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Non-combining Incremental Relaying Protocol for Amplify-and-forward Cooperative Systems

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Abstract: In this study, a two-hop amplify-and-forward cooperative system is considered. By exploiting the limited feedback from the destination, this study has proposed a Non-combining Incremental Relaying (NCIR) protocol. The asymptotic behavior of the symbol error probability is analyzed and its spectral efficiency issue is addressed. The study also utilizes the relay selection technique to further improve the system performance. Simulation results demonstrate that the proposed scheme outperforms the conventional alternatives in terms of both error performance and bandwidth efficiency.

Key words: Incremental relaying, cooperative, relay link, bandwidth efficiency, error performance

INTRODUCTION

In recent years, cooperative communications (Wang *et al*., 2009) has been widely recognized as a promising technique to enhance the system error performance and extend the cell coverage among various cooperative protocols (Yang and Zhiren, 2012). Decode-and-forward (DF) and Amplify-and-forward (AF) are two main categories. The latter, because its simplicity, can achieve full diversity order and so is the focus of this study. The incremental AF relaying protocol exploits the limited feedback from the destination and can further improve the spectral efficiency because it makes more efficient use of the degrees of freedom of the wireless channel (Laneman *et al*., 2004; Dan-Yang *et al*., 2009; Desta *et al*., 2011; Ramesh and Vaidehi, 2006). Some pioneering scholarly work has gone into practical incremental relaying schemes (Hwang *et al*., 2009; Laneman *et al*., 2004; Tin and Kong, 2008; Zhou and Lau, 2008). However, the proposed strategies so far only focused on single-relay cooperation and there has been little study on incremental relaying for the systems with multiple relays (Wei *et al*., 2007; Jazaeri *et al*., 2011) which is often the case in practice. Liu *et al*. (2009) presented and analyzed the incremental relaying schemes in wireless multi-relay networks. Based on a simple fact that the erroneous signals from the source may confuse the final decision, this study has proposed to employ a non-combining receiver at the destination. Through theoretical analysis, it will be shown that the novel scheme outperforms the conventional counterparts in terms of both error performance and spectrum efficiency. Moreover, the study integrate the decentralized relay selection method to optimize the system further.

SYSTEM MODEL

We consider a typical cooperative system where the source S communicates with the destination D via N relays $R_i|_{i=1}^N$. Each node is equipped with a single antenna and operates in a half-duplex mode, i.e., cannot transmit and receive simultaneously. The direct link between S and D exists. We assume that there is a reliable limited feedback channel for relay cooperation. The channels between any two terminals are supposed to be independent quasi-static Nakagami-m fading and the additive noise at each receiver is modeled as a zero-mean complex Gaussian random variable. For simplicity, we assume an equal power allocation among the source and relays. Under the assumptions above, the instantaneous receive Signal-to-noise Ratio (SNR) of links S→D, S→R_i and R_i→D are independent Gamma variables, denoted as $\gamma_{sd}\sim G(m_{sd}, \rho\bar{\gamma}_{sd}/m_{sd})$, $\gamma_{si}\sim G(m_i, \rho\bar{\gamma}_{si}/m_i)$ and $\gamma_{id}\sim G(m_i, \rho\bar{\gamma}_{id}/m_i)$, respectively, where ρ stands for the system average SNR, $\bar{\gamma}$'s capture the average channel gains and m's are the fading severity parameters. According to the AF protocol described (Laneman *et al*., 2004), the end-to-end SNR associated with relay i can be represented as $\gamma_i = \gamma_{si}\gamma_{id}/(\gamma_{si}+\gamma_{id}+1)$.

INCREMENTAL RELAYING PROTOCOLS

Here, the incremental relaying protocols proposed for single-relay systems are generalized to the multiple-relay

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scenarios. Based on different levels of feedback overhead, two schemes are considered. 1) Combining incremental relaying-I (CIR-I): S broadcasts its message to D and the are lays first. If an error is detected at D, it sends feedback signals to inform all the N relays to forward the source message one by one. Finally, the N+1 source message replicas are combined at D for detection. 2) Combining incremental relaying-II (CIR-II): The basic operations are identical to CIR-I, except that any relay R_i remains inactive until all the previous i-1 ones fail to help the source to make correct decision at D. Such a process continues till successful detection at D or all the N relays have been activated. It is obvious that CIR-II makes better use of power and bandwidth at the cost of more feedbacks.

On the other hand, we notice that if the direct S→D link is erroneous, it impairs the destination to make correct decisions after combined with relayed signals. This is because that although combining results in higher received SNR, the noise realization which makes such link erroneous still does harm to the combined signal. Motivated by this observation, we propose a NCIR scheme as follows.

Similar to CIR-II, when the destination fails to detect the source message from the direct link, it activates the $S \to R_1 \to D$ transmission through feedback. The difference lies in the decisions at the destination. In our protocol, D makes decision only based on the signal from R_1, since the direct transmission is detrimental as stated above. If this relayed transmission still fails, the second relay R_2 is activated and D makes decisions according to the 'fresh' $S \to R_2 \to D$ signal. This process continues until the total N relays have been utilized. It can be observed that the proposed NCIR scheme avoids analog signal storage compared with CIR-I/II which may significantly simplify system design.

Since the detection is performed link-by-link, the symbol error rate of NCIR cooperation can be written as:

$$P_{NCIR} = P_{SD}\prod_{i=1}^{N} P_{SR_iD} \tag{1}$$

where, P_{SD} and P_{SR_iD} are the error probabilities of the direct transmission and the dual-hop relaying, respectively. Due to the lack of tractable expressions for P_{SR_iD} in Nakagami-m environment, here we provide an asymptotic analysis for NCIR cooperation.

It has been widely accepted that the probability density function of the instantaneous SNR of the AF relay channel can be written as $f_{\gamma i}(\gamma) = \beta i \rho^{-m} \gamma_{m-1} + o(\gamma^{m-1})$, where $\beta_i = m_i^m(\bar{\gamma}^{-m}_{si} + \bar{\gamma}^{-m}_{id})$ (Li and Kishore, 2007). By abandoning the higher order term o(.) and invoking the analytical tool of:

$$\int_0^\infty Q(\sqrt{k\gamma})\gamma^t dt = \frac{2^t\Gamma(t+3/2)}{\sqrt{\pi}(t+1)}(k\bar{\gamma})^{-(t+1)}$$

(Wang and Giannakis, 2003), the asymptotic error probability of the dual-hop relaying $S \to R_i \to D$ can be expressed by:

$$\begin{aligned} P_{SR_iD} &\to \int_0^\infty Q(\sqrt{k\gamma_i})\beta_i\rho^{-m_i}\gamma_i^{m_i}d\gamma_i \\ &= \frac{2^{m_i-1}m_i^{m_i}\Gamma(m_i+1/2)}{\sqrt{\pi}\Gamma(m_i+1)(k\rho)^{m_i}}(\bar{\gamma}_{si}^{-m_i} + \bar{\gamma}_{id}^{-m_i}) \end{aligned} \tag{2}$$

where, k is a modulation type dependent constant. Noticing that the approximate error probability of direct transmission is:

$$P_{SD} \to \frac{2^{m_{sd}-1}m_{sd}^{m_{sd}}\Gamma(m_{sd}+1/2)}{\sqrt{\pi}\Gamma(m_{sd}+1)(k\rho)^{m_{sd}}}\bar{\gamma}_{sd}^{-m_{sd}}$$

(Wang and Giannakis, 2003), the error probability of the NCIR protocol can be calculated as:

$$P_{NCIR} \to \frac{2^{m_A-N-1}}{\pi^{(N+1)/2}(k\rho)^{m_A}}\frac{m_{sd}^{m_{sd}}}{\Gamma(m_{sd}+1)\bar{\gamma}_{sd}}\prod_{i=1}^{N}\frac{\beta_i}{m_i}\Gamma(m_i+1/2) \tag{3}$$

Where:

$$m_A = m_{sd} + \sum_{i=1}^{N} m_i$$

The order of ρ indicates that the proposed NCIR protocol achieves full diversity order. We can also derive the average number of active transmissions as:

$$T_{NCIR} = 1 + P_{SD}\sum_{n=1}^{N} n(1 - P_{SR_nD})\prod_{i=1}^{n-1} P_{SR_iD} \tag{4}$$

It can be easily translated into power and channel bandwidth consumptions.

RELAY SELECTION AND SCHEDULING

For the considered multiple-relay cooperation protocol, the participating relays assist the source transmission in a predetermined order. In conventional fixed AF relaying, this order does not affect the system performance. However, in incremental relaying which is the focus of this study, such an order is of importance to the bandwidth efficiency. Since better relay link corresponds to more reliable transmission, it's natural to schedule the relay with the best link quality first and then the second best and so forth. The selection procedure is implemented by extending the timer-based method (Bletsas *et al.*, 2006), where each relay starts a timer as soon as it receives the feedback from the destination. The initial timer value T_i at R_i is determined by the instantaneous dual-hop relay link SNR, i.e., $T_i = \lambda/\gamma_i$, where λ is a constant. When its timer expires, R_i broadcasts a flag packet to signal its presence. For the relay node R_i, it has to count the number of flag packets heard from other relays before T_i expires. If this number is n_i, then R_i has the (n_i+1)th best relay channel quality and will be activated when the former n_i relays all have failed to cooperate. This decentralized scheduling method significantly reduces the overhead of the system.

We now consider a special case that only the relay with the best dual-hop channel is allowed to participate in the incremental relaying. This scheme can further reduce the average required transmissions to $T_{SNCIR} = 1+P_{SD}$ and result in a Selective Non-combining Relaying (SNCIR) protocol. By utilizing the fact that:

$$f_{max(\gamma i)}(\gamma) = m_s\rho^{-ms}\gamma^{ms-1}\prod_{i=1}^{N} \beta_i/m_i+o(\gamma^{ms-1})$$

Where:

$$m_S = \sum_{i=1}^{N} m_i$$

(Zhang *et al.*, 2009), we can obtain the symbol error rate of SNCIR protocol as:

$$P_{SCIR} \rightarrow \frac{2^{m_A-2}\Gamma(m_S+1/2)}{\pi(k\rho)^{m_A}} \frac{m_{sd}^{m_{sd}}}{\Gamma(m_{sd}+1)\bar{\gamma}_{sd}} \prod_{i=1}^{N} \frac{\beta_i}{m_i} \quad (5)$$

It's also expected that SNCIR outperforms the conventional selective combining incremental relaying (SCIR) which will be validated in the next section.

RESULTS

We consider a two-relay system employing QPSK modulation over Nakagami-m fading channels. The fading parameters are assumed as $m_{sd} = 1$, $m_1 = 0.5$ and $m_2 = 1.5$.

The average channel gains are set to be $(\bar{\gamma}_{s1}, \bar{\gamma}_{1d})$ and $(\bar{\gamma}_{s2}, \bar{\gamma}_{2d})$. Figure 1 depicts the symbol error rate of the proposed incremental relaying protocols. It is verified that the NCIR protocol significantly outperforms the combining schemes and the presented asymptotic analysis is tight at medium to high SNR regions. Similar comparisons can also be observed in Fig. 2 for selective incremental relaying.

The average numbers of transmissions related to different protocols are illustrated in Fig. 3, from which it is seen that the proposed NCIR scheme outperforms the

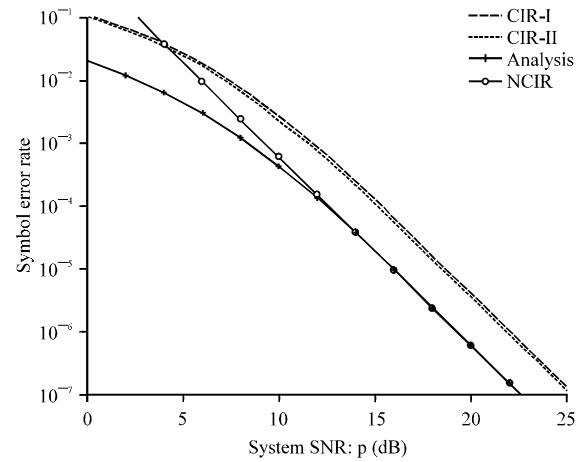

Fig. 1: Symbol error rate of combining and non-combining incremental relaying protocols

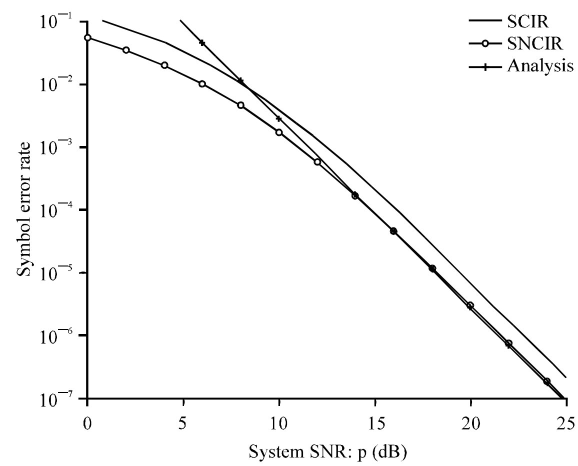

Fig. 2: Symbol error rate of selective incremental relaying protocols

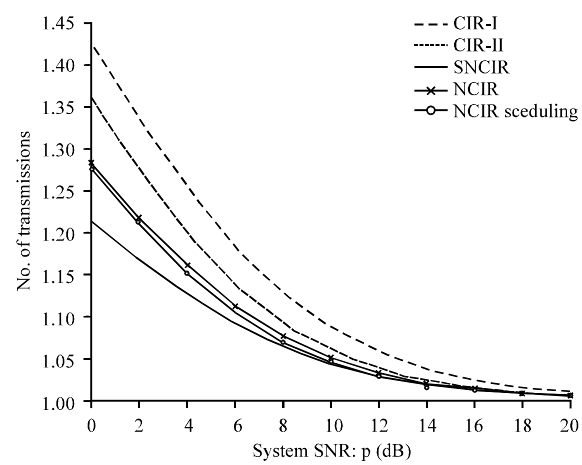

Fig. 3: Average number of active transmissions

combining alternatives in terms of bandwidth efficiency. And by using relay scheduling and selection techniques, the bandwidth efficiency can be further improved.

CONCLUSIONS

We proposed and analyzed the non-combining incremental relaying protocols for wireless cooperative systems over Nakagami-m fading channels. It's shown that the proposed method significantly improves the error performance and bandwidth efficiency compared with conventional counterparts which rely on combining techniques. Spectral efficiency can be further improved through relay scheduling and selection.

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