in a realistic study which consist of two-hop multiple relays scenario with a partial relay selection scheme on the first hop which subject to Rayleigh fading due to the lack of line of sight (LOS) path and the second hop experiences Rician fading because of the existence of a LOS path. For an example, this scenario finds applicability in the design of micro/macro cellular multi-hop transmissions with Rician propagation characteristics.

The rest of this paper is organized as follows. Section II gives a brief introduction to the FD Relay system model. The next Section presents how to get the outage probability and BER performance metrics. In Section IV, results carried out by simulation are presented followed by conclusion section.

II. SYSTEM AND CHANNEL MODEL

We consider cooperative wireless system, consisting of one source node S ,one destination node D and N candidate full-duplex (FD) relay nodes for R_i $(1 \leq i \leq N)$ relays that can serve under AF protocol and where the relays shared information with the destination. All relays are equipped with one receive antenna and one transmit antenna. The S and D nodes operate in half-duplex mode and are equipped with a single antenna. We assume that there is no direct communication link between the source and the destination due to the large-scale channel fading such as the log–distance and shadowing path loss effect. The transmit powers of the source and all relays are denoted respectively by P_S and P_R . The channel state information (CSI) of all links is assumed to be available at the relays and destination. Besides, in this model all channels in source-relay link experience independent identical Rayleigh flat fading, while all channels in relay-destination link experience independent identical Rician flat fading.

The received signal at i^{th} relay R_i at the first hop transmission can be expressed as:

$$y_{SR_i} = \sqrt{P_S} h_{SR_i} x_s + \sqrt{P_R} h_{LI_i} x_{R_i} + n_{SR_i} \tag{1}$$

where x_s is the signal transmitted by S , x_{R_i} is the signal transmitted by the relay R_i . h_{SR_i} and h_{LI_i} denote the corresponding channel coefficients of source to relay R_i (SR_i) link and loop-interference between relay output (transmit antenna) and input (receive antenna), respectively. And n_{SR_i} is the additive white Gaussian noise (AWGN) term at the i^{th} relay, with zero mean and equal variance N_0.

The received signal at destination D is given by,

$$y_{R_iD} = \sqrt{P_R} h_{R_iD} x_{R_i} + n_{R_iD} \tag{2}$$

where h_{R_iD} is the channel coefficient between the relay R_i and the destination (R_iD), and,n_{R_iD} is AWGN at D with zero mean and unit variance N_0.

Then, the corresponding instantaneous received SNRs of the link SR_i , R_iD are defined respectively as, $\gamma_{SR_i} = P_S \left|h_{SR_i}\right|^2 / N_0$, $\gamma_{R_iD} = P_R \left|h_{R_iD}\right|^2 / N_0$ and for loop-interference channel $\gamma_{LI_i} = P_R \left|h_{LI_i}\right|^2 / N_0$. The instantaneous signal-to-interference plus noise ratio (SINR) for the link (SR_i) is given as $\gamma_i = \gamma_{SR_i} / (\gamma_{LI_i} + 1)$.

III. Outage Probability and Bit Error Rate Analysis Of Our Proposed System

In this work, let R_b is the "best relay" selected based on the partial relay selection criteria [4] :

$$\gamma_b = \arg\max_{1\le i\le N} \{\gamma_i\} \quad (3)$$

According to Rayleigh fading of the best first hop (SR_b) link, the cumulative distribution function (CDF) of γ_b is given by :

$$F_{\gamma_b}(\gamma) = \left[1 - e^{(-\gamma\alpha)}\right]^N \quad (4)$$

where $\alpha = (\bar{\gamma}_{LI_b} + 1)/\bar{\gamma}_{SR_b}$ denotes the average SNIR of the SR_b link with $\bar{\gamma}_{SR_b} = P_S \times E\left(\left|h_{SR_b}\right|^2\right)/N_0$, $\bar{\gamma}_{LI_b} = P_R \times E\left(\left|h_{LI_b}\right|^2\right)/N_0$.

The best relay-destination channel (R_bD) experience Rician fading, and its probability density function (PDF) of corresponding instantaneous SNR, γ_{R_bD} is given by

$$f_{\gamma_{R_bD}}(\gamma) = \frac{(K+1)e^{-K}}{\bar{\gamma}_{R_bD}} e^{-\frac{(K+1)\gamma}{\bar{\gamma}_{R_bD}}} I_0\left(2\sqrt{\frac{K(K+1)\gamma}{\bar{\gamma}_{R_bD}}}\right) \quad (5)$$

where $\bar{\gamma}_{R_bD} = P_R \times E\left(\left|h_{R_bD}\right|^2\right)/N_0$ and K is the Rician factor. The zeroth order modified Bessel function of the first kind is denoted by $I_0(\cdot)$ [5].

The end-to-end SNIR of the system for AF scheme, γ_{e2e}^{AF}, can be expressed as [6] :

$$\gamma_{e2e}^{AF} = \frac{\gamma_b \gamma_{R_bD}}{\gamma_b + \gamma_{R_bD} + 1} \quad (6)$$

The outage probability P_{out} can be defined as the probability that the instantaneous end-to-end SNIR, falls below a threshold γ_{th}. Therefore mathematically, P_{out} is given by :

$$P_{out}(\gamma_{th}) = Pr\left(\frac{\gamma_b \gamma_{R_bD}}{\gamma_b + \gamma_{R_bD} + 1} < \gamma_{th}\right) = F_{\gamma_{e2e}^{AF}}(\gamma_{th}) \quad (7)$$

where $F_{\gamma_{e2e}^{AF}}$ is the CDF of γ_{e2e}^{AF}.

The Bit Error Rate (BER) can be determined by [5]:

$$P_{ber} = \frac{a\sqrt{b}}{2\sqrt{\pi}} \int_0^\infty \frac{e^{-b\gamma}}{\sqrt{\gamma}} F_{\gamma_{e2e}^{AF}}(\gamma) d\gamma \quad (8)$$

where, $(a, b) = (1,2)$ for binary phase-shift keying (BPSK) modulation.

IV. Simulation and Results

In this section, we present simulation results for outage probability and BER, with AWGN $N_0 = 1$, $P_s = P_R$ is normalized to 1 and for different values of Rician K-factor ($K = 0\,dB, 5\,dB, 10\,dB$). The threshold transmission is set to $\gamma_{th} = 3dB$. BPSK modulation is used in the BER simulation. Fig.1 illustrates the outage probability for $N = 4$ relays. As seen in Fig.1, when the K -factor increase the outage probability decrease. Note also, the result with $K = 10\,dB$ produce improved outage probability. Under the same scenario, Fig. 2 investigates the BER performance. The Fig.2 reveals that the simulation results well match with the similar trends of outage probability. We can see also from this figure, with Rician K-factor increase BER decrease with SNR gain.

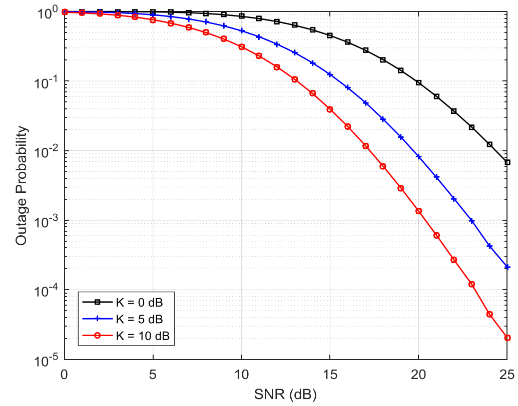

Fig. 1. Outage probability for different K factors

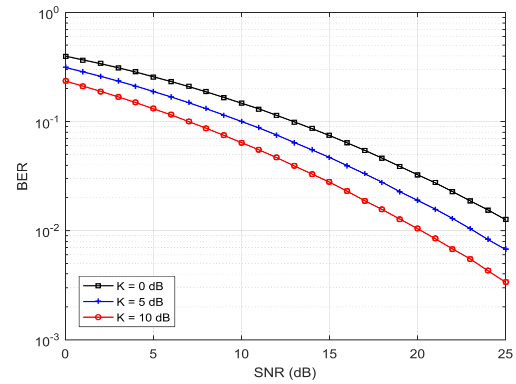

Fig. 2. BER using BPSK modulation for different K factors

V. Conclusion

In this work, the performance of multiple full-duplex relay network using partial relay selection has been investigated over mixed Rayleigh-Rician fading with AF protocol. We provide analytical expressions for outage probability and average BER from CDF of the end-to-end SINR. The simulation results take different values of Rician K-factor and are useful for performance optimization of cooperative relay systems.

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