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Cooperative Diversity with a New Incremental Relay Protocol and its Performance Evaluation

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Abstract. A new incremental relay (INR) protocol with multiple blind amplify-and-forward (AF) relays is analyzed, where the selection combining (SC) at the destination receiver is used at the phase of cooperative diversity. To study the end-to-end performance of the INR transmission, the bit error rate (BER) of BPSK over *i.i.d.* Rayleigh fading channels is evaluated. BER results are presented for performance illustration and comparisons.

Keywords: cooperative diversity, incremental relay (INR), selection combining (SC), fixed-gain, amplify-and-forward (AF).

1. Introduction

The cooperative diversity scheme that uses relay channels provides an effective way to combat multipath fading in wireless channels and also saves the transmission energy of source transmitters. With regular relaying schemes [1]-[5], a relaying transmission will always be used for cooperative diversity. Although this regular relay scheme renders a better performance, it also needs more bandwidth for relaying transmissions. To save the bandwidth cost while obtain receiver performance improvement, the incremental relay (INR) scheme [6]-[8] has been used. With the INR scheme, there are two phases of transmissions, and the relay transmission is not used at once. In the first phase, only the direct transmission on the source-to-destination (S-D) channel is used and the destination receiver will monitor the reception quality according to some criterion. If the criterion is not satisfied with the direct transmission, then the relaying transmission from the source-to-relay (S-R) and relay-to-destination (R-D) channels are employed and some diversity combining method is executed at the destination receiver.

In the existing INR schemes [4]-[7], the criterion used for relaying transmissions is to compare the received signal-to-noise ratio (SNR) from the direct S-D path to a preset threshold. If the SNR is smaller than the threshold, relaying transmission is used. On the other hand, if the SNR is larger than the threshold, only the received signal from the direct path is used for following signal detection. Thus, in the existing INR scheme, the determination of using the relaying transmission is separate from the signal detection as another stage.

In this paper, a new INR protocol with fixed-gain amplify-and-forward relays is proposed, where the determination of relaying transmission is integrated with the signal detection in one stage. With the new INR protocol, the decision of signal detection also renders the determination whether the relaying transmission is used or not. This new INR protocol is called the decision-based INR in contrast to the existing SNR-based INR. In addition, for performance evaluation of the decision-based INR protocol, BPSK signalling on Rayleigh fading channels is considered and a selection combining (SC) scheme [9] is used for cooperative diversity.

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The rest of the paper is organized as follows. In Section II, the dual-hop *i.i.d.* Rayleigh fading channels and corresponding equivalent SNR of fixed-gain AF relays for the INR protocol are described and formulated. In Section III, the BER of BPSK using the SC is analyzed. In Section IV, the results of BER performance are presented and performance comparisons between INR protocols are given. Conclusions are drawn in Section V.

2. Modelling

2.1 Channel Model

The architecture of cooperative diversity systems over dual-hop relay channels is depicted in Fig. 1, where the scenario of one source node (S), one destination node (D), and *L* relays is considered.

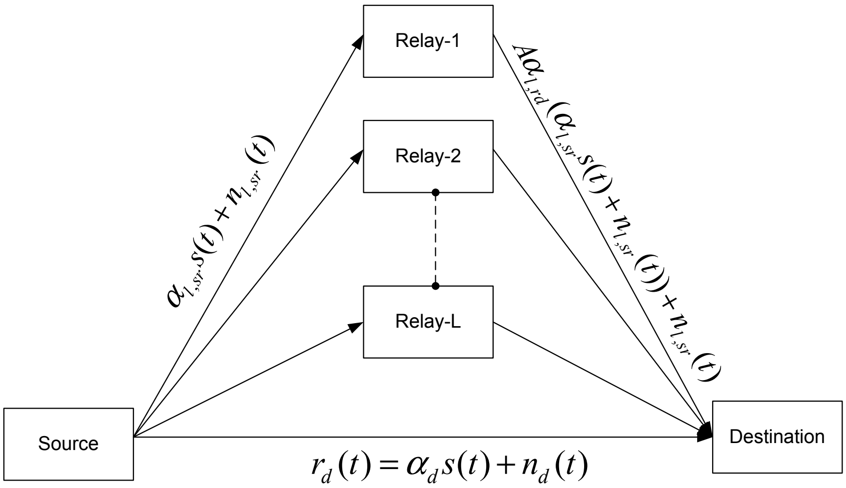

Fig. 1: Cooperative diversity system with multiple dual-hop relays.

In the context, the blind non-generated relay and the case of are considered. For the *l*-th relay, let the fading factors of the S-D, S-R, and relay-to-destination (R-D) be denoted by $\alpha_d, \alpha_{l,sr}$ and $\alpha_{l,rd}$, respectively. Along the dual-hop path, the received signals at time instance *t* and the *l*-th relay $(l=1,2)$ are given by

$$r_{l,sr}(t)=\alpha_{l,sr}s(t)+n_{l,sr}(t) \tag{1}$$

for the S-R channel, and

$$r_{l,sr}(t)=A\alpha_{l,sr}(\alpha_{l,sr}s(t)+n_{l,sr}(t))+n_{l,sr}(t) \tag{2}$$

for the R-D channel, where *A* is the fixed relay gain, $s(t)=\pm\sqrt{E_b}$ is the transmitted BPSK signal with energy E_b, $n_{l,sr}$ and $n_{l,rd}$ are the white Gaussian channel noises both with zero mean and power N_0. For the direct path for the S-D channel, the received signal at the destination is

$$r_d(t)=\alpha_d s(t)+n_d(t) \tag{3}$$

where n_d is another white Gaussian channel noise with zero mean and the same power N_0. Throughout the paper, we assume that $\alpha_d, \alpha_{l,sr}$ and $\alpha_{l,rd}$, are mutually independent and identically distributed (*i.i.d.),* and their probability density functions (pdf) are given by the Rayleigh distribution function

$$f(x)=\frac{1}{2\sigma^2}e^{-\frac{x}{\sigma^2}}, \quad x\geq 0 \tag{4}$$

where $2\sigma^2=E[\alpha^2]$, and α denotes $\alpha_d, \alpha_{l,sr}$ or $\alpha_{l,rd}$. For the Rayleigh distributed fading factors, the SNR of each fading channel has a Gamma distribution with the pdf

$$f_\gamma(x)=\frac{1}{\bar{\gamma}}e^{-\frac{x}{\bar{\gamma}}}, \quad x\geq 0 \tag{5}$$

where $\bar{\gamma}$ is the corresponding average SNR. Thus, the cumulative distribution function (cdf) of the SNR is given by $F_\gamma(x) = 1 - e^{-x/\bar{\gamma}}$.

Let $\gamma_{l,h}$ denote the equivalent SNR of the dual-hop path via the l-th relay, and $F_{\gamma_h}(y)$ be its cdf. For each dual-hop path, the equivalent SNR $\gamma_{l,h}$ is given by [10],[11]

$$\gamma_{l,h} = \frac{\gamma_{l,sr}\gamma_{l,rd}}{\gamma_{l,rd} + \lambda} \tag{6}$$

where $\gamma_{l,sr}$ and $\gamma_{l,rd}$ are the SNRs of the l-th S-R and R-D paths, respectively, and $\lambda = A^2 E_b / N_0$. The cdf and pdf of $\gamma_{l,h}$ have been shown in [11] as

$$F_{\gamma_h} = 1 - \frac{2}{\bar{\gamma}}\sqrt{\lambda x}K_1\left(\frac{2}{\bar{\gamma}}\sqrt{\lambda x}\right)e^{-\frac{x}{\bar{\gamma}}} \tag{7}$$

and

$$f_{\gamma_h}(x) = \frac{2}{\bar{\gamma}}e^{-\frac{x}{\bar{\gamma}}}\left[\frac{1}{\bar{\gamma}}\sqrt{\lambda x}K_1\left(\frac{2}{\bar{\gamma}}\sqrt{\lambda x}\right) + \frac{2}{\bar{\gamma}}\sqrt{\lambda x}K_0\left(\frac{2}{\bar{\gamma}}\sqrt{\lambda x}\right)\right] \tag{8}$$

respectively, where $K_i(\cdot)$ is the i-th-order modified Bessel function of the second kind.

2.1. Decision-Based INR model

For the cooperative diversity with incremental relays, the source node S simultaneously sends data to D and all relays. For the decision-based INR protocol, the destination receiver makes its detection decision for signal detection based on its received signal $r_d(t)$ by comparing $|r_d(t)|$ to a present threshold η_γ If $|r_d(t)| > \eta,$ the destination receiver detects the signal directly. On the other hand, if $|r_d(t)|$ is smaller than the threshold, the receiver request another copy of the original signal from relays, and an incremental stage is applied. With the incremental stage, the SC scheme is used to choose the received signal either from the relays or direct path, where the received signal with the largest SNR is used for signal detection.

The above INR policy can be characterized by the following threshold comparison

$$\text{If} \begin{cases} |r_d(t)| \geq \eta_\gamma, & \text{use direct path only} \\ |r_d(t)| < \eta_\gamma, & \text{use SC diversity} \end{cases} \tag{9}$$

where $|r_d(t)| > \eta,$ implies that the transmission quality via the direct path is not good enough and relaying with SC is employed. Notice that, if the threshold is very large or when it increases, the above INR tends to be the one that uses the relays and SC, which is the regular cooperative diversity scheme.

3. Performance Evaluation

In this section we derive the BER for the above INR protocol for BPSK signalling.

For the stage of incremental relay, if a relay path is selected with the SC scheme at the destination receiver. The selected relay path must be the one with a higher SNR.

Let $f_{\gamma_m}(x)$ and $F_{\gamma_m}(x)$ represent the pdf and cdf of the SNR of the selected relay path, respectively, where $\gamma_m = \max_{1\leq l\leq L}\{\gamma_{l,h}\}$ is the resultant SNR for the selected relay channel. Since the two relay channels are *i.i.d.*, the cdf $F_{\gamma_m}(x)$ can be obtained as

$$F_{\gamma_m}(x) = \left[F_{\gamma_h}(x)\right]^L = \left[1 - \frac{2}{\bar{\gamma}}\sqrt{\lambda x}K_1\left(\frac{2}{\bar{\gamma}}\sqrt{\lambda x}\right)e^{-\frac{x}{\bar{\gamma}}}\right]^L \tag{10}$$

Let $f_{\gamma_m}(x)$ be the pdf of γ_m. Then, we have

$$f_{\gamma_m}(x) = \frac{d}{dx}\left[F_{\gamma_h}(x)\right]^L = Lf_{\gamma_h}(x)\left[F_{\gamma_h}(x)\right]^{L-1} \tag{11}$$

In the following analysis, equally probable signalling is assumed for BPSK signaling. Let r_s be the signal of the final selected path at the phase of incremental relay transmission. Then, the BER is characterized by

$$P_e(\overline{\gamma}_d, \overline{\gamma}_{sr}) = P_0(r_1 \geq \eta_\gamma) + P_0(-\eta_\gamma < r_1 < \eta_\gamma, r_s \geq 0) \tag{12}$$

where $P_0(-\eta_\gamma < r_1 < \eta_\gamma, r_s \geq 0)$ represents the error probability when incremental relays are used. This error probability can be written in the form

$$\begin{aligned} &P_0(-\eta_\gamma < r_1 < \eta_\gamma, r_s \geq 0) \\ &= P_0(0 < r_1 < \eta_\gamma, \gamma_d \geq \gamma_m) + P_0(-\eta_\gamma < r_1 < \eta_\gamma, r_m \geq 0; \gamma_m \geq \gamma_d) \end{aligned} \tag{13}$$

where r_m denotes the received signal from the selected relay path.

4. Numerical Results

In this section, the BER performance is evaluated. In Fig. 2, the BER versus the average SNR is plotted for different values of η_γ. Then, the performance of the decision-based INR scheme is compared to that of existing SNR-based INR scheme in Fig. 3, where the BER against the threshold η_γ is illustrated.

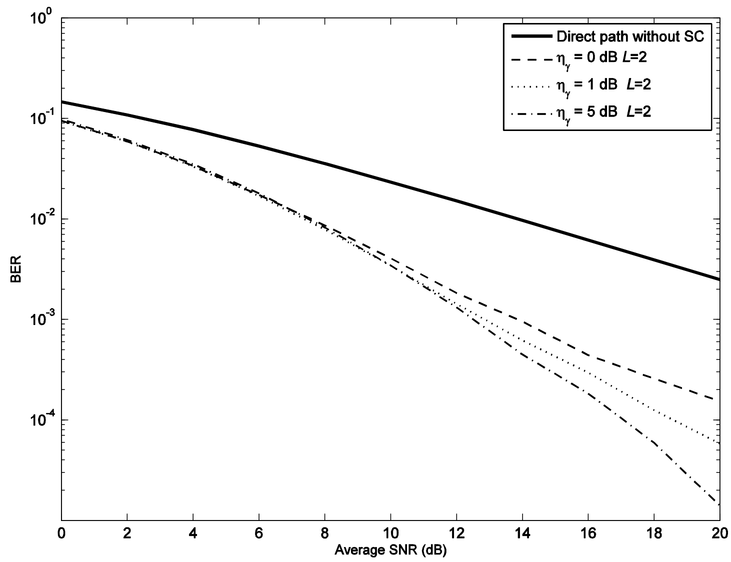

Fig. 2: The BER for different values of η_γ.

5. Conclusions

The decision-based INR protocol is analyzed for BPSK signaling on Rayleigh fading channels and corresponding BER is evaluated. Based on the numerical results, the decision-based INR protocol has a better performance than the existing SNR-based one. With different values of thresholds for relaying criterion, the performance of decision-based INR protocol will also have various BERs, which can be designed according to specific performance requirement.

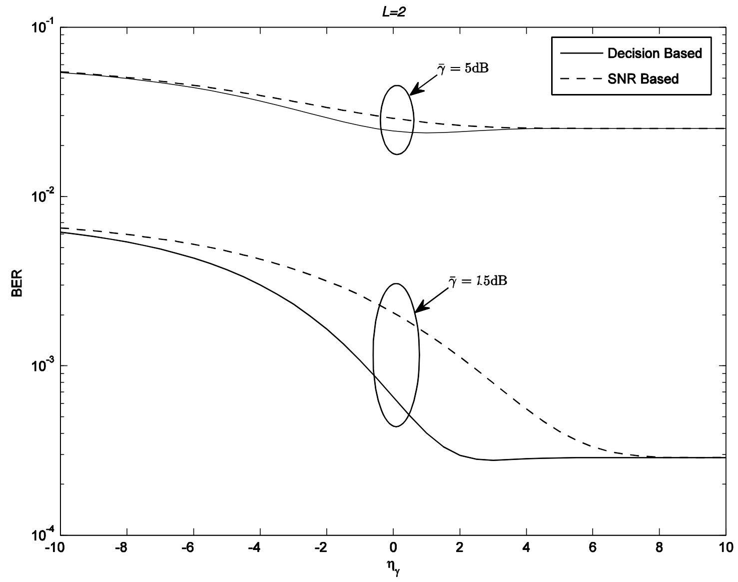

Fig. 3: Performance comparisons between decision-based and SNR-based INR protocols.

6. Acknowledgements

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