



Performance analysis of multi-antenna relay networks with imperfect channel estimation

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ABSTRACT

In this paper, we present the performance of multi-antenna selective combining decode-and-forward (SC-DF) relay networks over independent but non-identical Nakagami-m fading channels with imperfect channel estimation. The outage probability, moment generating function (MGF) and symbol error probability (SEP) will be derived in closed-form using the SNR statistical characteristics. To make the analysis tractable, we have derived the MGF and SEP for integer values of fading severity, m . Also, to make the relations more simple, we develop high signal to noise ratio (SNR) analysis for the performance metrics of our system. Subsequently, we propose optimal and adaptive power allocation algorithms along with the equal power allocation method. Finally, for comparison with analytical formulas, we perform some Monte-Carlo simulations.

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1. Introduction

Cooperative communication has attracted the attention of research society over recent years. In cooperative communications, each user benefits other users to transmit its signal to the intended destination. Using cooperative communications, we can mitigate the harsh channel environment such as fading, shadowing and path loss. To establish cooperation among users, different relay protocols can be utilized depending on the channel condition, distance among users and hardware complexity. Decode-and-forward (DF), amplify-and-forward (AF), coded cooperation (CC) and compress and forward (CF) are some of the basic cooperative protocols [1]. In this paper, we mainly focus on DF relay systems. DF relaying schemes refer to cases where the relay explicitly decodes the message transmitted by the source and forwards a newly generated signal to the destination, as illustrated in Fig. 1. Several selective combining schemes have been introduced in recent years. In [2], the authors introduced an opportunistic relaying method that a single relay is selected based on the best end-to-end instantaneous SNR criterion. They derived analytical results at high SNRs and the outage probability was not derived in closed-form. The authors in [3,4] analyzed an adaptive DF relay method which only a number of relays were selected to send the message to the destination. They proved that increasing the number of relays could not always decrease the outage probability. A selection combiner (SC) at the destination with AF relays has been studied in [5] over Nakagami-m fading channels where a closed-form formula for the outage probability was derived. The authors in [6] presented closed-form formulas for the performance of selective DF relaying over Nakagami-m fading channels without considering the direct link between the source and destination. In [7], introduced a closed-form expression for the outage probability and average channel capacity SC-DF relay networks over independent and non-identical Rayleigh fading channels was presented. In [2–7], the authors assume that the relay selection is performed according to the error free channel state information (CSI). However, in practical scenarios, the communication links are not known and have to be estimated. Since channel estimation is necessary for the selection procedure, channel estimation error due to the fading, quantization error and other error causing factors is inevitable.

In [8], the authors derived closed-form expression for the AF relaying system in the presence of channel estimation errors over Rayleigh fading channels. In [9], the symbol error analysis is investigated for a multi-relay scenario with imperfect channel estimation. In [10], Seyfi et al. investigated the effect of feedback delay and CSI errors in SC-DF relay systems. They derived the average symbol error rate and asymptotic diversity order of the system. Seyfi et al. analyzed the effect of feedback delay in [11]. In [12], the authors have analyzed the performance of a dual-hop multi-branch cooperative relay network in terms of symbol error rate over Rayleigh fading channels. They have analyzed both AF and DF relaying protocols with the assumption that the imperfect channel coefficients are available. A closed-form

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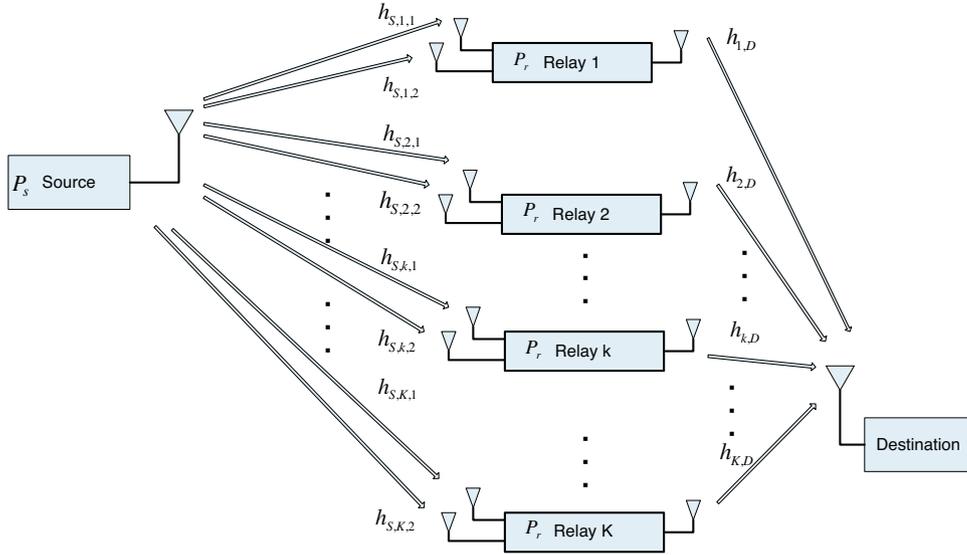


Fig. 1. System model of a selective cooperative relay network.

expression for the outage probability, average symbol error rate and capacity of a Rayleigh fading SC-DF relay network is derived in [13]. The authors have assumed that relay selection is done based on erroneous CSI. In [14], the authors have studied a bidirectional multi-relay networks in the presence of imperfect CSI. They have derived the outage probability of the system as the performance benchmark. A closed-form expression for the outage probability of a dual-hop multi-branch relay network with imperfect CSI assumption is derived in [15]. The authors have analyzed the network for both AF and DF relaying protocols over Log-normal fading channels.

However, to the best of our knowledge, no one has derived the exact closed-form expressions for the outage probability and SEP of a multi-antenna SC-DF relay network over independent and non-identical (i.n.i.d.) Nakagami-m fading channels with CSI errors. In this paper, we derive closed-form formulas for the outage probability and SEP of the mentioned system. In addition, we reduce the outage probability by using optimal and adaptive power allocation algorithms. To establish the cooperation transmission, the destination terminal estimates the downlink CSI via the received training sequences from each relay belonging to the decoding set. Afterwards, the destination broadcasts the index of the best relay using a delayed feedback channel. Note that the feedback channel causes errors in addition to the quantization and estimation errors. Since the channel coefficients are received by the relays with a specific amount of delay and the channels are changing as the time passes, relay selection is done based on old channel coefficients instead of current coefficients. In this paper, we only consider the effect of channel estimation errors. To improve the performance, we consider two receiving antennas at the relays. Since the relays may have power consuming limits, we only consider one sending antenna for the relays. Therefore, by adding one single antenna and the same power consumption, we have better performance versus one relay antenna scenario. Here, we present analysis for the relay with two antennas since going from one antenna to two results in much more gain than going from two antennas to three or more. The remainder of this paper is organized as follows. Section 2 introduces the system and channel model under consideration. Section 3 gives an analytical approach to evaluate the outage probability, MGF and SEP of the system. High SNR results are derived in Section 4. In Section 5, we formulate the optimization problem and solve it numerically. Finally, Section 6 presents Monte-Carlo simulations to verify the analytical results and Section 7 concludes the paper.

2. System model

Consider a cooperative relay system consisting of $K + 1$ users, one acting as the source and K serving as the relays. Each relay has two receiving antennas. Let us denote the source by s , the destination by d , and label the relays from 1 to K . P_s is the source transmission power, $h_{s,k,1}$ and $h_{s,k,2}$ are the channel coefficient between source and first receiving antenna of the k th relay (i.e., the $s - k - 1$ link), and between source and the second receiving antenna of the k th relay (i.e., the $s - k - 2$ link), respectively. $h_{k,d}$ is the channel coefficients between the k th relay and the destination, i.e., the $k - d$ link. σ_k^2 and σ_d^2 are the noise variances at the relay and destination, respectively. Moreover, the instantaneous SNR for $s - k - 1$, $s - k - 2$ and $k - d$ links are given by $\gamma_{s,k,1} = (P_s |h_{s,k,1}|^2) / \sigma_k^2$, $\gamma_{s,k,2} = (P_s |h_{s,k,2}|^2) / \sigma_k^2$ and $\gamma_{k,d} = (P_r |h_{k,d}|^2) / \sigma_d^2$, respectively. Increasing the number of receiving antennas from two to three will give much less gain than going from one to two [16]. Therefore, in order to have the largest gain increment and the least increase in hardware complexity, we study a relay system with two receiving antennas.

In SC-DF relaying scheme, all relays attempt to decode the source's message in phase I and act as candidate relays for forwarding the message in phase II only if they have successfully decoded the received signal form the source message. For the sake of simplicity, we assume the case where no diversity combining is employed at the destination. Hence, the system reduces to a dual-hop transmission where the maximum achievable rate is limited by the minimum capacity among $s - k$ and $k - d$ links. Given that the k th relay is selected according to the estimated channels available at the SC, the end-to-end SNR can be computed as

$$\hat{\gamma}_{SC} = \max_{k=1, \dots, K} \min(\hat{\gamma}_{s,k}, \hat{\gamma}_{k,d}) \quad (1)$$

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