Analysis of full-duplex AF Relaying under Imperfect Channel State Information

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Abstract—**This paper investigates the outage probability and throughput of full-duplex (FD) relaying with the presence of imperfect channel state information (CSI). We consider an amplify-and-forward (AF) protocol cooperative communication system where a source node communicates with a destination node with the help of more relay nodes. In the relay selection (RS) scheme, only the best relay which maximizes the effective signal-to-interference-and-noise ratio (SINR) at the receiver end is selected. Simulation results show the impacts of channel estimation errors on full-duplex cooperative relay system and are useful in the evaluation of practical implementations.**

Keywords—outage probability, throughput, full-duplex relay, amplify-and-forward (AF), imperfect channel estimation (CSI).

I. Introduction

Relaying has garnered a great deal of attention as promising technique for extending coverage and improving the transmission coverage in wireless communications. Full-duplex (FD) relays can transmit and receive simultaneously over the same frequency band, hence enable a significant improvement of spectral efficiency compared to half-duplex (HD) relays. However, FD relaying mode suffers from the loop interference (LI) caused by the signal leakage between the output and input antennas of the relay. In addition, relay communication using AF protocol has attracted much attention and can boost the performance of a communication system [1].

In [2] the authors proposed different relay selection strategies such as an optimal relay selection policy. Most of the several works on selection cooperation assume that the perfect channel state information (CSI) is available at every terminal as in [3]-[4]. However, in practice, the channel estimation can not be ideal, and the channel estimation error is inevitable. The impacts of imperfect CSI for FD multiple relay channels are necessary and attractive, compared with many previous works which focus only on single relay.

In this work, we assume optimal relay selection (RS) technique in cooperative network with imperfect CSI. We investigate the outage of probability and throughput of FD multiple relays system in the presence of channel estimation errors and residual LI.

This paper is organized as follows. Sections II introduce the system and channel model. Section III presents and discusses the simulation results in terms of the outage probability and throughput. Section IV concludes the paper.

II. System And Channel Model

A full-duplex AF multi-relays cooperative system is considered where two nodes, source (S) and destination (D) communicate with the help of the best relay node, which is selected among N available relays $(i = 1,2, \ldots, N)$ such that the maximum possible SNIR is received by the destination node via the selected relay path. Each relay is equipped with one receive antenna and one transmit antenna. S and D nodes are single-antenna devices. The direct link from the source to the destination is assumed to be very weak due to the presence of deep fading or shadowing. The transmit powers of the source and all relays are denoted by P_S and P_R, respectively. The imperfect channel estimation is also considered in this paper. Regarding to the channel model, we consider the case that the channel coefficients is obtained with some errors.

In this model, we assume the dual-hop channels undergo flat Rayleigh fading. Denote the fading channel from S to i^{th} relay as $h_{Si} \sim \mathcal{CN}\left(0, \sigma^2_{h_{Si}}\right)$, from i^{th} relay to D as $h_{iD} \sim \mathcal{CN}\left(0, \sigma^2_{h_{iD}}\right)$ and let denote the LI channel at the i^{th} relay $f_i \sim \mathcal{CN}\left(0, \sigma^2_{f_i}\right)$. Under imperfect channel estimation, noted that $\hat{h}_{Si}$ and $\hat{h}_{iD}$ are the channel estimates of the true channels h_{Si} and h_{iD}, respectively and $\hat{f}_i$ the estimated channel gains obtained at the relay. Based on assumption of MMSE (Minimum Mean Square Error), the relations between the actual and the estimated channels are given by:

$$\begin{aligned} h_{Si} &= \hat{h}_{Si} + e_{Si} \\ h_{iD} &= \hat{h}_{iD} + e_{iD} \\ f_i &= \hat{f}_i + e_{f_i} \end{aligned} \quad (1)$$

where e_{Si} , e_{iD} and e_{f_i} are the channel estimation errors corresponding to h_{Si}, h_{iD}, and f_i, respectively. These estimation errors are all assumed to be Gaussian distributed with zero mean and with variance of $\sigma^2_{e_{Si}}$, $\sigma^2_{e_{iD}}$ and $\sigma^2_{e_{f_i}}$, respectively.

The received signal at the i^{th} relay and destination D can be expressed as, respectively:

$$r_{Si} = \sqrt{P_S} h_{Si} x_s + \sqrt{P_R} f_i x_{R_i} + n_{Si} \quad (2)$$

$$y_{iD} = \sqrt{P_R} h_{iD}\, x_{R_i} + n_{iD} \quad (3)$$

where x_s is the signal transmitted to the i^{th} relay by S with a normalized average transmit energy $E[|x_S|^2] = 1$, x_{R_i} is the signal transmitted by the relay R_i, with average transmit power energy $E\left[\left|x_{R_i}\right|^2\right] = 1$. n_{Si} and n_{iD} are the zero mean Additive

White Gaussian Noise (AWGN) at the i^{th} relay, and D respectively with variance N_0.

The relay R_i subtracts an estimate of the LI from its received signal. Therefore the received signal is obtained after applying interference cancellation methods to mitigate the LI [5] :

$$\begin{aligned}\hat{r}_{Si} &= r_{Si} - \sqrt{P_R}\hat{f}_i x_{R_i} \\ &= \sqrt{P_S}(\hat{h}_{Si} + e_{Si})x_s + \sqrt{P_R}e_{f_i}x_{R_i} + n_{Si}\end{aligned} \tag{4}$$

The transmit signal from the i^{th} relay is given by $x_{R_i} = \beta_i \hat{r}_{Si}$ where the amplification factor is given by $\beta_i = \left[P_S|\hat{h}_{Si}|^2 + P_S\sigma^2_{e_{Si}} + P_R\sigma^2_{e_{f_i}} + N_0\right]^{-\frac{1}{2}}$.

Based on the channel estimation model, we can rewrite the received signal at D from the i^{th} relay as :

$$\begin{aligned}y_{iD} = \sqrt{P_R}\beta_i\hat{h}_{iD}\,&\left[\sqrt{P_S}(\hat{h}_{Si} + e_{Si})x_s + \sqrt{P_R}e_{f_i}x_{R_i}\right. \\ &\left. + n_{Si}\right] \\ &+ \sqrt{P_R}\beta_i e_{iD}\left[\sqrt{P_S}(\hat{h}_{Si} + e_{Si})x_s\right. \\ &\left. + \sqrt{P_R}e_{f_i}x_{R_i} + n_{Si}\right] + n_{iD}\end{aligned} \tag{5}$$

By dividing the desired signal message power by the error power due to channel estimation error, interference and noise power, the end-to-end SINR can be obtained from (5) as :

$$\gamma_{e2e} = \frac{\hat{\gamma}_{Si}\hat{\gamma}_{iD}}{\hat{\gamma}_{Si}\lambda_{iD} + \hat{\gamma}_{iD}\lambda_{Si} + \lambda_{Si}\lambda_{iD} + \eta} \tag{6}$$

where $\hat{\gamma}_{Si} = \frac{P_S|\hat{h}_{Si}|^2}{N_0}$, $\hat{\gamma}_{iD} = \frac{P_R|\hat{h}_{iD}|^2}{N_0}$, $\lambda_{Si} = 1 + \epsilon_{e_{Si}}$, $\lambda_{iD} = 1 + \epsilon_{e_{iD}}$, $\epsilon_{e_{Si}} = \frac{P_S\sigma^2_{e_{Si}}}{N_0}$, $\epsilon_{e_{iD}} = \frac{P_R\sigma^2_{e_{iD}}}{N_0}$, $\epsilon_{e_{f_i}} = \frac{P_R\sigma^2_{e_{f_i}}}{N_0}$ and $\eta = \epsilon_{e_{f_i}}(\hat{\gamma}_{iD} + \epsilon_{e_{iD}} + P_R)$.

The optimal relay selection scheme where the relay that provides the highest end-to-end SNIR is selected among all, N participating relays is considered in this work [2]. In other words, let the best relay, R_i^b, maximize the received end-to-end SNIR over all relays, which is given by:

$$R_i^b = arg \max_{i=1,\cdots,N}(\gamma_{e2e}) \tag{7}$$

III. Simulation and Results

In this section, some numerical results are provided for illustrating outage probability and throughput. We consider an BPSK modulation with AWGN $N_0 = 1$, $\sigma^2_{h_{Si}} = \sigma^2_{h_{iD}} = 1$ and $\sigma^2_{f_i} = 0.01$ and $P_S = P_R = P$ is normalized to 1. The relays are in the middle of a line between S and D. The target transmission rate is set to $R_{th} = 2\ bits/s/Hz$,when threshold $\gamma_{th} = 2^{R_{th}} - 1$. In our simulations, we assume that the variances of channel estimation errors are identical across all links, i.e $\sigma^2_{e_{Si}} = \sigma^2_{e_{iD}} = \sigma^2_{e_{f_i}} = \sigma^2_e$ varies from 0.001 to 0.1. Fig 1 and Fig 2 both show the outage probability and throughput respectively, when $N = 3$ relays. They indicate the effects of imperfect CSI on the proposed system compared to perfect channel estimation ($\sigma^2_e = 0$). It is shown from Fig. 1, a higher outage probability degradation is seen as the estimation error variance σ^2_e increases, at high SNR. Fig. 2 illustrates the throughput under the same parameters. It is shown from Fig. 2, that as σ^2_e increases the throughput decreases gradually.

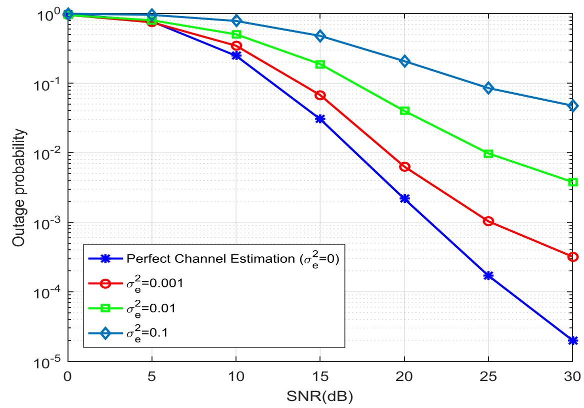

Fig. 1. Outage probability versus SNR for FD multi-relays system with imperfect CSI.

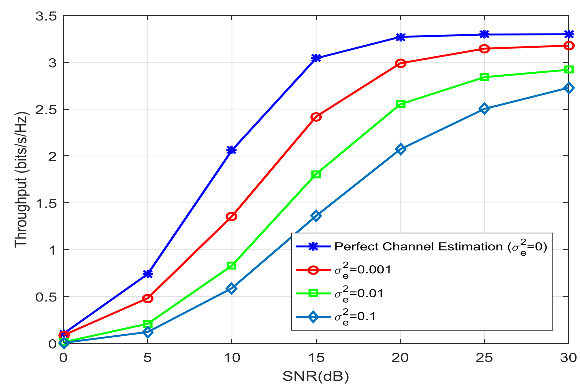

Fig. 2. Throughput versus SNR for FD multi-relays system with imperfect CSI

IV. Conclusion

In this paper, we analyze the outage probability and throughput of AF cooperative multiple FD relay systems under imperfect channel estimation. A simulation is carried out to show performances and illustrate the effects of different values of channel estimation errors on the proposed system. Altogether, these results are of great importance guidelines for cooperative relaying systems, where perfect CSI is never achievable.

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