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Effects of CEE on ASER performance for Cooperative AF Relay Systems with PSA-CE Schemes

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Abstract

In this paper, we propose the analytical approach for amplify-and-forward (AF) relay cooperative transmission in the presence of channel estimation error (CEE) generated by pilot symbol assisted-channel estimation (PSA-CE) schemes over quasi-static Rayleigh fading channels. Average symbol error rate (SER) is expressed as the well-known closed-form by using moment generating function (MGF) of the received signal-to-noise ratio (SNR), which quantifies the SNR penalty arising from CEE. Moreover, the effect of CEE on SER performance is verified based on the number of pilot symbols and the accuracy of the derived average SER expression of M-ary phase shift keying (MPSK) is confirmed by comparison with simulation results.

Keywords: *AF, CEE, Rayleigh fading channels, SER, MGF, SNR, MPSK*

1. Introduction

The cooperative relaying has been widely discussed in wireless networks [1, 2]. Two main relaying networks are usually used for cooperative diversity schemes [1-4]: amplify-and-forward (AF) and decode-and-forward (DF). In the former, the relay retransmits the receiving signal after amplifying it, whereas in the latter, the relay detects the received signal and then retransmits a regenerated signal. At the destination, the receiver can employ a variety of diversity combining techniques to benefit from the multiple signal replicas from the relays and the source. The performance of relay schemes has been analyzed for various system and channel models. The advantages of the regular cooperative diversity come at the expense of the spectral efficiency since the source and all the relays must transmit on orthogonal channels. It means that general relay schemes still have trade-off between diversity gain and spectral efficiency. In order to mitigate the reduction of spectral efficiency, there are two approaches: two-way cooperative relay protocol and the opportunistic relaying method. In the former, the relay node transmits the received signals from both the source and the destination at the same time. In the latter, the single-relay node is selected so that only two channels are need (one for the direct link and the other for the selected indirect link) [5-8]. However, they need to additional process or feedback information for channel states. The best-relay selection scheme for cooperative networks is introduced in [5] where it has been shown that this scheme has the same diversity order as the cooperative diversity using space-time-coding in terms of the outage probability for both DF and

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AF schemes. Furthermore, the authors in [9], based on the given relay's selection probability, showed the general averaged symbol error rate (ASER) expression as a closed-form having the specified the number of multiple summations and the length of each summation for the N th best opportunistic AF relay systems. Then, it is confirmed that the approach in [9] can be applicable not only to derive more accurate ASER in opportunistic AF schemes [8] but also to analyze the performance of opportunistic DF schemes [10]. Those researches have been carried out for the case of ideal channel estimation.

In [11], the authors provided a framework for evaluating the bit error rate (BER) performance of AF relay-assisted cooperative transmission in the presence of imperfect channel estimation. Nevertheless, a framework in [11] does not include pilot symbol assisted-channel estimation (PSA-CE) schemes which can be applied in practical systems so that error rate performance gives error-floor even at high signal-to-noise ratio (SNR) region. So far as we know, the general approach based on PSA-CE schemes for AF relaying has not been addressed in the literature yet. Furthermore, no one has expressed ASER expressions with channel estimation error (CEE) of PSA-CH schemes, in which the effect of CEE can be explained in terms of the received signal-to-noise ratio (SNR) and ASER. At first, we have extended the analytical approach in [11] to PSA-CH schemes for AF relay networks. Then, by using moment generating function (MGF) [12], the ASER expression is derived as well-known form. Moreover, the derived error formula is analytically verified to be an approximated solution. Numerical results obtained from analytical solutions and Monte-Carlo simulations are compared. The remainder of the paper is organized as follows: Section II describes the system model for AF relaying. In section III, the average error rate expressions are provided. The numerical results are presented in Section IV and also concluding remarks are given in Section IV.

2. System Model for AF relay networks with PSA-CE Schemes

2.1. AF Relay System and Channel Model

Figure 1 shows the block diagram of AF relay networks. Let us consider regular AF relay networks with a source (S), a destination (D), and L relays (R). Note that the number of relays is L. In this paper, it is assumed that the source and and R relays transmit over orthogonal frequency bands. At first, let us describe the quasi-static Rayleigh fading channel model to derive the analytical approach for PSA-CE scheme. For $i \in \{1, 2, \cdots, L\}$, let h_0, h_i, and h_{L+i} be the channel coefficients of source-to-destination, source-to-i th relay, and i th relay-to-destination links, respectively. The wireless channels between any pair of nodes are assumed quasi-static independent and non-identically distributed (INID) Rayleigh fading during the frame transmission [13-15]. In means that channel coefficients are assumed to be a constant during the several symbol times (*i.e.*, during a frame transmission). From here, let us define N_P amd N_D as the number of pilots and the number of modulated data symbols within a frame so that the length of frame is $N_F \left(= N_P + N_D\right)$.

Generally, regular AF scheme requires $L+1$ phases of transmission. During the first phase, the source node transmits a signal to all relays and the destination. For the first frame transmission, the received signals are presented

$$y_i^p = h_i s^p + n_i^p \tag{1}$$

where y_0^p is the received signal from source to destination and y_i^p for $i \in \{1, 2, \cdots, L\}$ is the received signal from source to the ith relay. In addition, $p \in \{1, 2, \cdots, N_F\}$ is time index within a given frame and then s^p can be the pilot symbols for $1 \le p \le N_P$ or transmitted MPSK data symbols for $N_P < p \le N_F$. Note that $\{s^p\}$ are mutually independent random variables with with $E\left[s^p\right] = 0$ and $E\left[|s^p|^2\right] = 1$. In addition, $\{n_i^p\}$ are complex additive white Gaussian noise (AWGN) terms. Without loss of generality, we assume $E\left[n_i^p\right] = 0$ and $E\left[\left|n_i^p\right|^2\right] = \sigma^2$. Note that $E\left[\cdot\right]$ is the expectation operator.

2.2. PSA-CE Schemes for S-D and S-R links

Let us consider the channel estimation process for the first phase transmission. For S-D and S-R links, the estimated channel coefficients can be obtained as

$$\hat{h}_i = \frac{1}{N_P} \sum_{p=1}^{N_P} s^{p*} y_i^p = h_i + e_i \tag{2}$$

where $e_i = \frac{1}{N_P} \sum_{p=1}^{N_P} s^{p*} n_i^p$ is the CEE with $E[e_i] = 0$ and $E[|e_i|^2] = \sigma^2 / N_P$. Note that $s^p\big|_{1 \le p \le N_P}$ with $|s^p|^2 = 1$ are pilot symbols known to the destination and all relays nodes. By using the known pilot symbols and the estimated channel coefficient of (2), the noise variance can be estimated as

$$\hat{\sigma}_i^2 = \frac{1}{N_P} \sum_{p=1}^{N_P} \left| y_i^p - \hat{h}_i s^p \right|^2 . \tag{3}$$

Note that for large N_P, the estimated noise variance of ((3)) can be approximated as

$$\hat{\sigma}_i^2 \approx \tilde{\sigma}_i^2 = E\left[\left| y_i^p - \hat{h}_i s^p \right|^2\right] = \frac{N_P - 1}{N_P} \sigma^2 . \tag{4}$$

2.3. PSA-CE Schemes for R-D links

In the other phases of transmission, each relay retransmits the receiving signal after amplifying it. Therefore, the received signal from ith relay to destination can be expressed as

$$y_{L+i}^p = h_{L+i} G_i y_i^p + n_{L+i}^p \tag{5}$$

with $i \in \{1,2,\cdots,L\}$ and $G_i = 1/\left|\hat{h}_i\right|$ is the amplifying gain of the i th relay and n_{L+i}^p is a complex AWGN with $E\left[n_{L+i}^p\right]=0$ and $E\left[\left|n_{L+i}^p\right|^2\right]=\sigma^2$. From (1) and (2), eq. (5) can be represented as

$$y_{L+i}^p = h_{L+i}^{'} s^p + n_{L+i}^p{}' \tag{6}$$

with $h_{L+i}^{'} = h_{L+i}\hat{h}_i / |\hat{h}_i|$ and $n_{L+i}^p{}' = \frac{h_{L+i}}{|\hat{h}_i|}(-e_i s^p + n_i^p) + n_{L+i}^p$. For the i th R-D link, the estimated channel gain can be written as

$$\hat{h}_{L+i} = \frac{1}{N_P}\sum_{p=1}^{N_P} s^{p*} y_{L+i}^p = h_{L+i}^{'} + e_{L+i} \tag{7}$$

where $e_{L+i} = \frac{1}{N_P}\sum_{p=1}^{N_P} s^{p*} n_{L+i}^p{}'$ is the CEE with $E[e_{L+i}]=0$ and $E[|e_{L+i}|^2]=\sigma^2/N_P$. By using the known pilot symbols and the estimated channel coefficient of (7), the noise variance can be estimated as

$$\hat{\sigma}_{2,i}^2 = \frac{1}{N_P}\sum_{p=1}^{N_P}\left|y_{L+i}^p - \hat{h}_{L+i}s^p\right|^2 \tag{8}$$

and $\hat{\sigma}_{2,i}^2$ can be approximated for large N_P as

$$\hat{\sigma}_{L+i}^2 \approx \tilde{\sigma}_{L+i}^2 = \left(1 + \frac{|\hat{h}_{L+i}|^2 + \sigma^2/N_P}{|\hat{h}_i|^2}\right)\frac{N_P - 1}{N_P}\sigma^2. \tag{9}$$

3. Performance Analysis of AF Cooperative Relay Networks with CEE of PSA-CH schemes

3.1. Decision Variable and Combined SNR

When we take into account MRC process at the destination, the noise variance normalization is necessary so that we need not only the estimated channel coefficients but also the estimated noise variance. Under MRC at the destination node, the decision variable for data symbols (i.e., $N_P < p \le N_F$) can be written as

$$z_{tot}^p = \hat{h}_0^* y_0^p \frac{1}{\hat{\sigma}_0^2} + \sum_{i=1}^{R}\hat{h}_{L+i}^* y_{L+i}^p \frac{1}{\hat{\sigma}_{L+i}^2}. \tag{10}$$

Note that in order to derive the combined instantaneous SNR, we need the approximation for (10) as the form related with $\tilde{\sigma}_0^2$ of (4) and $\tilde{\sigma}_{L+i}^2$ of (9). It leads to

$$z_{tot}^p \approx \hat{h}_0^* y_0^p \frac{1}{\tilde{\sigma}_0^2} + \sum_{i=1}^{R}\hat{h}_{L+i}^* y_{L+i}^p \frac{1}{\tilde{\sigma}_{L+i}^2} \tag{11}$$

and then, the instantaneous received SNR can be approximated as

$$\gamma_{tot} \approx \gamma_0 + \sum_{i=1}^{R} \gamma_{AF_i} \tag{12}$$

with

$$\begin{aligned} \gamma_i &= \frac{|\hat{h}_i|^2}{\sigma^2 (N_P + 1)/N_P} \\ \gamma_{AF_i} &= \frac{\gamma_i \gamma_{L+i}}{\gamma_i + \gamma_{L+i} + 1/(N_P+1)} \approx \frac{\gamma_i \gamma_{L+i}}{\gamma_i + \gamma_{L+i}}. \end{aligned} \tag{13}$$

The probability density function (PDF) of γ_i can be presented for the Rayleigh fading channel as

$$f_{\gamma_i}(x) = \frac{1}{\overline{\gamma}_i} \exp\left(-\frac{x}{\overline{\gamma}_i}\right) \tag{14}$$

where $\overline{\gamma}_i$ is the average SNR defined as

$$\overline{\gamma}_i = E[\gamma_i] = \frac{E\left[|\hat{h}_i|^2\right]}{\sigma^2 (N_P + 1)/N_P} \tag{15}$$

with $E\left[|\hat{h}_i|^2\right] = E\left[|h_i|^2\right] + \sigma^2 / N_P$. Note that the approximation of (12) is caused by the fact that not the real noise variances but the estimated noise variances can be utilized at the destination. Furthermore, from the approximated version of γ_{AF_i} in (13), we can derived MGF as the well-known closed-form.

3.2. Derivation of ASER

Consequently, the conditional SER can be obtained as

$$P_S\left(\{\gamma_i\}_{i=0}^{2L}\right) = \frac{1}{\pi} \int_0^{(M-1)\pi/M} \exp\left(-\gamma_0 s + \sum_{i=1}^{L} \gamma_{AF_i} s\right) d\phi \tag{16}$$

with $s = g_{PSK} / \sin^2(\phi)$ and $g_{PSK} = \sin^2(\pi / M)$ [14]. Then, the averaged version of (16) can be expressed as

$$P_S = \frac{1}{\pi} \int_0^{(M-1)\pi/M} M_{\gamma_0}(s) \prod_{i=1}^{R} M_{\gamma_{AF_i}}(s) \tag{17}$$

where

$$M_{\gamma_0}(s) = \frac{1}{1 + \overline{\gamma}_0 s} \tag{18}$$

is the MGF of γ_0 and

$$M_{\gamma_{AF_i}}(s) = \frac{1}{\overline{\gamma}_i \overline{\gamma}_{L+i}} \int_0^{\infty}\int_0^{\infty} \exp\left(-\frac{xy}{x+y}s - \frac{x}{\overline{\gamma}_i} - \frac{y}{\overline{\gamma}_{L+i}}\right) dydx \qquad (19)$$

is the MGF of γ_{AF_i} which can be represented as

$$M_{\gamma_{AF_i}}(s) = \overline{\gamma}_i \overline{\gamma}_{L+i} \left[\frac{c-2\overline{\gamma}_i}{\Delta \overline{\gamma}_i} + \frac{c-2\overline{\gamma}_{L+i}}{\Delta \overline{\gamma}_{L+i}} + \frac{2\overline{\gamma}_i \overline{\gamma}_{L+i} s}{\Delta^{3/2}} \left(2\operatorname{arctanh}\frac{\sqrt{\Delta}}{c}\right)\right] \qquad (20)$$

with $c = \overline{\gamma}_i \overline{\gamma}_{L+i} s + \overline{\gamma}_i + \overline{\gamma}_{L+i}$ and $\Delta = c^2 - \overline{\gamma}_i \overline{\gamma}_{L+i}$ [7, 12].

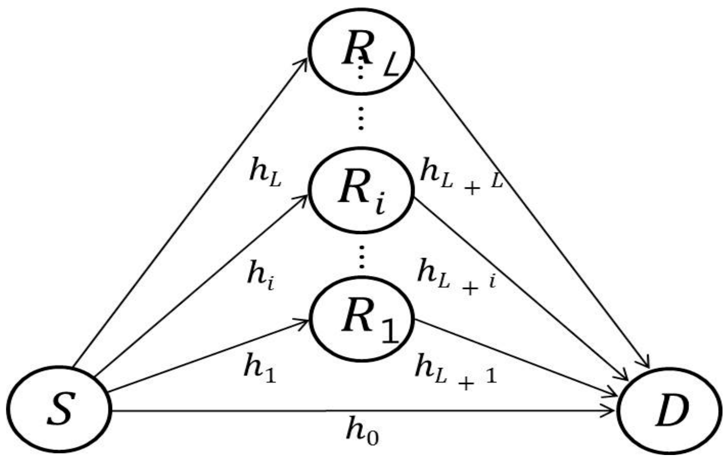

Figure 1. Block Diagram of AF Relay Systems

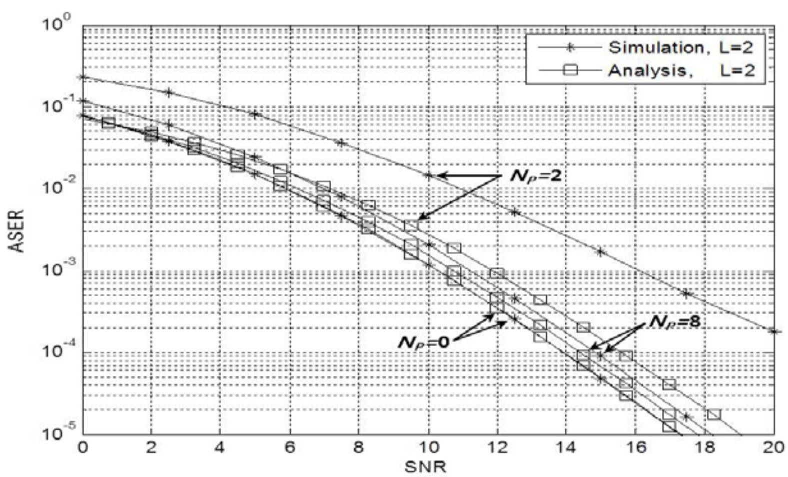

Figure 2. ASER versus SNR (dB) with respect to different N_P

($SNR = E\left[|h_0|^2\right]/\sigma^2$**,** $M = 2$**,** $L = 2$**,** $N_P = 0,2,8$**)**

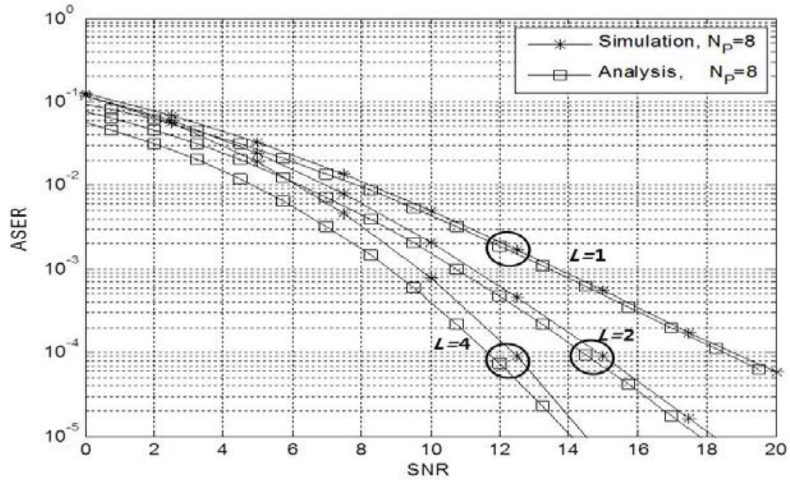

Figure 3. ASER versus SNR (dB) with respect to different L ($SNR = E\left[|h_0|^2\right]/\sigma^2$, $M=2$, $L=1,2,4$, $N_P=8$)

4. Numerical Results and Discussion

In this section, we show numerical results of average SER and verify their accuracy by comparing simulation results. We assumed for the channel conditions that $E\left[|h_i|^2\right]=E\left[|h_0|^2\right]$, $E\left[|h_{L+i}|^2\right]=E\left[|h_0|^2\right]/L$ for $i\in\{1,2,\cdots,L\}$, and $SNR=E\left[|h_0|^2\right]/\sigma^2$. Figure 2 shows the averaged BERs versus SNR for AF relay systems with $M=2$, $L=2$, and $N_P\in\{0,2,8\}$. Note that $N_P=0$ means the ideal channel estimation in witch analytical results exactly match with simulated ones. From this figure, we can find that for the case of $N_P\neq 0$, there are mismatches between analytical results and simulated ones. Those mismatches decrease in proportion to the increase of N_P. Note that those mismatches can be caused by approximations related with the derivation of received SNRs. Figure 3 shows the average error rate comparison versus the source-to-destination link's SNR with respect to different $L\in\{1,2,4\}$. It can be noticed from Figure 3 that the derived analytical results with $N_P=8$ can be well-matched with simulated ones. Moreover, the mismatch increases according to the increase of L. In this paper, $E\left[|h_{L+i}|^2\right]=E\left[|h_0|^2\right]/L$ is assumed and it means the transmission power constraint of relays. Therefore, in proportion to L, each R-D link's SNR decreases, the effect of CEE for the given R-D link increases, and the effect of approximation for the total combined SNR is accumulated. In addition, we can find that the diversity order increases linearly with the number of relay L.

Consequently, it is confirmed that the derived analytical approach can be used as a general tool to verify effects of CEE caused by PSA-CE schemes on the average SER and cooperative diversity gain over quasi-static Rayleigh fading channels. Simulation results show the accuracy of the derived ASER expression.

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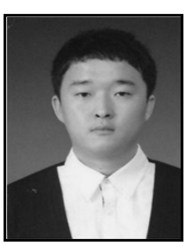

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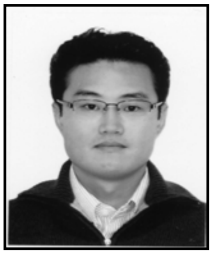

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